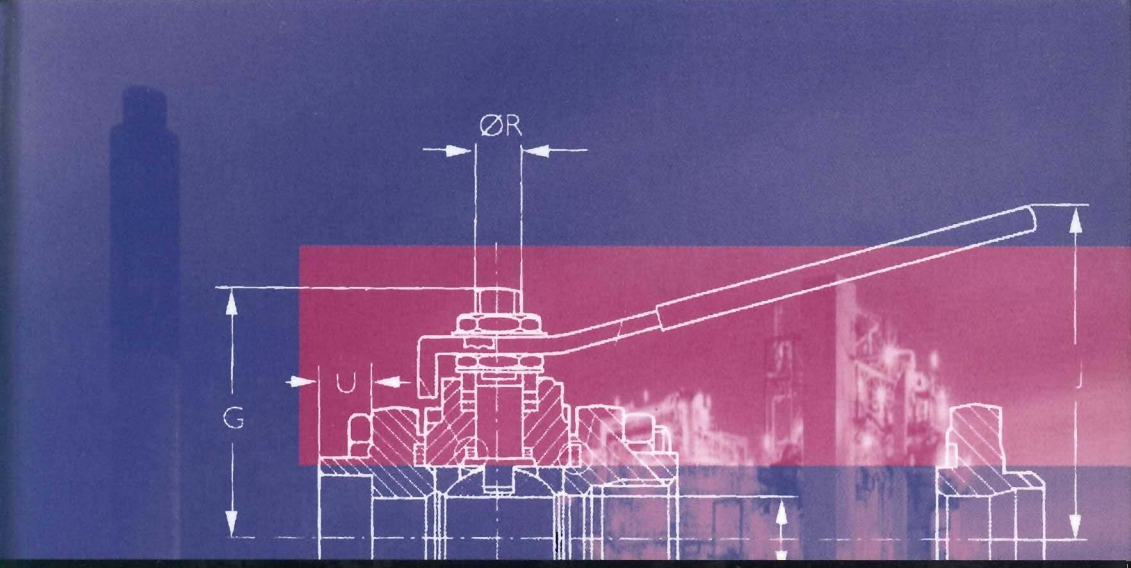


Valves, Piping & Pipelines Handbook

Third Edition

ELSEVIER
ADVANCED
TECHNOLOGY

Valves, Piping and Pipelines Handbook

3rd Edition

Valves, Piping and Pipelines Handbook

3rd Edition

T. Christopher Dickenson F.I.Mgt.

ELSEVIER
ADVANCED
TECHNOLOGY

UK Elsevier Science Ltd, The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, UK
USA Elsevier Science Inc., 665 Avenue of the Americas, New York, NY 10010, USA
JAPAN Elsevier Science Japan, Tsunashima Building Annex, 3-20-12 Yushima, Bunkyo-ku, Tokyo 113, Japan

Copyright ©1999 Elsevier Science Ltd.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means: electronic, electrostatic, magnetic tape, mechanical, photocopying, recording or otherwise, without permission in writing from the publishers.

Third edition 1999

Library of Congress Cataloging-in-Publication Data
Dickenson, T. Christopher.
Valves, piping, and pipelines handbook / T. Christopher Dickenson. – 3rd ed.
p. cm
ISBN 1-85617-252-X (hc)
1. Valves Handbooks, manuals, etc. 2. Piping Handbooks, manuals, etc. 3. Pipelines Handbooks, manuals, etc. I. Title.
TS277.D53 1999 99-26575
621.8'4–dc21 CIP

British Library Cataloguing in Publication Data
A catalogue record for this title is available from the British Library.

ISBN 1 85617 252X

No responsibility is assumed by the Publisher for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions or ideas contained in the material herein.

Published by
Elsevier Advanced Technology,
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, UK
Tel.: +44(0) 1865 843000
Fax: +44(0) 1865 843971

Printed and bound in Great Britain by
Cambridge University Press

Preface

"A Vital Contribution to Modern Industry"

Over recent years, a number of significant developments in the application of valves have taken place: the increasing use of actuator devices, the introduction of more valve designs capable of reliable operation in difficult fluid handling situations; low noise technology and most importantly, the increasing attention being paid to product safety and reliability. Digital technology is making an impact on this market with manufacturers developing intelligent (smart) control valves incorporating control functions and interfaces.

Computer Integrated Processing is now a fact of life.

New metallic materials and coatings available make it possible to improve application ranges and reliability. New and improved polymers, plastic composite materials and ceramics are all playing their part.

Fibre-reinforced plastic pipe systems, glass-reinforced epoxy pipe systems and the traditional low-cost polyester pipe systems have all undergone sophisticated design and manufacturing technology changes. The potential for growth and expansion of the industry is huge.

The 3rd Edition of the *Valves, Piping and Pipelines Handbook* salutes these developments and provides the engineer with a timely first source of reference for the selection and application of valves and pipes.

It would not have been possible to provide so much information and data in this Handbook without the co-operation given by the individuals and companies listed overleaf, as well as the manufacturers who supplied information and data. Their contribution is gratefully acknowledged.

This is the decade of the customer, and the *Valves, Piping and Pipelines Handbook 3rd Edition* is intended to provide essential, practical product information and reference data where and when they are needed most.

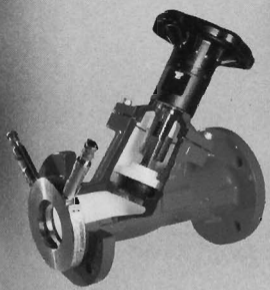
T. Christopher Dickenson F.I.Mgt.
September 1999

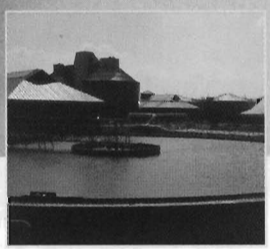
CONTENTS

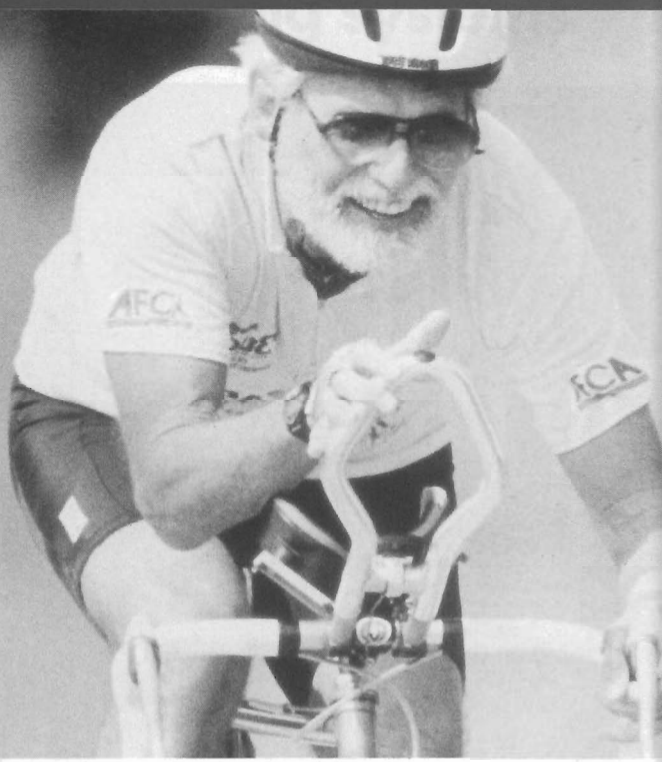
Section 1.	**Fundamentals**	
	Classification of Valves	3
	Basic Valve Nomenclature	11
	Valve Selection Guides	14
	Pipes and Pipelines—Definitions and Explanations	27
Section 2.	**Valve Types Design and Construction**	
	Plug Valves (Cocks)	41
	Ball Valves	47
	Ball Float Valves	63
	Butterfly Valves	67
	Rotary Disc/Rotor Valves	85
	Globe Valves	91
	Gate Valves	98
	Needle Valves	107
	Pinch Valves	110
	Diaphragm Valves	118
	Slide Valves	127
	Screw-down Valves	133
	Spool Valves	138
	Solenoid Valves	146
	Swing Check (Flap) Valves	164
	Penstocks	168
	Miscellaneous Valves	172
Section 3.	**Pressure Valves and Services**	
	Check Valves	185
	Safety and Relief Valves	200
	Self-Acting Reducing Valves	225
	Air Relief Valves	236
	Foot Valves	243

HOW MANY 100 YEAR OLD PAC SETTERS DO YOU KNOW?

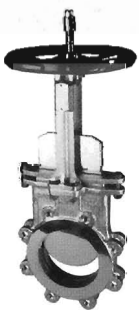
CONTROL & DURABILITY



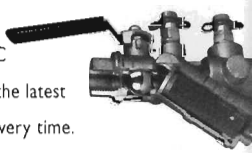




OVER A HUNDRED YEARS' EXPERIENCE HA GONE INTO PERFECTING A PRODUCT RAN AND SERVICE THAT IS WAY OUT IN FRON



With over 100 years of manufacturing experience, Hattersley know that the differenc between success and failure can be a fine balancing act. It's knowing business trends can change at any time, that has helped Hattersley to stay at the forefront of the valve industry, by developing and manufacturing hundreds of different valves for a multitude of industrial and HEVAC applications. So for a combination of experience and the latest in technical know-how, rely on Hattersley to deliver every time.



Hattersley have the largest selection of quality valves available. • Bronze Gate Valves • Cast Iron and Ductile Iron Gate Valves • Knife Gat
• Bronze, Cast Iron, Ductile Iron and Steel Globe Valves • Bronze, Cast Iron and Ductile Iron Check Valves • Bronze Radiator Valves - Drain Taps -
• Bronze Ball Valves • Bronze Plug and Gland Cocks • Commissioning Valves • Autoflow Bronze and Ductile Iron Automatic Balancin
• Cast Iron Lubricated Plug Valves • Eccentric Plug Valves • Cast Iron Non-lubricated 3-way Plug Valves • Butterfly Valves • Pop Safety Valves - Reli
• Diaphragm Valves • Equilibrium Ball Valves • GroovEnd Ductile Iron Valves

FOR FURTHER INFORMATION CALL OUR SALES TEAM ON THE NUMBER BELOW

Hattersle

QUALITY RELIABILITY & SERVICE ASS

Hattersley Newman Hender Ltd Ormskirk Lancashire L39 2XG Telephone: 01695 577199 Facsimile: 01695 5
Email: uksales@hattersley-valves.co.uk export@hattersley-valves.co.uk Web site: http://www.hattersley-valves

Section 4.	**Control and Automation**	
	Valve Actuators	249
	Control Valves	280
	Float Control Valves	301
	Temperature Control Valves	306
	Regulators	314
Section 5.	**Pipes**	
	Iron and Steel Pipes	325
	Fibre-Reinforced Plastic (FRP) Pipe	339
	Thermoplastic Pipe	356
	Pipe Joints and Couplings	396
	Expansion and Contraction Joints	427
	Corrosion and Cathodic Protection	443
	Corrosion of Stainless Steel	457
	Valve Corrosion	462
	Protective Coatings and Linings	465
Section 6.	**Pipelines/Pipework**	
	Pipeline Cleaning	479
	Pipe Cutting and Bending	497
	Pipeline Inspection and Evaluation	511
	Jacketing and Dual Containment	522
Section 7.	**Performance and Calculations**	
	Flow of Liquids through Pipes	533
	Flow of Mixtures through Pipes	556
	Compressible Flow in Pipes	572
	Losses in Bends and Fittings	584
	Strength of Pipes (Calculations)	601
	Buried Pipes	610
	Collapsing Pressure for Pipes and Tubes	628
	Boiler-Feed Calculations	637
	Steam Flow Calculations	645
	Cavitation	658
	Noise Control	667
	Balancing of Hydronic Systems	682
Section 8.	**Duties and Services**	
	Water Services	693
	Hygienic Services	718
	Steam Services	728
	Fire-Safe Valves	743
	Fire Hydrant Valves	754

	Marine Services	759
	Vacuum Services	763
	Cryogenic Valves	768
	Nuclear Services	775
	High Pressure Services	784
Section 9.	**Engineering Data**	
	Glossary	793
	Standards and Designations	800
Section 10.	**Author's Acknowledgements**	851
Section 11.	**Buyers' Guide to Valves and Pipes**	
	Classified Index by Product Category	855
	Alphabetical List of Manufacturers	863
	Trade Names Index	865
	Editorial Index	867
	Advertisers Index	872

Acknowledgements—Illustrations and Tables

Page Number	Company
3	Neles-Jamesbury
8 top	Neles-Jamesbury
8 bottom	Neles-Jamesbury
28	B F Goodrich
29	Biwater Industries
42 top	Serck Audco Valves
45	Johnson Valves
46 Figure 6(a and b)	Serck Audco Valves
47	International Hwashen Corporation
48 Figure 1	Fortune Manufacturing Co
49 top	Worcester Controls
49 bottom	Worcester Controls
50 top	Neles-Jamesbury
50 Figure 2	Orbit-Harwin Valves
52 top	Flow Safe, Inc
52 bottom	Tyco Valves and Controls
53 Figure 4	Argus
54	Argus
55 Figure 5	Neles-Jamesbury
55 Figure 6	Neles-Jamesbury
56 Figure 7	Neles-Jamesbury
56 Figure 8	Argus
57 top	Worcester Controls
57 Figure 9	Argus
59 Figure 10	Neles-Jamesbury
60 Figure 11	Argus
63	Guest and Chrimes
64	Guest and Chrimes
64 Figure 1	Guest and Chrimes
67	KSB Armaturen GmbH
68	KSB Armaturen GmbH
69 Figure 1	Neles-Jamesbury
70 top	KSB Armaturen GmbH
70 Figure 2	Neles-Jamesbury
71 Figure 3	Neles-Jamesbury
71 Figure 4	Baronshire Engineering Ltd
72	KSB Armaturen GmbH
73 Figure 5	Wouter Witzel GmbH
74 Figure 6	Neles-Jamesbury
75	Guest and Chrimes
76 Figure 7	Tyco Valves and Controls
77 Figure 8	Posi-Flate
77 Figure 9	Posi-Flate
79 Figure 10	Neles-Jamesbury
81 top	Tyco Valves and Controls
81 bottom	Tyco Valves and Controls
82 Figure 12	Charles Winn (Valves) Ltd
87 Figure 5	Quality Controls Inc
88 Figure 6	Quality Controls Inc
89 top	Quality Controls Inc
89 Figure 7	Nu-Con Equipment
93 bottom left	OMB SpA
93 bottom right	ASAHI/America
94 Figure 3	Hitachi Valve
95 top	OMB SpA
95 Figure 4	KSB Armaturen GmbH
95 Figure 5	KSB Armaturen GmbH
98	Brooksbank Valves Ltd
99 bottom	KSB Armaturen GmbH
102 top	KSB Armaturen GmbH
102 bottom	Johnson Valves
103 bottom	Guest and Chrimes
104 Figure 5	OMB SpA
104 Figure 6	OMB SpA
104 Figure 7	OMB SpA
105	OMB SpA
108 bottom	Johnson Valves
111 Figure 2	Red Valve Company Inc
112 Figure 4	Red Valve Company Inc
115 Figure 10	Crane® Resistoflex
116 Figure 11	Crane® Resistoflex
116 Figure 12	Crane® Resistoflex
122 Figure 3	Humphrey Products
124 Figure 6	Kemutec Powder Technology
125 Figure 7	Kemutec Powder Technology
129 Figure 3	Hopkinsons Ltd
130 Figure 5	Hopkinsons Ltd

Page Number	Company
131 Figure 6	Bush-Wilton
134	Grasso
135	Spirax Sarco
136	Spirax Sarco
137	Johnson Valves
146	Asco Joucomatic Ltd
147 Figure 1	Asco Joucomatic Ltd
148 Figure 2	Asco Joucomatic Ltd
149 Figure 3	Asco Joucomatic Ltd
150 Figure 4	Asco Joucomatic Ltd
151 Figure 5	Asco Joucomatic Ltd
152 Figure 6 (a and b)	Automatic Switch Co
152 top	Asco Joucomatic Ltd
153 Figure 7 (a and b)	Automatic Switch Co
153 Figure 8 (a and b)	Automatic Switch Co
154 Figure 9	Asco Joucomatic Ltd
154 Figure 10	Asco Joucomatic Ltd
155	Asco Joucomatic Ltd
156 Figure 11	Asco Joucomatic Ltd
156 Figure 12	Asco Joucomatic Ltd
158 top left	Asco Joucomatic Ltd
158 top right	Asco Joucomatic Ltd
164 Figure 1	SOCLA Danfoss Water Valves
165 bottom	Simon Hartley Ltd
166 Figure 3	Abacus Valves Manufacturing Ltd
167 Figure 4	K. Controls Ltd
170 Figure 3	Simon Hartley Ltd
171 Figure 4	Simon Hartley Ltd
171 Figure 5	Simon Hartley Ltd
172 Figure 1	Crosby Valve Inc
174 Figure 2	Italvalvole/Zella
175 Figure 3	Apporecchi e Macchine Idrauliche Speciali
176 Figure 5	Apporecchi e Macchine Idrauliche Speciali
177 Figure 6	Dezurik, a division of SPX
178 Figure 8	Banjo Corp
178 Figure 9	Banjo Corp
179 Figure 10	Worcester Controls
179 Figure 11	SchuF Armaturen & Apparatebau GmbH
179 Figure 12	SchuF Armaturen & Apparatebau GmbH
180 Figure 12	SchuF Armaturen & Apparatebau GmbH
180 Figure 13	SchuF Armaturen & Apparatebau GmbH
185	K. Controls Ltd
186 top	Johnson Valves
186 Figure 1	Delta Pacific Valves
188 Figure 3	SOCLA Danfoss Water Valves
188 bottom left	SOCLA Danfoss Water Valves
188 bottom right	Johnson Valves
189 Figure 5	SOCLA Danfoss Water Valves
190 Figure 6	SOCLA Danfoss Water Valves
190 Figure 7	SOCLA Danfoss Water Valves
191 Figure 8	SOCLA Danfoss Water Valves
191 Figure 9	Durabla Fluid Technology Inc
192	Durabla Fluid Technology Inc
193	Durabla Fluid Technology Inc
194 Figure 10	Durabla Fluid Technology Inc
195 Figure 11	Abacus Valves Manufacturing Ltd
195 top	Baronshire Engineering Ltd
196 Figure 12	Spirax Sarco
197	Durabla Fluid Technology Inc
198 Figure 13	Kepner Products Company
198 Figure 14	Kepner Products Company
201 Figure 1	Spirax Sarco
202 Figure 2	IMI Bailey Birkett Ltd
202 Figure 3	Realm
202 Figure 4	IMI Bailey Birkett Ltd
204-206 Table 1	Crosby Valve Inc
207 Figure 5	IMI Bailey Birkett Ltd
208 Figure 6	Crosby Valve Inc
209 Figure 7	Crosby Valve Inc
210 Figure 8	Crosby Valve Inc
211 Figure 9	IMI Bailey Birkett Ltd
212 Figure 10	IMI Bailey Birkett Ltd
212 Figure 11	IMI Bailey Birkett Ltd
213 Figure 12	Plast-O-Matic Valves Inc
213 Figure 13	Fort Valve Inc.
214 Figure 14	Circle Seal Controls Inc
214 Figure 15	Circle Seal Controls Inc
215 Figure 16	Crosby Valve Inc
216 Figure 17	Crosby Valve Inc
217 top	Flow Safe Inc.
217 bottom	Spirax Sarco
218 Figure 18	Anderson, Greenwood-Co
218 Figure 19	Crosby Valve Inc
218 Figure 20	Spirax Sarco
219 Figure 21	IMI Bailey Birkett Ltd
226 Figure 1	Spirax Sarco
227 Figure 2	Spirax Sarco
227 Figure 3	Spirax Sarco
233 Figure 5	Spirax Sarco
233 Figure 6	Spirax Sarco
235 Figure 8	Spirax Sarco
238 top left	Guest and Chrimes
238 top right	Guest and Chrimes
240	Guest and Chrimes
243 Figure 3	SOCLA Danfoss Water Valves
244 top	SOCLA Danfoss Water Valves
244 Figure 2	SOCLA Danfoss Water Valves
245 Figure 3	SOCLA Danfoss Water Valves
245 Figure 4	SOCLA Danfoss Water Valves
245 Figure 5	SOCLA Danfoss Water Valves
246 Figure 6	SOCLA Danfoss Water Valves
249	Saunders Valve Co
252	Neles-Jamesbury
253	Neles-Jamesbury
254	KSB Armaturen GmbH
255	KSB Armaturen GmbH
256	Neles-Jamesbury
257	Rotork Controls Ltd

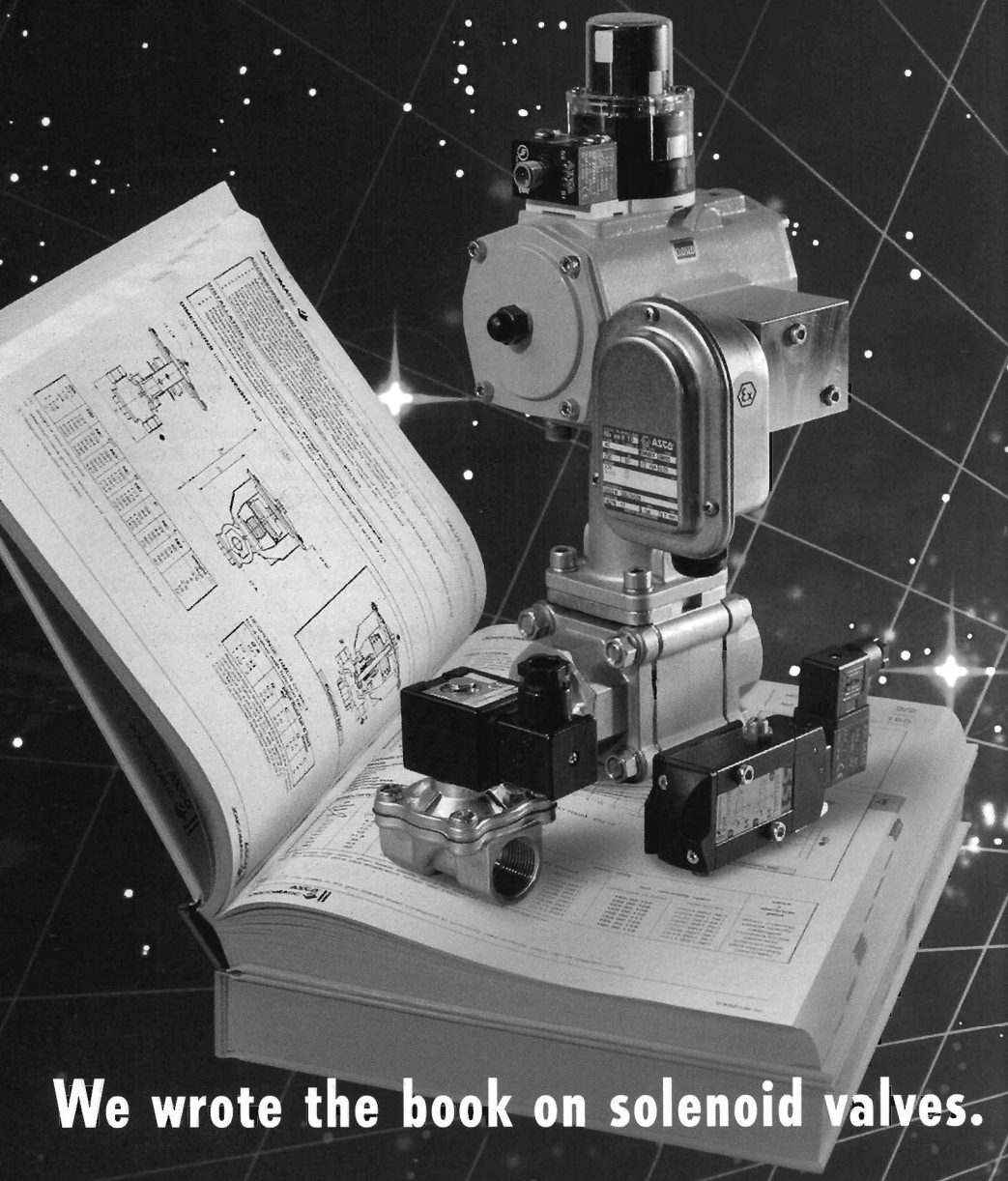
Page Number	Company
258	Shafer Valve Co
260 Figure 1	KSB Armaturen GmbH
260 Figure 2	KSB Armaturen GmbH
261 Figure 3	Neles-Jamesbury
262 Figure. 4	Shafer Valve Co
263 Figure 5	Shafer Valve Co
264 Figure 6	Bel Valves
265	KSB Armaturen GmbH
267 Figure 7	Rotork Controls Ltd
268 Figure 8	Hitachi Valve
268 Figure 9	Rotork Controls Ltd
269 Figure 10	Rotork Controls Ltd
270 Figure 11	Rotork Controls Ltd
271 Figure 12	Rotork Controls Ltd
273 Figure 13	Rotork Controls Ltd
274 Figure 14	Dreamo Electro-Mechanik GmbH
275 Figure 14	Dreamo Electro-Mechanik GmbH
276	Rotork Controls Ltd
277 Figure 16	El-O-Matic International
277 top	Tyco Valves and Controls
278 Figure 17	Exeeco Ltd
280 Figure 1	Spirax Sarco
281 top	Spirax Sarco
281 bottom	Dezurik, a division of SPX
282 bottom right	Plast-O-Matic Valves Inc
282 top left	Severn Glocon
282 top right	Guest and Chrimes
284 Figure 2	Spirax Sarco
284 Figure 3	Spirax Sarco
285 Figure 4	Dezurik, a division of SPX
286 Figure 5	Spirax Sarco
287 Figure 6	Spirax Sarco
287 Figure 7	Spirax Sarco
288 Figure 8	Spirax Sarco
288 Figure 9	Spirax Sarco
288 Figure 10	Spirax Sarco
289 Figure 11	APV/Invensys
290 Figure 12	APV/Invensys
291 Figure 13	APV/Invensys
292 Figure 14	K. Controls Ltd
293 Figure 15	Realm
294 top	Osmonics
294 Figure 16	Gemü Valves Ltd
295	SOCLA Danfoss Water Valves
296	SOCLA Danfoss Water Valves
297 Figure 17	Emile Egger-Co. AG
297 Figure 18	Emile Egger-Co. AG
298 Figure 19	Asco Joucomatic Ltd
298 Figure 20	Asco Joucomatic Ltd
299 Figure 21	Asco Joucomatic Ltd
299 Figure 22	Curtis Wright Control Flow Corporation
304 Figure 6	Spirax Sarco
305 Figure 7	Spirax Sarco
307 Figure 2	Spirax Sarco
308 Figure 3	Spirax Sarco
310 Figure 5	Spirax Sarco
310 Figure 6	Spirax Sarco

Page Number	Company
315 top left	Dycon Dynamic Controls
315 top right	Dycon Dynamic Controls
316 Figure 3	Apco Controls
316 Figure 3	Fisher Rosemount
317 Figure 4	Fisher Rosemount
317 bottom	Fisher Rosemount
318 Figure 6	Circle Seal Controls Inc
319 Figure 7	Circle Seal Controls Inc
325	Griffin Pipe Products Co.
326	Hitachi Valve
327	Biwater Industries
328	Griffin Pipe Products Co.
329 Table 1	Biwater Industries
330 Figure 1	Biwater Industries
330 Figure 2	Biwater Industries
330 Table 2	Biwater Industries
331 Table 3	Biwater Industries
331 Table 5	Biwater Industries
333 Figure 3	Griffin Pipe Products Co.
334	Rath Manufacturing Company Inc
335 Table 7	Special Metals Corporation
336	Dow Chemical Co
337	Dow Chemical Co
338 Figure 4	Crane
339 Figure 1	George Fischer
340 Figure 2	George Fischer
341	George Fischer
356 Table 1	George Fischer
357	George Fischer
358 Figure 1	George Fischer
359 top	Harvel Plastics
360	George Fischer
361	Upnor Ltd
368	Agru Company
369	George Fischer
370 top	George Fischer
370 bottom	ASAHI/America
371	ASAHI/America
372	ASAHI/America
374 Figure 4	Wiik and Hoeglund
378	George Fischer
379	George Fischer
380	George Fischer
384 Table 6	George Fischer
391 top	George Fischer
393 Table 7	George Fischer
395	Harvel Plastics
396	Griffin Pipe Products Co.
400-401 Figure 1	Griffin Pipe Products Co.
402	Griffin Pipe Products Co.
403 Figure 2	Biwater Industries
403 Figure 3	Victualic
404 Figure 4	Victualic
405 Figure 5	Victualic
405 bottom	Victualic
406 Figure 6	Harvel Plastics
407	Griffin Pipe Products Co.
408 Figure 8	Biwater Industries

Page Number	Company
410 top	Biwater Industries
411	Biwater Industries
412 Figure 13	APV/Invensys
413 Figure 14	3X Engineering France
414 top	3X Engineering France
422 Figure 15	George Fischer
422 bottom	George Fischer
423	George Fischer
425 top	International Hwashen Corporation
441 Figure 13	George Fischer
445 top	Victualic
449 Figure 4	Metal Samples
450 top	Metal Samples
450 Figure 5	Metal Samples
454 Figure 7	Pi Conversion Engineering Ltd
454 Figure 8	Pi Conversion Engineering Ltd
467	Plascoat International
468 top	Dow Chemical Co
468 bottom	Dow Chemical Co
472 Table 2	Biwater Industries
474	Dow Chemical Co
475 top	Dow Chemical Co
475 bottom	Dow Chemical Co
483 Table 3	T. D. Williamson, Inc.℠
484 top	I.S.T. Molchtechnik GmbH
484 Figure 2	T. D. Williamson, Inc.℠
486-487 Figure 3	T. D. Williamson, Inc.®
488-489 Figure 4	T. D. Williamson, Inc.®
492 Table 5	T. D. Williamson, Inc.®
497	E. H. Wachs Co
498	E. H. Wachs Co
499 top	E. H. Wachs Co
499 bottom	Tubelar Engineering
501 top	E. H. Wachs Co
507	T. D. Williamson, Inc.®
508 top	T. D. Williamson, Inc.®
508 bottom	T. D. Williamson, Inc.®
509	T. D. Williamson, Inc.℠
510	T. D. Williamson, Inc.®
514	Radiodetection
515 Figure 1	Dyno-Rod
516 Figure 2	Dyno-Rod
517 Figure 3	Cabletime Systems Ltd
519	Radiodetection
520	Shafer Valve Co
522 Figure 1	Controls Southeast Inc
523 Figure 2	Controls Southeast Inc
523 Figure 3	Controls Southeast Inc
525 Table 1	Controls Southeast Inc
526 Figure 4	Controls Southeast Inc
528 Figure 5	International Plastic Systems Ltd
529 Figure 6	Enfield Industrial Corporation
638	Spirax Sarco
640	Weir Pumps
641	Weir Pumps
656 Table 2	Spirax Sarco
661 Figure 5	Kent Process Control
665	Dresser Valve Division
668	Neles-Jamesbury
670 Figure 1	Neles-Jamesbury
670 Figure 2	Fisher Rosemount
671 Figure 3	Fisher Rosemount
672 Figure 4	Fisher Rosemount
672 Figure 5	Fisher Rosemount
673 Figure 6	Fisher Rosemount
673 Figure 7	Fisher Rosemount
674 Figure 8	Neles-Jamesbury
674 Figure 9	Neles-Jamesbury
675 Figure 10	Neles-Jamesbury
677 Table 1	Crosby Valve Inc
679 Figure 12	Engineering Applications Ltd
679 Figure 13	Engineering Applications Ltd
680 Figure 14	Engineering Applications Ltd
680 Figure 15	Engineering Applications Ltd
684	Tour + Andersson AB
694	SOCLA Danfoss Water Valves
695 Table 1	Spirax Sarco
697 Figure 3	APV/Invensys
698 Figure 4	Dezurik, a division of SPX
699 Figure 5	KSB Armaturen GmbH
699 right	Guest and Chrimes
700 Figure 6	Wouter Witzel GmbH
701 Figure 7	Dezurik, a division of SPX
702	Guest and Chrimes
703 bottom	Adams
703 top	Brooksbank Valves Ltd
704	Johnson Valves
707	SOCLA Danfoss Water Valves
708 top	Lancashire Fittings Ltd
708 bottom	Delta Capillary Products Ltd
716 Figure 8	IMI Bailey Birkett Ltd
716 Figure 9	IMI Bailey Birkett Ltd
719	Realm
720	Realm
721 Figure 1	Bray Valves + Controls (UK)
721 Figure 2	Quality Controls Inc
722 Figure 4	GSR Ventiltechnik GmbH
723 Figure 5	Dresser Valve Division
725 Figure 8	Schott Industrial Glass
726	Harvel Plastics
729 Figure 1	Spirax Sarco
730 Figure 2	Spirax Sarco
731 Figure 3	Spirax Sarco
733 bottom	J. G. Black Polymers Ltd
733 top	Crosby Valve Inc
734 bottom	Crosby Valve Inc
735 Figure 4	Spirax Sarco
739 Figure 5	B.T.G.
739 Figure 6	Spirax Sarco
746 Table 1	Solvent + Pratt
748 Figure 3	Hindle Cockburns Ltd
749 bottom	OMB SpA
749 Figure 4	Solvent + Pratt
750 Table 3	Solvent + Pratt
753	OMB SpA

Page Number	Company	Page Number	Company
754	Brooksbank Valves Ltd	771 Figure 2	Tyco Valves and Controls
755 Figure 1	Guest and Chrimes	772 Figure 3	Neles-Jamesbury
755 top	Brooksbank Valves Ltd	773 top	IMI Bailey Birkett Ltd
756 Table 1	Guest and Chrimes	773 Figure 4	Circle Seal Controls Inc
757 Figure 2	IMI Bailey Birkett Ltd	775	Worcester Controls
759	Brooksbank Valves Ltd	776	Vanatome
761 bottom	KSB Armaturen GmbH	777 Figure 2	Crane® Resistoflex
761 top	Blakeborough Valves	778 Figure 3	EDF
764 bottom	Neles-Jamesbury	782	Mannesmannrohren-Werke AG
764 Figure 2	Neles-Jamesbury		
765 Figure 3	Neles-Jamesbury	784	Neles-Jamesbury
766 Figure 4	Circle Seal Controls Inc	786	GSR Ventiltechnik GmbH
768	Reiss Engineering Co. Ltd	788 Figure 6	Adams
769	Solvent + Pratt	788 middle	Kepner Products Company
770 Figure 1	Tyco Valves and Controls	789	Adams

Note:
Figures from T. D. Williamson, Inc.®:
Reproduced with the permission of T. D. Williamson, Inc.® Registered Trademarks of T. D. Williamson, Inc. in the United States and in foreign countries.



We wrote the book on solenoid valves.

As the inventor of the solenoid valve, ASCO JOUCOMATIC has been guiding new developmen since 1888. Today, our product range which totals in excess of 5,000 standard types, and the availability of more than 30,000 special versions makes us the largest solenoid valve producer in the world. And it doesn't stop there; when it comes to tailor-made solutions in accordance with your specifications, we provide even more.
ASCO JOUCOMATIC has the right solution for every fluid control and fluid power application. We guarantee top quality and maximum operational reliability for all of our products. Of cours this is nothing more than what you would expect from a pioneer and leader in the field.

Our product catalogue shows this incredibly diverse range of solenoid valves.
Call, fax or e-mail us for a free copy.

ASCO JOUCOMATIC (Asco Controls BV)
Tel.: +31 33 277 79 11, Fax: +31 33 277 45 61
E-mail: ascojc@asco-joucomatic.nl
Internet: www.ascovalve.com and www.ascojoucomatic.com
Industrielaan 21, 3925 BD Scherpenzeel, The Netherlands

ASCO JOUCOMATIC

SECTION 1

Fundamentals

Classification of Valves

Basic Valve Nomenclature

Valve Selection Guides

Pipes and Pipelines—Definitions and Explanations

Classification of Valves

Valves may be classified in a number of ways, e.g. by category (general type), specific type, purpose or name; or by flow characteristics (e.g. straight-through, full-flow or throttled-flow). Descriptions can also differ slightly in different countries although the main type names are established internationally (with some exceptions).

Classification of valves by category is given in Table 1. This follows British Standards and general practice adopted by British manufacturers, but is also generally applicable to American practice. One major difference in this respect is that the important class of ball valves is considered as a type of plug valve in the tabular summary, whereas American practice would favour regarding it as a separate category. The ball valve is, in fact, a major type in its own right.

Modular ball valve based on standardised components.

Table 1. Classification of valves

Category	Patterns	Types of construction	Remarks
Cock	1. Plug 2. Gland 3. Packed cock 4. Compound gland	Tapered plug Plug retained by gland or packing Packing between plug face and body seat Stuffing box in cover	Also parallel plug.
Plug valve	1. Plain 2. Lubricated	1. Taper plug 2. Parallel plug 3. Ball plug	Passage through port in rotatable. plug supported or mounted to reduce friction.
Screw-down stop valve	1. Inside screw 2. Outside screw	1. Globe valve 2. Angle 3. Oblique 4. Others	Spherical body. Spherical body with ends at right angles. Spherical body, stem axis oblique. Usually described by type (e.g. needle valve) or geometry of body (e.g. tee valve).
Gate valve (wedge gate valve) Gate valve (slide valve)	1. Inside screw 2. Outside screw 3. Lever (a) Sliding stem (b) Rotary stem	1. Wedge (gate) 2. Sluice (valve) 3. Double disc	Closure effected by wedge action. (a) Solid wedge or (b) Split wedge. Solid wedge gate valve. Gate composed of parallel sliding discs or slides.
Check valve	1. Horizontal 2. Vertical 3. Angle	1. Swing (check) 2. Lift (a) Disc (b) Piston (c) Ball 3. Foot (valve)	Hinged flap check mechanism. Disc check mechanism. Disc plus piston check mechanism. Ball check. Check valve fitted to bottom of a suction pipe.
Butterfly valve	1. Double flanged 2. Water (a) Single flange (b) Flangeless	Each flange is individually bolted. Primarily designed for insertion between pipe flanges	Based on rotatable disc valve.
Diaphragm valve		Flexible diaphragm mounted over a weir.	
Ball (float valve)	1. Single beat 2. Double beat	1. Direct (lever)-operated 2. Pressure-operated 3. Droptight 4. Non-droptight	Single beat—flow through single seating ring. Double beat—flow through two seating rings.

Table 1 (*continued*)

Category	Patterns	Types of construction	Remarks
Safety valve	1. Direct spring-loaded 2. Direct weight-loaded 3. Lever and spring-loaded 4. Lever and weight-loaded 5. Tension spring-loaded 6. Torsion bar		Also designated by: 1. High-lift valve. 2. Full-lift valve. 3. Pilot-operated valve. 4. Electrically-assisted valve.
Relief valve	1. Direct spring-loaded 2. Direct weight-loaded		Also designated by: 1. High-lift (relief) valve. 2. Pilot-operated (relief) valve.
Pressure control valve	1. Self-contained 2. Spring-loaded 3. Weight-loaded 4. Pressure-loaded 5. Externally-piped 6. Tight-closing 7. Non-tight-closing 8. Relay-operated	1. Pressure-reducing 2. Pressure-retaining 3. Indirect	
Air relief valve	1. Single-orifice LP 2. Single-orifice HP 3. Single-orifice with integral isolating valve 4. Double-orifice with integral isolating valve		
Turbine valve	1. Regulating 2. Quick-closing 3. Starting 4. Exhaust 5. Guarding		
Free discharge valve	1. Needle-type 2. Hollow jet-type 3. Sleeve-type		

Valves are classified and described by specific type in Section 2, which also include a number of individual designs best categorised as miscellaneous. Some other valve types are given in Table 2.

Descriptions of various valve types may also differ and Table 3 lists some other descriptions, standard terminology in this case being based on that adopted for Table 1. This is by no means complete, but is offered as a general guide.

Table 2. Some other valve types

Category	Description
Flow-regulating valve	For controlling rate of flow in a system.
Temperature-regulating valve	For controlling fluid temperature level in a system.
Automatic process-control valve	For controlling rate of flow relative to value of a command system.
Anti-vacuum valve	An automatic type of air valve for the prevention of the formation of vacuum or the release of vacuum in large bore pipelines.
Blow-down valve	A valve which is used for cleaning sludge and other foreign matter from a boiler.
Bulkhead valve	A gate valve.
Free-ball valve	A valve in which a ball, free to rotate in any direction, is moved at 90° to the flow stream from a position removed from the flow stream until finally rolling into a circular orifice for shut off.
Fusible-link or fire valve	A fire prevention valve which has a weighted lever held open by a wire and fusible link which melts at an increase in room temperature.
Hydraulic valve	A control valve for either water, oil, or hydraulic systems.
Jet-dispersal valve	A valve incorporating an element by virtue of which the energy within the emitting jet is dissipated.
Penstock	A single-faced type of valve consisting of an open frame and door, and used in terminal positions only: usually located in tanks or channels as a means of controlling flow into a pipe.
Plate valve	A gate valve incorporating a sluicing effect.
Radiator valve	A valve for controlling the flow of water through a radiator.
Rotary-slide valve	A valve in which rotation of internal parts regulates flow by opening or closing a series of segmental ports.
Rotary valve	A spherical-plug valve in which the plug, which rotates through 90°, is provided with a circular waterway to match the body and ports.
Solenoid valve	A valve operated by an electrical solenoid.
Spectacle-eye valve	A type of parallel slide valve in which the 'spectacle gate' has one 'lens' of circular waterway and the other of solid section.
Thermostatic mixing valve	A valve which combines temperature selection and flow control in the same body.
Throttle valve	A non-tight-closing butterfly valve with a centrally-hinged flap which can be locked in any desired position.

Classification of valves by function yields the following general list where any individual type of valve may be capable of performing one or more of these functions. Excluded from this list are specific functions or specialised services for which special designs of valves are normally employed.

(i) On-off service.
(ii) Throttling or flow control.
(iii) Preventing of reverse flow.

Table 3. Terminology

General or 'popular' description	Standard terminology
Back-pressure valve	Check valve
Block and bleed valve	Gate valve
Clack valve	Check valve
Conduit valve	Gate valve with full-bore aperture
Controllable check valve	Screw-down stop and check valve
Controllable non-return valve	Screw-down stop and check valve
Dashpot valve	Check valve (piston-check disc-type)
Excess-flow valve	Flow-regulating valve
Excess- or minimum-pressure valve	Flow-regulating valve
Flap valve	Check valve (swing-type)
Follower-ring valve	Gate valve
Fullway valve	Gate valve
Governor valve	Pressure-control valve
Non-return self-closing valve	Check valve
Parallel-gate valve	Safety valve (direct spring-loaded)
Proportional-flow valve	Flow-regulating valve
Reflux valve	Check valve
Retention valve	Check valve
Screw-down non-return and flood valve	Screw-down stop and check valve
Wheel valve	Screw-down stop valve
Y-type valve	Oblique valve

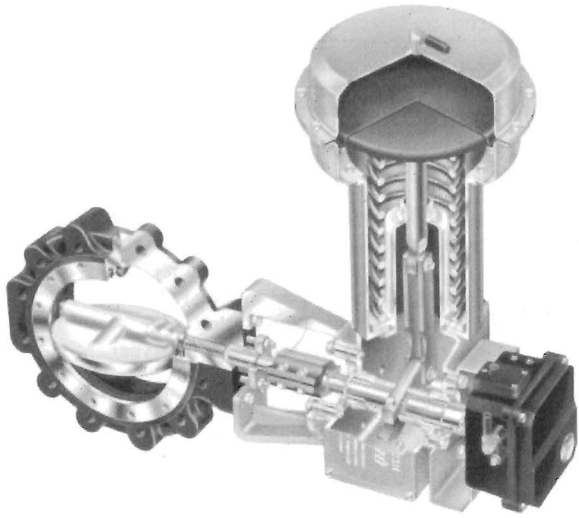
(iv) Pressure control.
(v) Directional flow control.
(vi) Sampling.
(vii) Flow limiting.

Valves classified by duty or the service they are intended to perform are described in Section 3. Necessarily these embrace types already described under specific types and the relevant chapters can be studied together where appropriate. A further source of reference and information in this respect is the chapter on Valve Selection Guides.

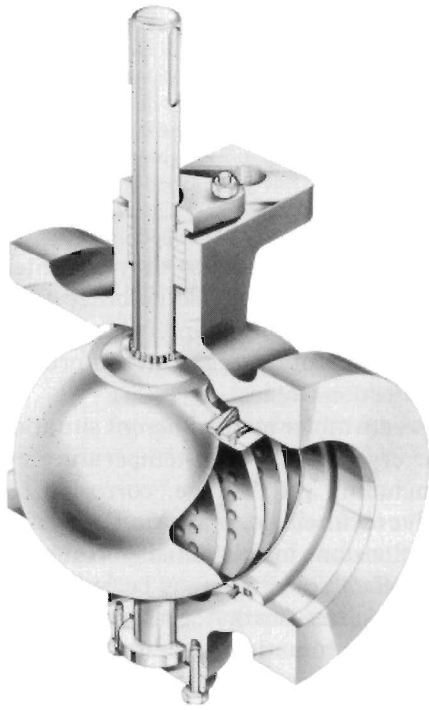
Industrial valves operate under many different situations and temperatures which range from the cryogenic to high-temperature applications and with different materials including grit, sludge, corrosive chemicals, gases and liquids. In general, valve technology is mature.

There are two main divisions in the industry: control valves giving precise control of flow and on/off valves which may be further subdivided into linear (multi-turn) and rotary (quarter-turn). Actuators which control the movement of a valve can be manual or automatic and are a major ancillary item for valves.

Valves can be purchased as standard products (commodity valves) or as engineered units, purpose-built for a specific application. The emphasis today is on providing solutions to problems and automation wherever possible.



High-performance butterfly valve with sectioned spring-diaphragm actuator for modulating control.



Rotary segment-control valve with noise-control trim.

Processes are required to be more economical and run uninterrupted for longer periods.

The intervals between production shut-downs for plant maintenance are growing longer and environmental protection legislation is becoming more stringent.

Intelligent valves, based on digital control technology and incorporating control functions and communication interfaces are already making an impact and computer integrated processing (CIP) is a reality. The most striking changes in valve technology appear to be in the field of materials of constructions with new metals, ceramics and composites being explored.

Valve connections

Valves are normally designed to take either threaded pipe ends, or with flanges for flanged connection. Threaded connections are simpler and cheaper to produce and more easily installed. However, it can prove difficult to remove valves so mounted without dismantling a considerable portion of the piping unless a number of extra fittings, such as unions, are incorporated.

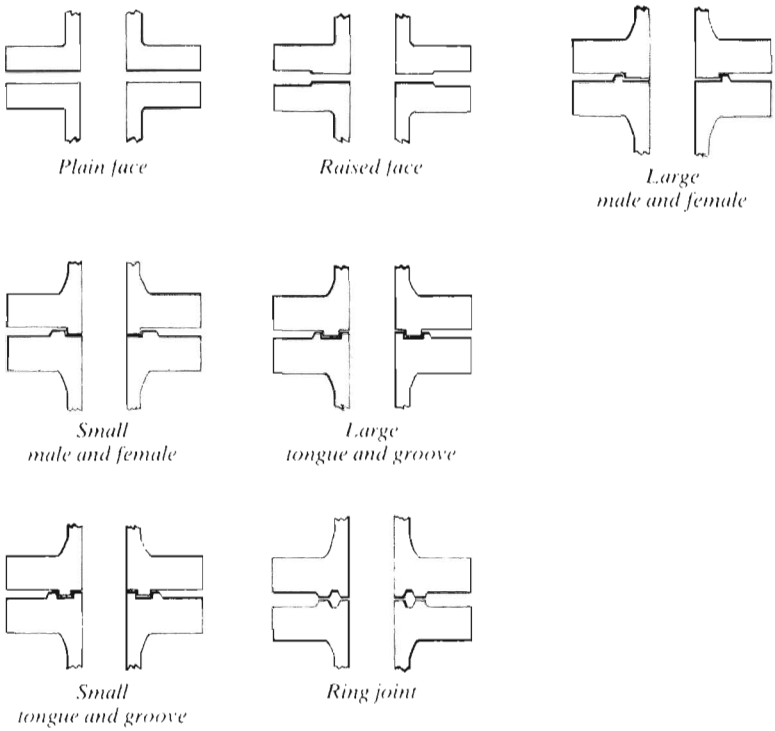


Figure 1. Flanged ends.

Flanged ends make a stronger, tighter and more leak-proof connection. Where heavy viscous media are to be controlled, as in refineries, process and chemical plants, etc., flanged-end valves are normally used. The initial cost is higher, not only because of the extra metal but because the flanges must be carefully and accurately machined. Also the installation cost is greater because companion flanges, to which the valve-end flanges are bolted, as well as gaskets, bolts and nuts must be provided.

All flat faces are commonly termed plain faces. Bronze and iron flat faces can have a machined finish. Cast iron raised faces may be smooth finished or have a serrated finish (preferably with no fewer than 16 serrations per inch) which may be spiral or concentric. Steel flat faces and raised faces should have a serrated finish of approximately 32 serrations per inch. The serrations may be either spiral or concentric.

Steel male and female and tongue-and-grooved faces should have a smooth finish. Steel ring-joint faces should have smooth finished grooves. If spiral-wound gaskets are used on flange faces, the flanges should have a smooth finish. Examples of flanged ends are shown in Figure 1.

Socket or butt-welded ends are used on all-welded pipeline systems. For specific services valves are also to permit connection to pipes by soldering or brazing. In the latter case the valve may be supplied with integral preformed brazing-material inserts.

Basic Valve Nomenclature

Most valves consist of a body containing a flow control element (discs, plug, gate, etc.) attached to and operated by rotation of a stem. (There are exceptions: e.g. swing check and pinch valves have no stem.) The stem, together with any stem seals, is enclosed within a bonnet. The top of the stem is fitted with a handwheel (or lever) for rotation of the stem (although some stems may have a sliding operation for quick action).

With threaded stems (giving a screw-down, screw-up motion) the threaded portion may be fully enclosed by the bonnet, known as inside screw; or exposed beyond the bonnet, known as outside screw. The former obviously provides maximum protection for the screw thread. Outside screws have the advantage of being easier to lubricate.

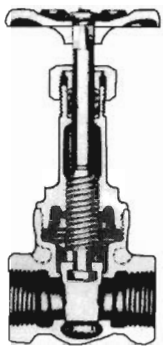
With rising-stem valves the handwheel and stem move together, giving a visual indication of the degree of valve opening. With a non-rising stem the handwheel does not rise (or fall) with the turning movement. The advantage of this type is that it can be installed in situations providing only minimum headroom above the handwheel.

Various types of bonnet may be used, e.g. screw-in, screw-on, union-style and bolted or flanged bonnet. Screw-in or screw-on bonnets are the simplest and cheapest, but largely limited to smaller valves used on low-pressure services. Union bonnets generally provide tighter sealing and are particularly suitable for valves which are dismantled frequently for servicing. Plain (flat) flange and male- and female-flanged bonnets are generally preferred for high-temperature or high-pressure valves, and also larger sizes of valves. An alternative type for high-pressure and/or high-temperature services is the breech-lock bonnet.

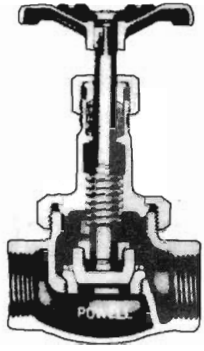
Valve trim

Trim is the term used to describe the parts of a valve which are replaceable, i.e. normally those parts likely to be subject to wear or degradation. The following parts are considered as trim:

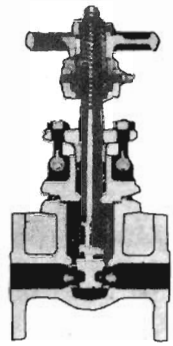
Gate valves—stem, seat ring, wedge, back-seat bushing.
Globe and angle valves—stem, seat ring, disc, disc nut, back-seat bushing.



Screwed bonnet.



Union bonnet.



Bolted flanged bonnet.

Disc valve—disc, disc nut, back-seat bushing.
Swing-check valves—disc, disc holder, disc nut, side plug, carrier pin, disc-holder pin, disc-nut pin, seat rings.
Lift-check valves—disc, disc guide, seat rings.

Stem seals and other internal seals (where fitted) are arguably included under the definition of trim, but are not normally used in describing trim materials.

Standard abbreviations

The following abbreviations are used to describe or designate valve parts, features, etc.:

All iron	all parts of iron construction.
All bronze	all parts of bronze construction.
BB	bolted (flanged) bonnet.
CWp	cold working pressure.
DD	double disc.
DW	double wedge.
FE	flanged end (connection).
FF	flat flange.
IBBM	iron body bronze-mounted.
IPS	iron pipe size.
ISNRS	inside screw non-rising stem.
ISRS	inside screw rising-stem.
NRS	non-rising stem.
RF	raised flange.
RS	rising stem.
SIB	screwed bonnet.

SW	solid wedge.
S int or int S	internal seat.
S ren or ren S	renewable seat.
OS & Y	outside screw and yoke.
WOG	water, oil, gas pressure rating.

Nomenclature covering the individual parts of various different types of valves is included in Section 2.

Valve Selection Guides

The main parameters concerned in selecting a valve or valves for a typical general service are:

(i) Fluid to be handled—this will affect both type of valve and material choice for valve construction.
(ii) Functional requirements—mainly affecting choice of type of valve.
(iii) Operating conditions—affecting both choice of valve type and constructional materials.
(iv) Flow characteristics and frictional loss—where not already covered by (ii), or setting additional specific or desirable requirements.
(v) Size of valve—this again can affect choice of type of valve (e.g. very large sizes are only available in a limited range of types); and availability (matching sizes may not be available as standard production in a particular type).
(vi) Any special requirements—e.g. quick-opening, free-draining, etc.

In the case of specific services, choice of valve type may be somewhat simplified, e.g. by following established practice or selecting from valves specifically produced for that particular service.

On a broad basis, Table 1 summarises the applications of the main types of general purpose valves. It has only limited use as a selection guide, i.e. can be regarded as a starting point. Table 2 carries general selection a stage further in listing valve types normally used for specific services. Table 3 is a particularly useful expansion of the same theme relating the suitability of different valve types to specific functional requirements.

Normally, for general services (and for many specific services), several valve types may appear as possible choices. These may then need evaluating individually, and comparing on the basis of the flow characteristics they offer. Even more important, calculations may be necessary to establish a suitable size of valve to meet a specific performance requirement, e.g. a maximum acceptance pressure drop or head loss through the valve.

Table 1. Valve types—typical applications

Valve category	General application(s)	Actuation	Remarks
Screw-down stop valve	Shut-off or regulation of flow of liquids and gases (e.g. steam).	(i) Handwheel (i) Electric motor (ii) hydraulic systems actuator (v) Hydraulic actuator (v) Air motor	(a) Limited application for low-pressure/low-volume systems because of relatively high cost. (b) Limited suitability for handling viscous or contaminated fluids.
Cock	Low-pressure service on clean, cold fluids (e.g. water, oils, etc.).	Usually manual	Limited application for steam services.
Gate valve	Normally used either fully open or fully closed for on–off regulation on water, oil, gas, steam and other fluid services.	(i) Handwheel (i) Electric motor (ii) hydraulic systems actuator (v) Hydraulic actuator (v) Air motor	(a) Not recommended for use as throttling valve. (b) Solid wedge gate is free from 'chatter' and jamming.
Parallel-slide valve	Regulation of flow, particularly in main services in process industries and steam power plant.		(a) Offers unrestricted bore at full opening. (b) Can incorporate venturi bore to reduce operating torque.
Butterfly valve	Shut-off and regulation in large pipelines in waterworks, process industries, petrochemical industries, hydroelectric power stations and thermal power stations.	(i) Handwheel (i) Electric motor (ii) hydraulic systems actuator (v) Hydraulic actuator (v) Air motor	(a) Relatively simple construction. (b) Readily produced in very large sizes (e.g. up to 18 ft or more).
Diaphragm valve	Wide range of applications in all services for flow regulation.	(i) Handwheel (i) Electric motor (ii) hydraulic systems actuator (v) Hydraulic actuator (v) Air motor	(a) Can handle all types of fluids, including slurries, sludges, etc., and contaminated fluids. (b) Limited for steam services by temperature and pressure rating of diaphragm.
Ball valve	Wide range of applications for all sizes, including very large sizes in oil pipelines, etc.	(i) Handwheel (i) Electric motor (ii) hydraulic systems actuator (v) Hydraulic actuator	(a) Unrestricted bore at full opening. (b) Can handle all types of fluids. (c) Low operating torque. (d) Not normally used as a throttling valve.
Pinch valve	Particularly suitable for handling corrosive media, solids in suspension slurries, etc.	(i) Mechanical (i) Electric motor (ii) hydraulic systems actuator (v) Hydraulic actuator (v) Fluid pressure (modified design)	(a) Unrestricted bore at full opening. (b) Can handle all types of fluids. (c) Simple servicing. (d) Limited maximum pressure rating.
Automatic process-control valve	Designed to meet particular service conditions.	To meet particular service conditions	Most commonly of single or double beat-globe valve configuration.
Air-relief valve	Used in water works, etc., to release entrapped air and prevent formation of vacuum 'pockets'	Automatic—responding to changes in flow pressure	
Turbine valve	Designed to meet requirements of steam and water turbines in industrial, marine and power	To meet particular service conditions	Provides guaranteed control over maximum and minimum turbine speeds and power in association

Table 2. Valve types for specific services

Service	Main	Secondary
Gases	Butterfly valves Check valves Diaphragm valves Lubricated plug valves Screw-down stop valves	Pressure-control valves Pressure-relief valves Pressure-reducing valves Safety valves Relief valves
Liquids, clear up to sludges and sewage	Butterfly valves Screw-down stop valves Gate valves Lubricated plug valves Diaphragm valves Pinch valves	
Slurries and liquids heavily contaminated with solids	Butterfly valves Pinch valves Gate valves Screw-down stop valves Lubricated plug valves	
Steam	Butterfly valves Gate valves Screw-down stop valves Turbine valves	Check valves Pressure-control valves Pre-superheated valves Safety and relief valves

Valve coefficients and flow values

The valve coefficient is a convenient method of relating flow rates to pressure drop through valves and, in fact, is sometimes called a flow value. This coefficient can only be determined empirically for a specific type of valve as it will be influenced by detail design and construction. It will also vary with the physical size of the valve and the degree of opening in the valve. Valve coefficient values are normally quoted for 100% opening (full open), with individual valves for each size.

Some confusion can arise from the fact that the coefficient quoted for a valve can have three different values depending on the basic units on which it was computed. Normally these are apparent from the designation of the valve coefficient, viz:

C_v in units of US gal/min, $1bf/in^2$
K_v or k_v in units of l/min, bar
f in Imperial units of Imp gal/min, $1bf/in^2$

The following conversions apply:

	K_v	C_v	f
K_v	—	14.28	17.09
C_v	0.07	—	1.1966
f	0.0589	0.8357	—

Table 3. Typical valve suitability chart

Valve type	Service or function										
	On–off	Throttling	Diverting	No reverse flow	Pressure control	Flow control	Pressure relief	Quick opening	Free draining	Low pressure drop	Handling solids in suspension
Ball	S	M	S	—	—	—	—	S	—	S	LS
Butterfly	S	S	—	—	—	S	—	S	S	S	S
Diaphragm	S	M	—	—	—	—	—	M	M	—	S
Gate	S	—	—	—	—	—	—	S	S	S	—
Globe	S	M	—	—	—	M	—	—	—	—	—
Plug	S	M	S	—	—	M	—	S	S	S	LS
Oblique (Y)	S	M	—	—	—	M	—	—	—	—	—
Pinch	S	S	—	—	—	S	—	—	S	S	S
Slide	—	M	—	—	—	M	—	M	S	S	S
Swing-check	—	—	—	S	—	—	—	—	—	S	—
Tilting-disc	—	—	—	S	—	—	—	—	—	S	—
Lift-check	—	—	—	S	—	—	—	—	—	—	—
Piston-check	—	—	—	S	—	—	—	—	—	—	—
Butterfly-check	—	—	—	S	—	—	—	—	—	—	—
Pressure-relief	S	—	—	—	—	—	S	—	—	—	—
Pressure-reducing	—	—	—	—	S	—	—	—	—	—	—
Sampling	S	—	—	—	—	—	—	—	—	—	—
Needle	—	S	—	—	—	—	—	—	—	—	—

Key:

S = Suitable choice

M = May be suitable in modified form

LS = Limited suitability

Typical flow coefficient equations can be shown as follows:

For liquids

$$Q = C_v \sqrt{\frac{\Delta P}{(s.g.)}}$$

where

Q = flow, gallons per minute
C_v = flow coefficient
ΔP = pressure drop, psi
s.g. = specific gravity (water=1)

For gases (non-critical flow):

$$Q = 16.07\, C_v \sqrt{\frac{Z(P_1^2 - P_2^2)}{T \times (s.g.)}}$$

where

Q = flow, SCFM
C_v = flow coefficient
P_1 = upstream pressure, psia
P_2 = downstream pressure, psia
Z = compressibility factor
T = absolute temperature (°F+460)
s.g. = specific gravity (air=1)

For gases (critical flow):

$$P_2/P_1 = R, \text{ and}$$

$$Q = 16.07\, C_v P_1 J \sqrt{\frac{Z}{T \times (s.g.)}}$$

where R and J are functions of the specific heat ratio 'r' as follows:

r	R	J	r	R	J
1.20	0.564	0.825	1.36	0.535	0.845
1.22	0.561	0.828	1.38	0.532	0.847
1.24	0.557	0.831	1.40	0.528	0.849
1.26	0.553	0.833	1.42	0.524	0.851
1.28	0.549	0.836	1.44	0.521	0.853
1.30	0.546	0.838	1.46	0.528	0.855
1.32	0.542	0.840	1.48	0.515	0.857
1.34	0.539	0.843	1.50	0.512	0.859

Combining flow coefficients

(1) Flow in parallel: $C_v = C_{v1} + C_{v2} + C_{v3} + \ldots$

(2) Flow in series: $\left(\frac{1}{C_v}\right)^2 = \left(\frac{1}{C_{v1}}\right)^3 + \left(\frac{1}{C_{v2}}\right)^2 + \left(\frac{1}{C_{v3}}\right)^2 + \ldots$

Flow characteristics of valves

Where the flow characteristics through the valve are of significance, the following notes can be useful.

Plug valves (Figure 1) offer a straightway passage through the ports with a minimum of turbulence. Flow can be in either direction and a quarter-turn will fully open or fully close the valve. Similar comment applies to ball valves.

Gate valves (Figure 2) present a substantially straightway flow through the ports in the full-open position since the wedge or 'gate' is lifted clear of the flow passage. Turbulence and pressure drop are low. Again flow can be in either direction.

Globe valves (Figure 3) are normally installed so that pressure is under the disc, assisting operation and eliminating a certain amount of erosive action. Turbulence and pressure drop are higher than with straightway valves.

Angle valves (Figure 4) have similar characteristics to globe valves, with flow directed through 90°. Again flow is normally directed under the disc. Reverse flow may be used in the case of high-temperature steam. Ball, globe and angle valves are suitable for throttling.

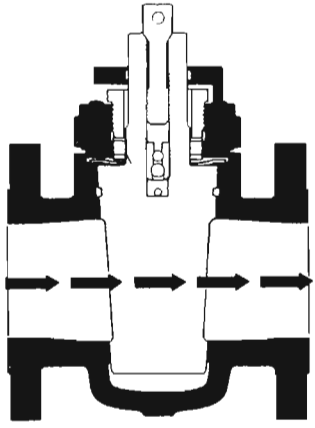


Figure 1. Plug valve.

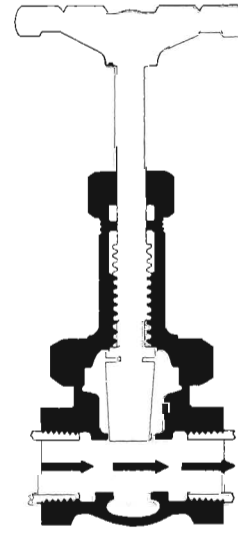
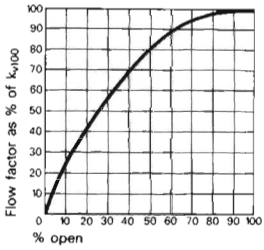


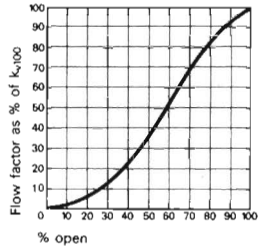
Figure 2. Gate valve.

Nominal Size	K_{v100}
3/8	41
1/2	95
3/4	180
1	327
1 1/4	484
1 1/2	725
2	1130
2 1/2	1700
3	–



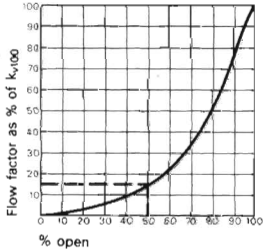
Gate

Nominal Size	K_{v100}
3/8	49
1/2	77
3/4	146
1	260
1 1/4	437



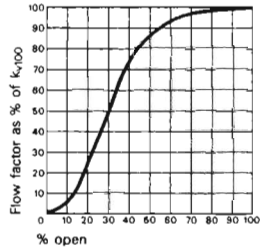
Lubricated plug

Nominal Size	K_{v100}
1/8	22
1/4	32
3/8	71
1/2	185
3/4	350
1	700
1 1/4	1000
1 1/2	1600
2	3100
3	6500
4	11000



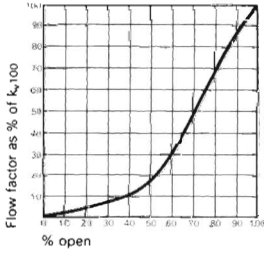
Ball

Nominal Size	K_{v100}
1/2	63
3/4	121
1	187
1 1/4	332
1 1/2	416
2	704
3	1700
4	2700



Diaphragm

Nominal Size	K_{v100}
2 1/2	1500
3	3000
4	5000
5	8000
6	12000
8	17000



Butterfly

Figure 8. Examples of flow values K_v.

The K_v table for angle-seat valves gives a K_{v100} factor of 327 for size 1 in, 484 for size $1^1/_4$ in and 725 for size $1^1/_2$ in.

In this example the correct size to use is $1^1/_4$ in (See also Table 5).

Example 2 (Figures 9 and 10)

(i) What is the K_v factor for a $1^1/_4$ in water pipeline with a flow of 300 l/min, an inlet pressure of 0.5 bar and an outlet pressure of 0 bar?

(ii) If a valve has to be fitted and the minimum acceptable flow rate in the pipeline is 250 l/min, which type of valve should be used?

Table 4. Typical 'K' values and pressure drops for various 150 mm (6 in) bore valves

Service	K value	Pressure drop*	
		bar	lbf/in²
Globe	5.0	0.59	8.5
Swing-check	3.5	0.40	5.9
Y-pattern	2.9	0.34	4.9
Angle (globe)	2.2	0.25	3.7
Venturi parallel-slide (with eyepiece)	1.1	0.13	1.9
Butterfly	1.0	0.12	1.7
Parallel-slide without eyepiece	0.15	0.021	0.3
Parallel-slide with eyepiece	0.05	0.007	0.1
Ball (full bore)	0.05	0.007	0.1
Straight pipe (the length of an average 6 in bore valve)	0.045	0.005	0.075

*Flow 40 m/s (140 ft/s) at 24 bar (350 lbf/in²) saturated steam.

Solution to (i) (Figure 9)

Calculate the K_v for the pipeline (K_{vp}).

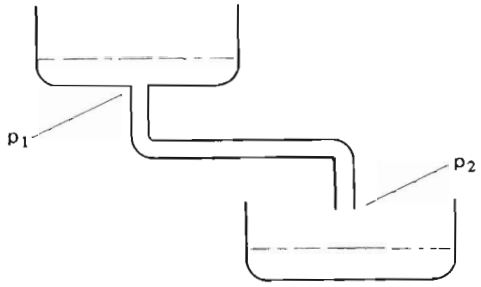


Figure 9.

Given:

$Q = 300\ l/min$

$\gamma = 1\ kg/dm^3$

$\Delta P = P_1 - P_2 = 0.5 - 0 = 0.5\ bar$

Then:

$$K_{vp} = Q\sqrt{\frac{\gamma}{\Delta P}}$$

$$= 300\sqrt{\frac{1}{0.5}}$$

$$K_{vp} = 424$$

Table 5. Typical sizes and operating ranges of valves

Valve	Size		Pressure range		Temperature range	
	Min.	Max.	Min.	Max.	Min.	Max.
	mm (in)		bar (lb/in^2)		°C (°F)	
Ball	6 (1/4)	1220 (48)	A	525 (7500)	−55 (−65)	300 (575)
Butterfly	50 (2)	1830 (72)	V	84 (1200)	−30 (−20)	538 (1000)
Butterfly-check	25 (1)	1830 (72)	A	84 (1200)	−18 (0)	260 (500)
Gate	3 (1/8)	1220 (48)	V	700 (10.000)	−277 (−455)	675 (1250)
Globe	3 (1/8)	760 (30)	V	700 (10.000)	−272 (−455)	540 (1000)
Plug, lubricated	6 (1/4)	760 (30)	A	350 (5000)	−40 (−40)	315 (600)
Plug, non-lubricated	6 (1/4)	406 (16)	A	210 (3000)	−75 (−100)	220 (425)
Swing-check	6 (1/4)	610 (24)	A	175 (2500)	−18 (0)	540 (1200)
Swing-check, Y-type	6 (1/4)	150 (6)	A	175 (2500)	−18 (0)	540 (1200)
Lift-check	6 (1/4)	250 (10)	A	175 (2500)	−18 (0)	540 (1200)
Tilting-disc	50 (2)	760 (30)	A	84 (1200)	−260 (−450)	590 (1100)
Diaphragm	3 (1/8)	610 (24)	V	21 (300)	−50 (−60)	230 (450)
Y (oblique)	3 (1/8)	760 (30)	V	175 (2500)	−272 (455)	540 (1000)
Slide	50 (2)	1900 (75)	A	28 (400)	−18 (0)	650 (1200)
Pinch	25 (1)	305 (12)	V	21 (300)	−75 (−100)	260 (500)
Needle	3 (1/8)	25 (1)	V	700 (10.000)	−78 (−100)	260 (500)

Key:
A = Atmospheric
V = Vacuum.

Solution to (ii) (Figure 10)

First it is necessary to calculate the K_v factor for the total system (K_{vt}).

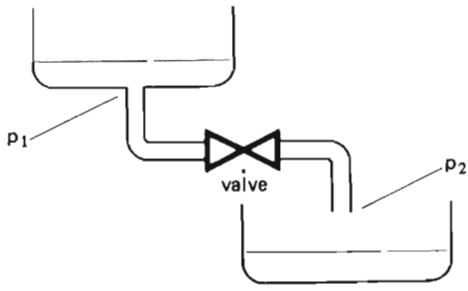


Figure 10.

Given:

$$\begin{aligned} Q &= 250\,\text{l/min} \\ \gamma &= 1\,\text{kg/dm}^3 \\ \Delta P &= P_1 - P_2 = 0.5 - 0 = 0.5\,\text{bar} \end{aligned}$$

Then:

$$K_{vt} = Q\sqrt{\frac{1}{\Delta P}}$$

$$= 250\sqrt{\frac{1}{0.5}}$$

$$K_{vt} = 354$$

The K_v factor for the valve (K_{vv}) can now be established by subtracting the K_v factor for the pipeline (K_{vp}) from the k_v factor for the total system (K_{vt}). For this purpose, the formula for calculating the flow factors in series should be used, which is:

$$\frac{1}{K_v^2 x} = \frac{1}{K_{v1}^2} + \frac{1}{K_{v2}^2} + \cdots \frac{1}{K_{vn}^2}$$

thus:

$$\frac{1}{K_{vt}^2} = \frac{1}{K_{vv}^2} + \frac{1}{K_{vp}^2}$$

$$\frac{1}{K_{vv}^2} = \frac{1}{K_{vt}^2} - \frac{1}{K_{vp}^2}$$

$$\frac{1}{K_{vv}^2} = \frac{1}{354^2} - \frac{1}{424^2}$$

$$= 7.98 \times 10^{-6} - 5.56 \times 10^{-6}$$

$$= 2.42 \times 10^{-6}$$

$$K_{vv} = \sqrt{\frac{1}{2.42 \times 10^{-6}}}$$

$$= 643$$

The calculation shows that the valve used must be one with a minimum K_{V100} factor of 640.

From the K_V tables it can be seen that a $1^1/_4$ in ball valve has a K_{V100} factor of 1000 and a $1^1/_4$ in diaphragm valve has a K_{V100} factor of 332.

Therefore only the $1^1/_4$ in ball valve can be used.

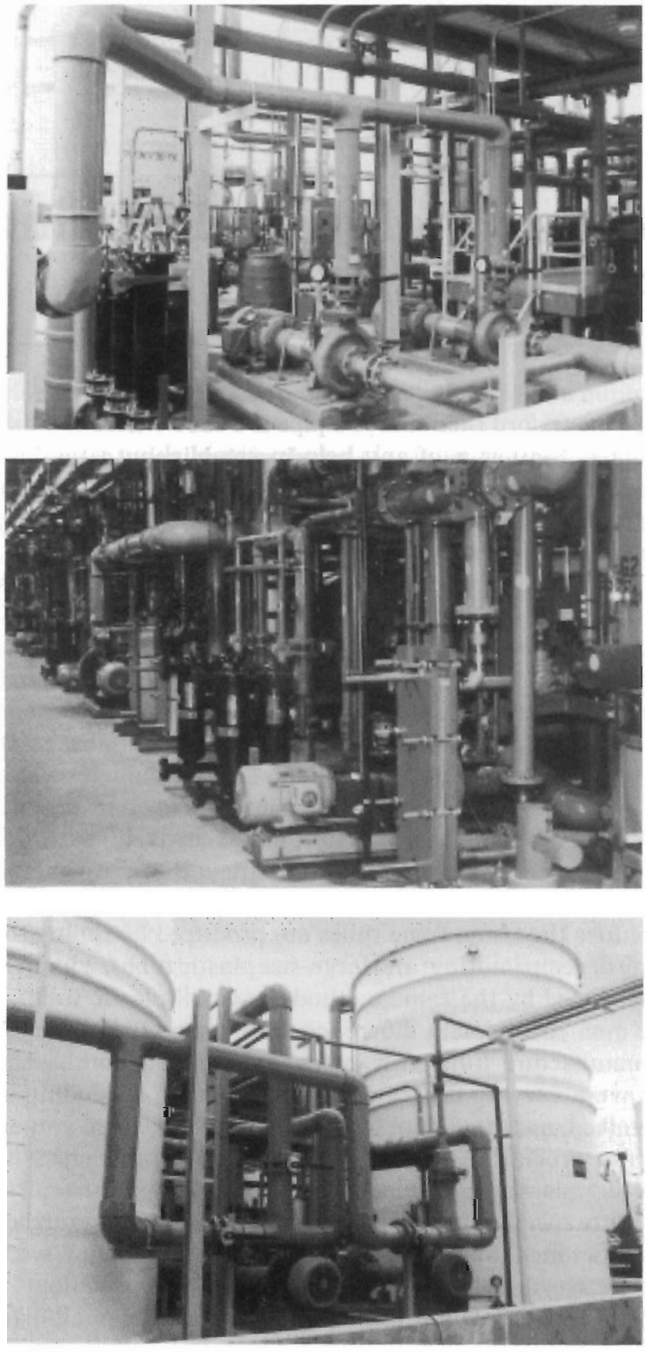
Pipes and Pipelines—Definitions and Explanations

According to the Oxford Dictionary, a pipe is a tube whereas a tube is a long, hollow cylinder. Neither is of any help in establishing true definitions, for there are recognised differences between pipes and tubes—but not those the dictionary gives. The more obvious distinction is that 'a pipe is a big tube, and a tube is a small pipe'—which is not far from the truth in application. But we are also concerned with differences in usage of terms in different industries—and in different countries.

Taking the big tube/small pipe premise as substantially correct, we can further comment that pipes which may run up to several metres or feet in diameter are cast, spun, welded up or otherwise fabricated, depending on the materials and sizes involved. Nobody could logically visualise producing very small sizes of pipes—e.g. under 25 mm (1 in) diameter—by such time consuming methods. It is much quicker and cheaper to produce them by extrusion. Hence tubes are basically (but not exclusively) extruded products, involving reduction in size during manufacture in the case of metal tubes, and a moulding process in the case of plastic tubes.

Just to confuse the issue, some tubes are produced by rolling to shape and seam welding or seam jointing; and large-size plastic tubes, which then become pipes, are produced by the same methods as small plastic tubes. But ignore that for the moment. A main difference does emerge from the two different methods of manufacture. Inherently, tubes have a smooth bore as manufactured. Pipes will have a varying degree of bore roughness, depending both on the material involved and the actual fabrication method. Once you extend tube-manufacturing process to pipe production, then these pipes also have a smooth bore (e.g. plastic pipes). Pipes produced by pipe-manufacturing methods normally require specific after-treatment to render them smooth bore.

With this difference (and there are exceptions to the rule), we can further differentiate between the two by size ranges and terminology adopted by different industries. One of the main users of smooth-bore small-diameter tubes is the hydraulic industry where line sizes may range from 3 mm (1/8 in) bore up to 32 mm (13 in) bore, or larger in low-pressure hydraulic systems—and



CPVC pipes and tubes.

we have called them lines, not pipes or tubes. The industry itself may call them hydraulic pipes, hydraulic tubes or hydraulic lines; and larger hydraulic tubes (pipe sizes!) are produced for cylinder tubes.

Industries and applications concerned with the conveyance of fluid products almost invariably refer to their tubular products as pipes or piping. Again, sizes may range down into tube sizes (and even be drawn or extruded products or true tubes)—e.g. gas pipes and small-bore water service pipes. But they are still pipes or piping. And the system they provide is a pipeline.

Hopefully this has established a satisfactory definition and explanation of why the title of this handbook is specifically concerned with pipes and pipelines, for these are the areas mainly covered. And those who work in these areas call

Ductile iron pipe for drinking water applications.

Summary of pipe materials—metallic

Material	Manufacturing process	Size range	Typical applications	Remarks
Aluminium	Drawing or rolling (seamless tube)		Cryogenic and chemical pipelines; lightweight hydraulic pipes.	Low weight and good corrosion resistance.
Copper	Drawing or rolling (seamless tubing)	Mainly small bore tubes	Marine applications. Hot water services (domestic).	Resistant to corrosion but costly.
Ductile iron	Spinning	Up to 600 mm (24 in)	Gas and water distribution systems.	Stronger than cast iron.
Grey cast iron	Casting	Up to 1200 mm (48 in)	Gas, water and drainage systems.	Brittle material.
Malleable iron	Heat-treated casting		Mainly used for small fittings.	Less brittle than cast iron.
Steel	Various	Up to 4000 mm (160 in)	Gas and oil pipelines.	Available in a wide range of tensile strengths.
Stainless steel	Various		Cryogenic and chemical pipelines. Stainless steel tubing for domestic water supplies, plumbing and heating.	Corrosion-resistant, but high cost.
Tungsten	Extrusion	Mainly small bore tubes	Marine applications. Specialised hydraulic systems.	Corrosion-resistant, non-sparking material.

their tubular products pipes, but tubes are mentioned and described where appropriate.

There remains one distinction between British and American practice to clarify. In the UK the handling and installation of pipes, performance calculations, etc., embracing the complete system are commonly referred to as pipework, e.g. pipework installations, pipework calculations, etc. In the USA the word 'pipework' does not appear to be accepted and is seldom, if ever, used. In the interest of rationalisation, this handbook uses the single description pipeline. It means the same as pipework.

It is to be regretted that similar rationalisation is not possible between British and American and metric units and standards. This leads to differences in values of 'flow loss' coefficients for pipe bends, valves, etc., the British/American coefficient being based on m^3/h at 1 bar pressure loss.

Equally, pipe sizes are standard in both millimetre and inch sizes, together with match fittings and valves. There are no exact equivalents. You work in standard manufactured sizes, either in millimetres or inches. To give equivalent sizes in tabular data for either would be meaningless. With rare exceptions, the exact equivalent size is just not obtainable.

That is a problem, too, which complicates the presentation of working formulae. We have attempted, within reason, to cover most possibilities in the case of the main formulae for flow-performance calculation in other forms embracing all the units most likely to be used, both in metric and Imperial units. Here, in fact, Imperial units are often less rational than their metric equivalents, with volumes expressed in cubic inches, US gallons, Imperial

Summary of pipe materials—non-metallic

Material	Size range	Corrosion resistance	Typical applications	Remarks
Asbestos cement	50 to 1050 mm (2 to 42 in)	Very good in most soils.	Buried water pipelines and drainage systems.	Brittle material.
Clay		Very good.	Drainage pipelines and ducts.	Brittle material. Normally salt-glazed.
Concrete	150 to 1950 mm (6 to 76 in)	Very good in most soils.	Drainage pipelines.	Produced in unreinforced and reinforced forms.
Spun concrete		Good resistance to sulphate attack and sewer gas.	Sewerage, drainage, etc.	Smooth, concentric bore. Smooth external finish. High-density, steel-reinforced.
Pre-stressed concrete	Up to 3000 mm (120 in)	Very good in most soils.	Large water and drainage pipelines.	Suitable for very large diameters.
Pitch/fibre	50 to 225 mm (2 to 9 in)	Very good in most soils.	Small drainage pipelines.	
Plastic pipes				
ABS	12 to 150 mm ($^1/_2$ to 6 in)	Corrosion-free but lower chemical resistance than PVC.	Alternative to PVC where better mechanical pipelines required.	Suitable for solvent jointing.
GRP	Up to 4800 mm (190 in)	Corrosion-free.	Large water and drainage pipelines.	Thermoset material. Also available in other reinforced-plastic matrix (RPM) constructions. Disadvantage: high cost.
Polyvinyl chloride UPVC	Up to 1050 mm (42 in)	Corrosion-free.	General purpose pipelines suitable for a wide variety of exterior and interior applications.	Unplasticised PVC. Suitable for solvent welding. Widely available.
Polyvinyl chloride CPVC	Up to 360 mm (14 in)	Corrosion-free.	Cold and hot water services, domestic plumbing, etc.	Rigid PVC.
Polypropylene (PP)	Up to 1000 mm (40 in) [UK sizes up to 16 in]	Similar to PE, but superior for resistance to detergents.	Applications requiring good combined temperature/pressure pipelines, e.g. effluent, pulp mills, etc.	Subject to embrittlement at low temperatures.
Polypropylene	Up to 300 mm (12 in)			Copolymer of PP with better resistance.
Polypropylene (PVDF)		High chemical-resistance, including: acids, alkalis and hydrocarbons.	Specialised applications: higher service temperatures than possible with other thermoplastic pipes.	Fusion-jointed.
Polybutylene (PB)	Up to 600 mm (24 in)		Hot-water applications—suitable for temperatures up to 110°C (230°F).	Cheaper than PEX, better abrasion resistance than PEH (particularly at elevated temperatures). Cannot be solvent-welded.
Polythene (PE) (PEL)	Up to 200 mm (8 in)	Corrosion-free.	Agriculture and irrigation.	Low-density polythene: pressures to 6 bar.
Polythene (PEM)	Up to 500 mm (20 in)	Corrosion-free.	Gas distribution. General purpose pipelines for exterior and interior applications.	Medium-density polythene: fusion-jointed or mechanical joints.
Polythene (PEH)	Up to 1800 mm (70 in)	Corrosion-free.	Water distribution, sewage, industrial effluent, etc. Gas distribution.	High-density polythene: fusion-jointed (socket, butt or saddle); also mechanical forms.
Polythene (HMW-PEH)	Up to 1200 mm (48 in)	Corrosion-free.		High molecular weight PEH: limited availability in pipe forms and expensive.
PEX			Hot water applications.	Cross-linked PE.
Fluorocarbon (FEP, PFA, PTFE)		Outstanding.	Used as liners bonded to GRP or metallic pipes for complete corrosion resistance. Limited availability in tube form (FEP and PFA).	

Equivalent specifications for stainless and high-resistant steels

Description	BS970 EN no.	AISI type	Avesta	Swedish		Sandvikan	Uddeholm	French	German	Krupps
				Fagersta	Nyby			Government	Ugine	
12/14% chromium Low carbon	331S42 (56A)	410	393	R.R.J.10	1410	2.C.27	S/S.1	Z.12.C.13	FIA/FIB	V13F
12/14% chromium 15% carbon	420S29 (56B)	410	393H	R.R.J.11	1415	4.C.27	S/S.31		FIU12	V5M
12/14% chromium 35% carbon	(56D)	420	739H	R.R.S.72	1435	7.C.27	S/S.6	Z.36.C.13	S12	V3M
18/20% chromium 2% nickel	431S29 (57)	431	249EH			4N2C36	S/S.22	Z.15.CN	18–02	V1M
18% chromium		430	249	R.R.M.20	1710	I.C.36	S/S.2 2.C.34		F17	V17F Extra
26% chromium 5% nickel			453E	R.R.V.62	27–4	I.R.8	S/S.45			V.2.A. Supra Special
26% chromium 5% nickel 1.5% molybdenum			453S	R.R.V.64	27–5MO	I.R.10	S/S.44			V.8.A. Supra Special
12% chromium 12% nickel	(58D)		832P	R.R.N.J.39	14–12	2.R.I.	S/S.33		Inoxargent	V.12.A. Supra
18% chromium 8% nickel 0.08% carbon	301S15 ($58^3/_8$)	304	832M	R.I.M.291	18–8EL	O.R.2	S/S.3.M.M.	Z.5.CN. 18–08	N.S.22.S.	V.2.A. Supra

18% chromium 8% nickel	320S25 (58A)	302	832	R.R.N.J.32	18–08	2.R.2.	S/S.3	Z.10.CN. 18–08		V.2.A Normal
18% chromium 8% nickel Free machining	303S21 (58M)	303	832C			2.R.2.A.	S/S.43			
18% chromium 10% nickel 1.5% molybdenum	315S16 (58H)		832SV	R.R.N.J.41	18–8EMO	O.R.3	S/S.4.M.M.			
18% chromium 8% nickel 1.5% molybdenum	315S16 (58H)		832S	R.R.N.J.40	18–81MO	2.R.3	S/S.4			V.8.A. Normal
18% chromium 8/10% nickel 1.5% molybdenum	321S12 (58B)	321	832T	R.R.N.J.51	18–8T	I.R.4	S/S.53	Z.10.CNT. 18–08	N.S.20C	V.2.A. Extra
18% chromium 10/12% nickel 1% niobium	347S17 (58G)	347	832T			I.R.41				
17% chromium 20% nickel			254	R.R.T.80	20–20	2.R.6.	S/S.15			
25% chromium 20% nickel		310	254E	R.R.T.83	25–20	3.R.9.	S/S.25	Z.20.CNS 25/20	N.S.30	N.C.T.3
18% chromium 10% nickel 2.5% molybdenum	304S15 (58E)	316	832SK	R.R.N.J.44	18–20MO	O.R.11	S/S.24	Z.8.CND. 18–08	N.S.M.C.	V.4.A. Supra

gallons or barrels, for example, depending on the industry or application involved.

In other more specialised cases, solutions and formulae are presented in one set of units only, being those most generally used, or in which the original solutions were derived. In that case conversion tables will be necessary if you want to use these with different units entered. As a final comment here, do remember that g or gravitational acceleration is the same in Imperial or metric units—$32.2 \text{ft/s}^2 = 9.81 \text{ m/s}^2 = g$.

The following table lists ASTM (American) pipe specifications and grades with British Standard equivalents and basic material descriptions.

Pipe specifications: American and British Standards

ASTM	Material	BS equivalent
A120	Carbon steel	1387
A53 Gr.A	Carbon steel	3601/23
A53 Gr.B	Carbon steel	3601/27
A106 Gr.A	Carbon steel	3602/23
API 5L Gr.A	Carbon steel	3602/27
A106 Gr.B	Carbon steel	3602/27
API 5L Gr.B	Carbon steel	3602/27
A333 Gr.1	Killed carbon steel	3603/LT50
A333 Gr.3	3.5% nickel	3603/503LT100
A335 Gr.P1	$^1/_2$% molybdenum	3604/240
A335 Gr.P12	1%Cr $^1/_2$% Mo	3604/620
A335 Gr.P11	$1^1/_4$%Cr $^1/_2$% Mo	3604/621
A335 Gr.P22	$2^1/_4$%Cr 1% Mo	3604/622
A335 Gr.P5	5%Cr $^1/_2$% Mo	3604/625
A335 Gr.P7	7%Cr $^1/_2$% Mo	3604/627
A335 Gr.P9	9%Cr 1% Mo	3604/629
A312 Gr.Tp304	Austenitic chromium nickel	3605/304 S18 (EN58E)
A312 Gr.Tp304L	Austenitic chromium nickel (extra low carbon)	3605/304 S14
A312 Gr.Tp316	Austenitic chromium nickel molybdenum bearing	3605/316 S18 (EN58J)
A312 Gr.Tp316L	Austenitic chromium nickel molybdenum bearing (extra low carbon)	3605/316 S14
A312 Gr.Tp321	Austenitic chromium nickel titanium stabilised	3605/321 S18 (EN58B)
A312 Gr.Tp347	Austenitic chromium nickel niobium stabilised	3605/347 S18 (EN58G)

British, American and German equivalent steel specifications

BS 970	Type of steel	SAE	AISI	Werkstoff	DIN
070 M 20	'20' C steel (hot rolled or normalised)	1020	C1020	0402	C22
080 M 30	'30' C steel	1030	C1030	0501	C35
	Bright C steel	1035	C1035	0503	C45
080 A 40	'40' C steel	1040	C1040	0503	C45
070 M 55	'55' C steel	1055	C1055	0601	C60
526 M 60	'60' C–Cr steel	5160	5160	8161	58 Cr-V4
150 M 28	C–Mn steel	1027 1330	C1027 1330	5066	30 Mn 4
530 A 40	1% Cr steel	5140	5140	7035	41 Cr 4
530 A 32	1% Cr steel	5132	5132	7035	34 Cr 4
530 A 36	1% Cr steel	5135	5135	7034	37 Cr 4
530 A 40	1% Cr steel	5140	5140	7035	41 Cr 4
709 M 40	1% Cr–Mo steel	4140	4140	7220	34 Cr–Mo 4
708 M 40	Cr–Mo steel	4140	4140	7225	42 Cr–Mo 4
708 A 42	1% Cr–Mo steel	4140	4140	7225	42 Cr–Mo 4
653 M 31	3% Ni–Cr steel			5755	22 (31) Ni–Cr 41
817 M 40	1.5% Ni–Cr–Mo steel	4340	4340	6582	34 Cr–Ni–Mo 6
410 S 21	Cr-rust-resisting steel	51410	410	4006	×10 Cr 13
420 S 29	Cr-rust-resisting steel	51410	410	4021	×20 Cr 13
420 S 37	Cr-rust-resisting steel	51420	420	4021	C 20 Cr 13
420 S 45	Cr-rust-resisting steel	51420	420	4034	×40 Cr 13
420 S 21	Cr-rust-resisting steel	51416	416	4024	×20 Cr 13
		51416 Se (S1416 Se)	416 Se		
816 M 40	Low Ni–Cr–Mo steel			6582	34 Cr–Ni–Mo 6

Colour codes for pipeline identification

Originally pipes or sections of pipes were painted in colours for identification. Identification colours are now more commonly applied with bands of self adhesive tapes, with colour-fast resistance to washing down, heat, etc.

Colour coding employed in UK practice is based on BS 1710: 1960, BS 1710: 1971 and BS 1710: 1975. British Standard colours are shown with colour specifications in accordance with BS 4800.

BS 1710: 1984 Optional colour code indications for general building services

Pipe contents	Basic colour	Colour code indication
Water		
Drinking	Green	Auxiliary blue
Cooling (primary)	Green	White
Boiler feed	Green	Crimson/white/crimson
Condensate	Green	Crimson/emerald green/crimson
Chilled	Green	White/emerald green/white
Central heating ‹100°C	Green	Blue/crimson/blue
Central heating ‹100°C	Green	Crimson/blue/crimson
Cold down services	Green	White/blue/white
Hot-water supply	Green	White/crimson/white
Hydraulic power	Green	Salmon pink
Sea, river, untreated	—	Green
Fire extinguishing	Green	Red
Oils		
Diesel fuel	Brown	White
Furnace fuel	—	Brown
Lubricating	Brown	Emerald green
Hydraulic power	Brown	Salmon pink
Transformer	Brown	Crimson
Other suggestions		
Natural gas	Yellow ochre	Yellow
Compressed air	—	Light blue
Vacuum	Light blue	White
Steam	—	Silver grey
Drainage	—	Black
Electrical conduits and ventilation ducts	—	Orange
Acid and alkalis	—	Violet

Standard service codes

Letter symbols are also used to identify pipes and pipelines, fittings, etc. The following summarises British practice.

Water (various)	
Cooling water	CLW
Hot (domestic) water	HWS
Steam	S
Treated water	TW
Wastewater	WW
Boiler-feed water	BFW
Brine	B
Cold water	
Mains	MWS
Down service	CWS
Drinking	DWS
Flushing	FWS
Pressurised	PWS
Cold-water down supply	CWDS
Chilled water	CHW
Fire fighting	
Fire extinguisher	FE
Fire hydrant	FH
Gases	
Town	G
Oxygen	O_2
Nitrous oxide	N_2O
Heating	
Low-pressure water	LPHW
Medium-pressure water	MPHW
High-pressure water	HPHW
Valves	
Air-release	ARV
Air	AV
Auto air	AAV
Ball	BV
Gate	GV
Lockshield	LSV
Non-return	NRV
Pressure-reduction	PRV
Safety	SV
Sluice	SV
Wheel	WV
Sewers	
Foul water	FWS
Surface water	SWS
Drains	
Foul water	FWD
Surface water	SWD
Pipes	
Discharge pipe	DP
Rainwater pipe	RWP
Vent pipe	VP
Effluents	
Foul water	FW
Radio-active water	RAW
Rainwater	RW
Surface water	SW

Fittings	
Bath	b
Bidet	bt
Wash basin	wb
Shower	sh
Urinal	u
Flushing cistern	fc
Sink	s
Drinking fountain	df
Water closet	wc
Manholes, etc.	
Back drop	BD
Invert	INV
Inspection chamber	IC
Manhole	MH
Fresh air inlet	FAI
Position	
High level	HL
Low level	LL
From below	FB
To below	TB
From above	FA
To above	TA
Flow	F
Return	R
Gullies	
Access	AG
Back inlet	BIG
Grease trap	GT
Road	RG
Sealed	SG
Yard	YG
Miscellaneous	
Half-round channel	HRC
Rainwater head	RWH
Condensate	C
Fuel	F
Vacuum	V
Cold feed	CF
Feed and expansion	F & E
Plug cock	PC
Access points	
Access cover	A/C
Cleaning eye	CE
Dry-weather flow	DWF
Fire hydrant	FH
Compressed air	CA
Refrigerants (identified by symbol for particular gas)	R_o
Draw-off point	DO
Open vent	OV
Stop cock	SC

Basic identification colours BS 1710: 1984

Pipe contents	Basic colour names	BS identification colour reference BS 4800
Water	Green	12 D 45
Steam	Silver grey	10 A 03
Oils—mineral, vegetable or animal; combustible liquids	Brown	06 C 39
Gases in either gaseous or liquefied condition (except air)	Yellow ochre	08 C 35
Acids and alkalis	Violet	22 C 37
Air	Light blue	20 E 51
Other liquids	Black	00 E 53
Electrical services and ventilation ducts	Orange	06 E 51
Safety colours		
	Red	04 E 53
	Yellow	08 E 51
	Auxiliary blue	18 E 53
Reference colours (if other than safety colours)		
	Crimson	04 D 45
	Emerald green	14 E 53
	Salmon pink	04 C 33
	Yellow	10 E 53
	Blue	18 E 51

SECTION 2

Valve Types Design and Construction

Plug Valves (Cocks)

Ball Valves

Ball Float Valves

Butterfly Valves

Rotary Disc/Rotor Valves

Globe Valves

Gate Valves

Needle Valves

Pinch Valves

Diaphragm Valves

Slide Valves

Screw-down Valves

Spool Valves

Solenoid Valves

Swing-Check (Flap) Valves

Penstocks

Miscellaneous Valves

Plug Valves (Cocks)

The description 'plug valve' or 'cock valve' is given to the simplest form of valve comprising a body with a tapered or, less frequently, a parallel seating into which a plug fits. The plug is formed with a through-port, the relative position of the port controlling the amount of opening through the valve (Figure 1). A 90° rotation of the plug fully opens or closes the fluid flow.

Greek and Roman periods saw the development of the plug cock valve and it remained virtually unchanged until the 19th century.

The development of the steam engine from the early 18th century led to further valve improvements including the introduction by Timothy Hackworth of adjustable springs instead of weights to the steam safety valve.

The groove-packed plug cock was introduced by Dewarance & Co in 1875, making a valve which was easier to operate and more suitable for steam. In 1886, Joseph Hopkinson introduced the parallel slide valve where the sealing of the valve was produced by line pressure on the disc.

This system is still manufactured today. Plug cock valves are not as efficient as ball valves and can only operate fully open or closed.

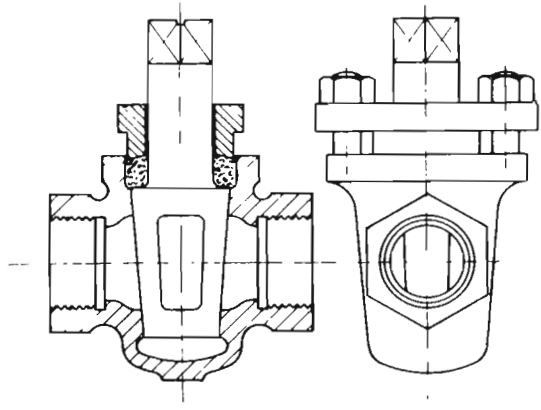
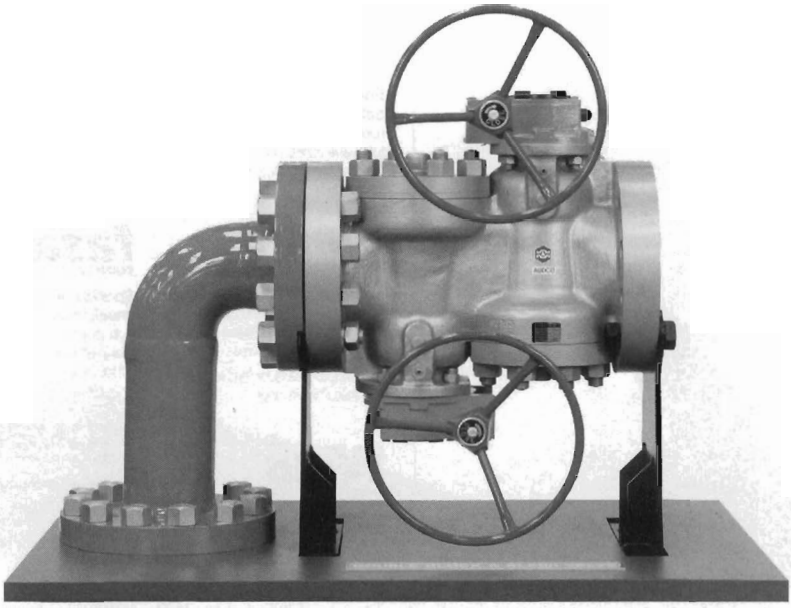


Figure 1.



High-performance pressure-balanced plug valve.

The simple plug valve is generally suitable for low-pressure, low-temperature applications, and can be made in quite large sizes: 250 to 300 mm (10 to 12 in) bore is quite common in some applications. Its main limitation is that if wide variations in fluid temperature are involved, differential expansion is inevitable, leading either to undue stiffness of operation or loss of pressure-tightness.

This can be overcome to some extent by employing a packed gland on which the plug rides (Figure 2). The packing is commonly graphited asbestos. In the smaller range, the sleeve-packed cock represents a distinct step forward in cock design (Figure 3). Not only does this have a perfectly cylindrical plug, more economical to produce than a tapered one, but the resilience afforded by the asbestos fabric sleeve longitudinally compressed by the two plugs screwed

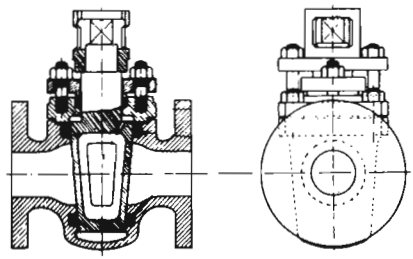


Figure 2.

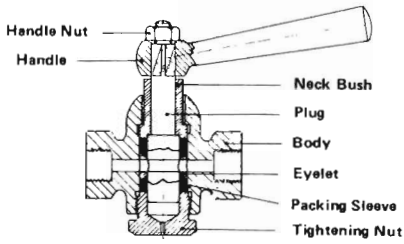
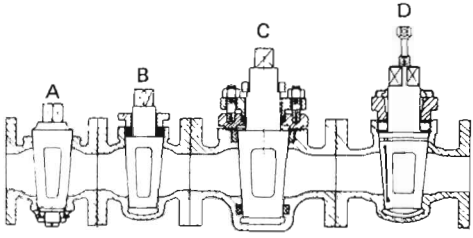


Figure 3.

into both top and bottom of the body provides for temperature variations and thereby prevents binding.

In the UK, the description 'plug valve' is specifically given to a cock which incorporates special design features to reduce the friction between the plug face and the body seat. The plug itself may be tapered or parallel and the movement plain or lubricated (Figure 4). There is also a further variation known as a ball-plug valve, where the plug element is spherical, with circular ports rotating between circular seats of concave section (Figure 5).



A Ground-plug cock with nut and washer base.
B Ground-plug cock gland packed.
C Groove-packed plug cock with gland and holding-down plate.
D Lubricated-plug cock gland packed.

Figure 4.

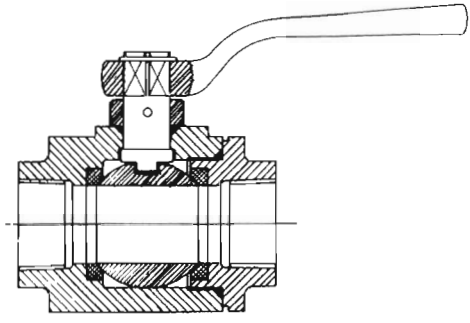
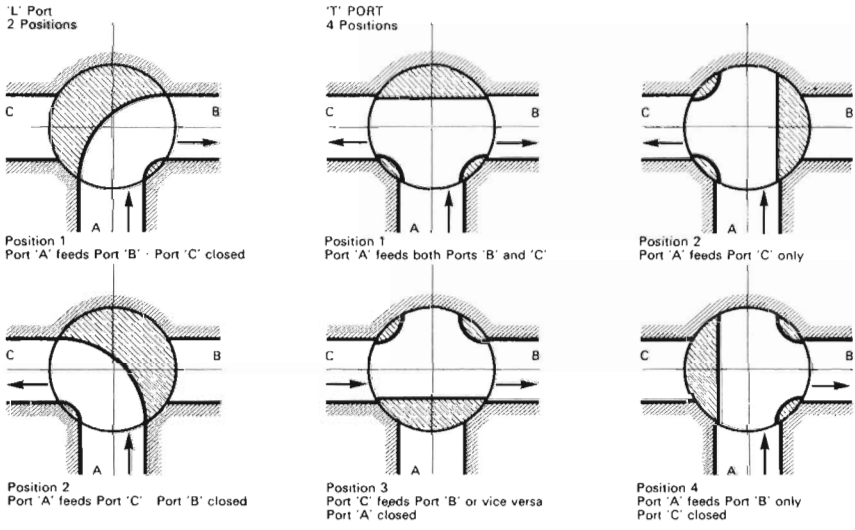


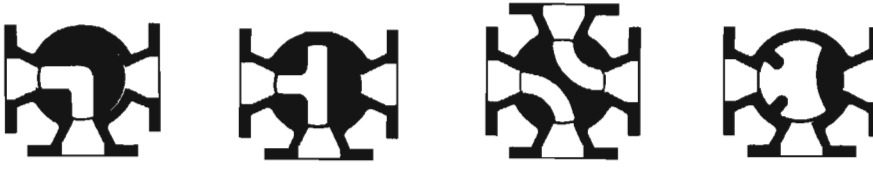
Figure 5.

Plug valves may be further categorised by pattern:

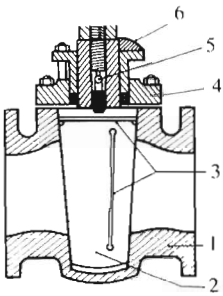
(i) Round opening—with full-bore round ports in both plug and body.
(ii) Rectangular (rectangular opening) with rectangular or similar shaped ports of substantially full-bore section.
(iii) Standard opening—where the area through the valve is less than the area of standard pipe.
(iv) Diamond port—where the opening through the valve is diamond-shaped. Such valves are also normally of venturi design.
(v) Multi-port—with three or more pipe connections, used mainly for transfer or diverting services.
(vi) Venturi design—with reduced-area porting (down to 40%) and featuring venturi flow through the body.
(vii) Short—with reduced-area ports and/or reduced face-to-face dimensions.
(viii) Vertical—with reduced-area seating ports and the plug passages reduced in section to form a throat.



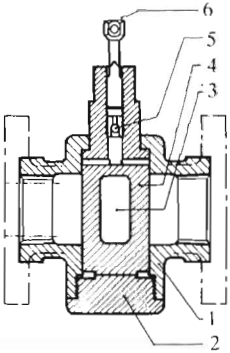
Operation of three-way cocks with 'L' and 'T' ports.



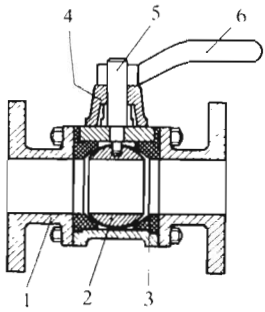
Examples of multi-port arrangements.



Taper-plug valve (lubricated)
1. Body
2. Plug
3. Lubricant grains
4. Cover
5. Lubricant check valve
6. Gland follower



Parallel-plug valve
1. Body
2. Bottom cover
3. Plug port
4. Plug
5. Lubricant grains
6. Lubricant screw



Ball-plug valve
1. Body
2. Ball
3. Seal
4. Bonnet
5. Spundle
6. Handle

Materials

Cocks and plug valves are produced in a variety of metals and plastics and also include lined types. Metals most commonly used are brass, bronze, steel and stainless steel.

Basic design proportions

A rectangular- or trapezoid-section port is commonly preferred as this can be accommodated in a plug of smaller diameter than that required for a circular port of the same area. The width of the port is then often made less than half of the bore to provide an effective positive lap for sealing. The length of port is then given by d/2, where d is the pipe diameter. In practice a small addition is usually made to this length to allow for radiusing the corners of the opening.

In the case of multi-port cocks or plug valves, negative lap may be called for to ensure that there is no complete shut-off during the transition of ports. This applies particularly when connected to a positive displacement pump (i.e. to prevent the pump pumping against a closed outlet).

See also the chapter on Ball Valves.

Pressure-balanced taper-plug valves

In larger taper-plug valves, pressure-balanced plugs are fitted for pressure pulsing or very high static pressure applications. With a non-pressure

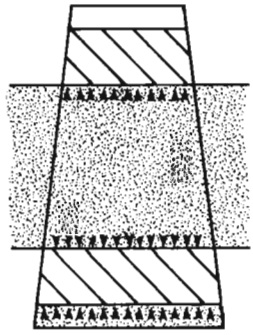


Figure 6(a). Non-pressure balanced taper plug.

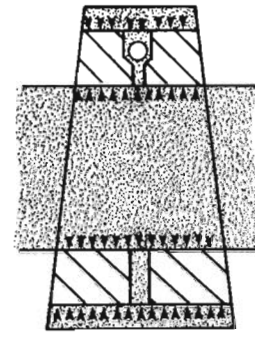


Figure 6(b). Pressure-balanced taper plug.

balanced plug, line pressure in an open valve can find its way into the large end chamber which exists below the plug. Under these conditions a resultant force exists tending to push the plug into its tapered seat with the danger of taper locking causing a seized valve, as shown in Figure 6(a). This resultant force persists whether the line pressure subsequently remains high or is reduced.

The development of an out-of-balance force on the plug is not an inevitable event with ordinary taper-plug valves, as there is normally sealant pressure acting on the small end of the plug. Nevertheless it can occur and can cause valve seizure.

With a pressure-balanced valve, the live-line pressure is used to replace sealant pressure by allowing the line to pressurize the small end chamber. A balancing force is produced which prevents taper lock without the need for sealant pressure. Figure 6(b) shows how a more balanced position is reached when line pressure is allowed to equalise the pressure acting on the end of the plug.

The pressure-balance system consists of two holes in the plug connecting chambers at each end of the plug with the line pressure. The hole in the small end of the plug contains a non-return valve. This enables sealant pressure to be built up if necessary, while allowing access of the line pressure to the small end chamber. Thus the pressure in the large end chamber always equals line pressure and the pressure in the small end chamber is always equal to, or greater than, the line pressure.

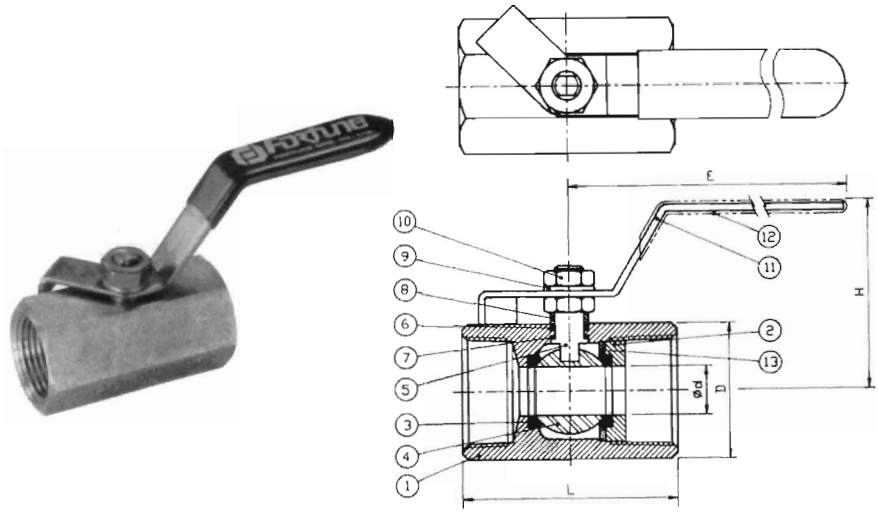
Ball Valves

The ball valve, or spherical-plug valve as it is sometimes known, was developed around 1936, although the idea of a ball valve dates back to ancient times. Modern ball valves, depending on type and pressure class, should be designed in conformity with international standards, e.g. BS 5351, API 6D and ANSIB 16.34. Normally, ball valves have polymer-based seals.

Ball valves are among the least expensive but most widely used of all valve types, as well as being available in an extremely wide range of sizes. Basic geometry involves a spherical ball located by two resilient sealing rings in a simple body form (Figure 1).

The ball has a hole through one axis, connecting inlet to outlet with full-bore flow when aligned with the axis of the valve. Rotating the ball through 90°

A typical range of ball valves.



Materials list:

No.	Part	Specification	Quantity
1	Body	ASTM A351-CF8M(316)	1
2	Inscrewed seat retainer	ASTM A351-CF8M(316)	1
3	Seat	R. TFE	2
4	Ball	ASTM A351-CF8M(316)	1
5	Stem	ASTM A276-316	1
6	Stem packing	PTFE	1
7	Thrust washer	PTFE	1
8	Gland	AISI 304	1
9	Stem washer	AISI 304	1
10	Handle nut	AISI 304	1
11	Handle	AISI 304	1
12	Handle cover	Plastic	1
13	Gasket	PTFE	1

Figure 1. Standard ball valve.

completely closes the flow passage with positive sealing via the sealing rings. Sealing is equally effective in both directions.

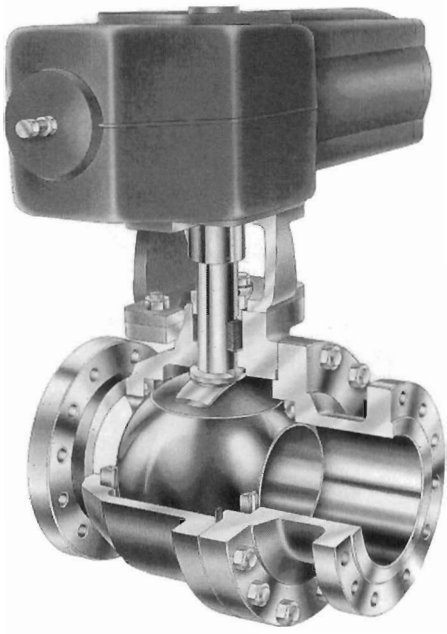
Body forms and matching ball hole may provide straight-through (full-bore parallel), reduced flow, or venturi flow. Ends can be flanged or threaded.

The ball itself may be free floating, in which case the squared off or splined end of the stem fits into a matching recess in the top of the ball. On larger valves the ball may be trunnion-mounted. Trunnion mounting reduces operating torque to about two-thirds that of the floating ball (Figure 2).

Ball valves are produced in top-entry and split-body forms for assembly and for renewal of the seals and ball. They are also produced in multi-port configurations, thus normally requiring a larger size of ball to accommodate multi-port drillings. These ports can be proportioned to give positive lap or negative lap as required (see also Figure 3).

Cut-away section of a multi-port valve.

Section view clearly illustrating how a characterised 'V' seat allows for precise flow control in a modulating ball valve.



Flanged full-bore ball valve.

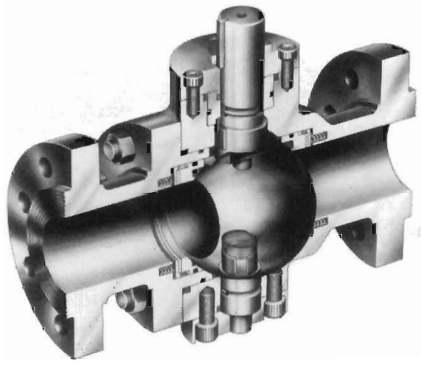


Figure 2. Trunnion-mounted ball valve.

Full operating movement is 90° rotation of the ball. Steps may be incorporated to limit movement of the operating lever, or continuous rotation may be possible. In either case the lever position is in line with the axis of the valve in the open position and at right angles to it in the closed position. Larger ball valves may be operated by handwheels through reduction gearing, or by powered actuators. In all cases opening/closing torque is low because the only friction forces involved are those of the ball rotating against its seals and the friction offered by the stem gland. The latter can range from O-rings to glands

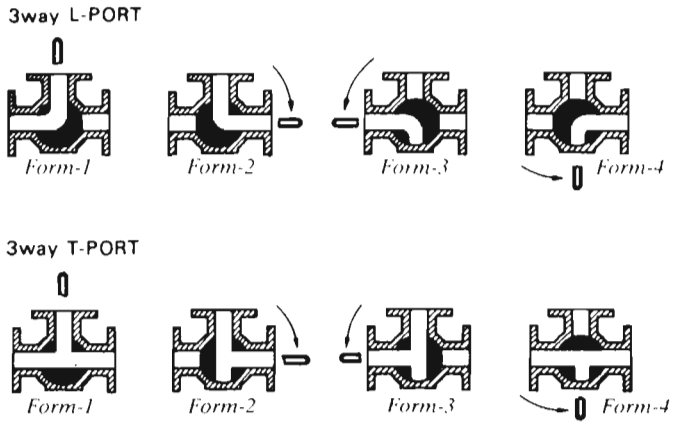
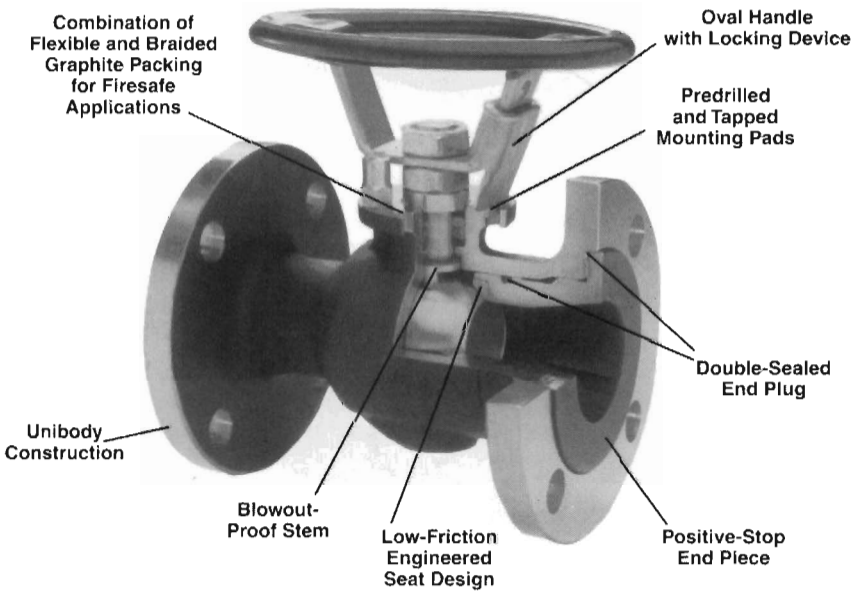
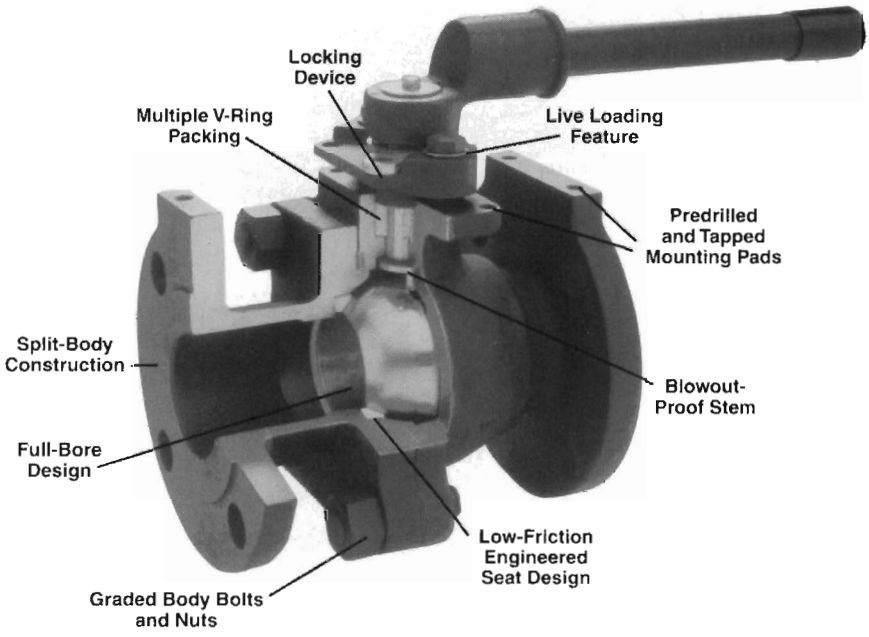


Figure 3. Three-way ball valve.

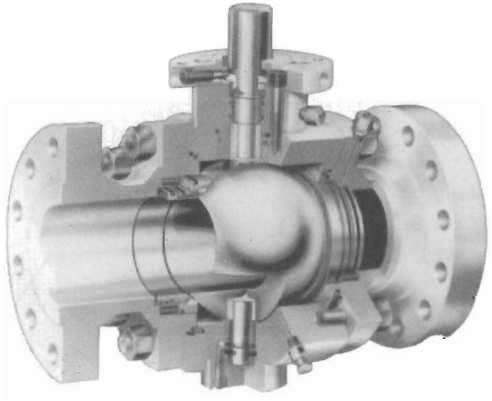


One-piece (unibody) ball valve.

fitted with die-formed packing rings. In some ball valves the ball is held against the seat by the cam action of a specially shaped stem. By turning the valve handwheel the ball is pulled away from the seat before being rotated. A precision spiral groove turns the stem and ball 90°, without ball-to-seat friction, to full-straight through-flow when open. The reverse action lowers the stem, turning the ball to the closed position, and the final handwheel turn tilts the ball and mechanically wedges it against the seat to seal the valve closed.



Two-piece (split body) flanged ball valve.



Full-port high-pressure ball valve.

Historically, ball valves have been produced with soft, not metal seats because generally soft seats have covered most applications satisfactorily.

Many valves of this type have seals made from PTFE, compounded with graphite, glass or steel powder to improve the material properties. However, abrasive media, high pressures and high temperatures can severely stress the polymeric seals normally used and lead to damage (Figure 4).

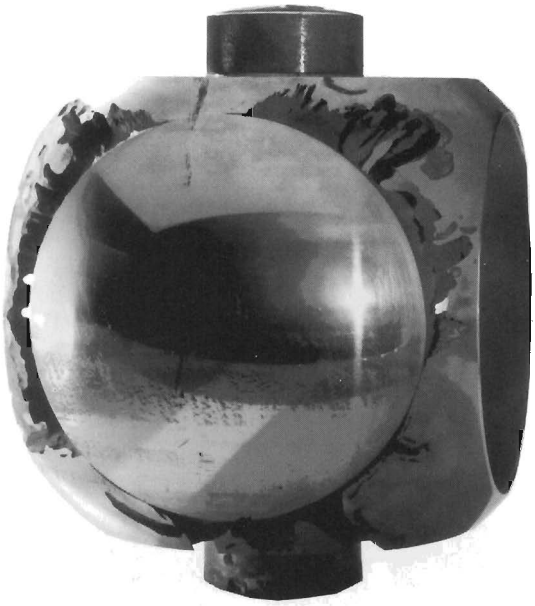


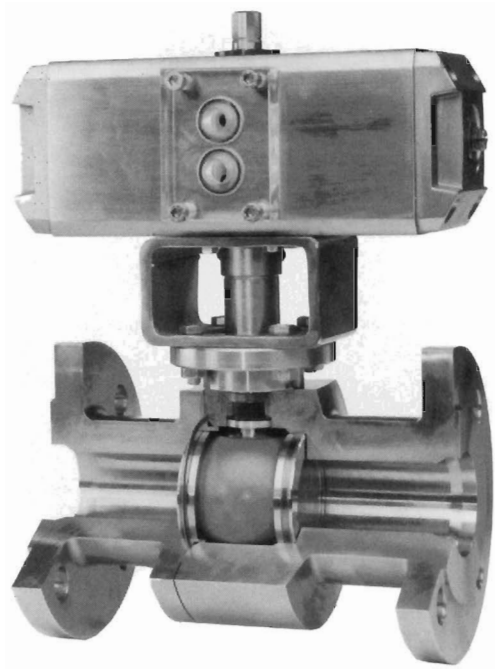
Figure 4. This ball was taken from a valve that had seen 3 years service in a cement works. The polymer sealing rings have been destroyed, the ball and the body severely damaged. Metallic seals can prevent such problems.

For nominal diameters of # DN50 PTFE, seals can only be loaded to a full pressure of PN100 up to a temperature of approximately 100°C; with nominal diameters above DN80, the operating pressure is limited to 50 bar. Only gradual improvements can be made if highly resistant polymers such as POM are used. Upper temperature limits are 250°C with huge restrictions on pressure/load capacity.

Metal-seated ball valves

Metal-seated ball valves first came to prominence in the 1960s. They offer a number of advantages including: tight shut-off, smooth control, no jamming, low torque, wide temperature range, good corrosion and wear resistance and stability under pressure. The greatest risk to metal-seated ball valves is posed by corrosion through pitting, fretting corrosion, intercrystalline corrosion and stress corrosion cracking. Media that contain even low quantities of aggressive substances are capable of causing corrosion.

Metal seals do not bed in as easily as soft seals under pressure. It is therefore important for the ball and sealing rings to be machined precisely and have both hard- and low-friction coatings applied to the base material.



Ball valves with metallic seals are suitable for use in high-solids abrasive media, for high and low temperatures, for extreme operating pressures, and for frequent operation. Even with critical media, they can be used for flow regulation. This pneumatically-activated ball valve is an ideal component for increasing plant safety. In the event of failure of the compressed-air supply the spring-loaded, pneumatic drive closes the valve automatically, rapidly and reliably.

Metallic seats tend to employ both nickel- and cobalt-based alloys and elements such as chrome and tungsten. However, the trend appears to be towards the use of different surface coatings for ball and sealing rings and choosing between them to suit the various circumstances.

With the seat-supported ball valve (Figure 5), the valve seals on the downstream side. The upstream pressure pushes the ball against the downstream seat, closing it tightly.

In the trunnion-mounted ball valve with a bellows seat (Figure 6), the valve seals on the upstream side. The internal pressure expands the bellows axially, pushing the seat against the ball. The seat is pressure-assisted and spring-energised. The bellows seat acts as the seating component. This type of ball valve is suitable for the most demanding on–off services.

The special control seat shown in Figure 7 works like a normal pressure-assisted seat in trunnion-mounted ball valves. The upstream pressure is led through the hole behind the seat, pushing it against the ball.

The seat is spring-energised to ensure low-pressure tightness. In control, the high-velocity flow passes through the restriction point of the partly open

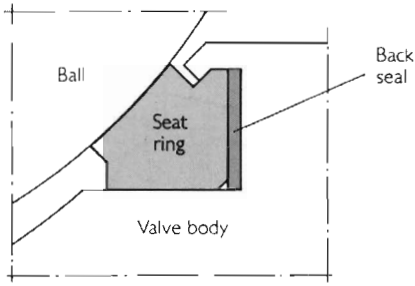


Figure 5. The metal seating principle in a typical seat-supported ball valve.

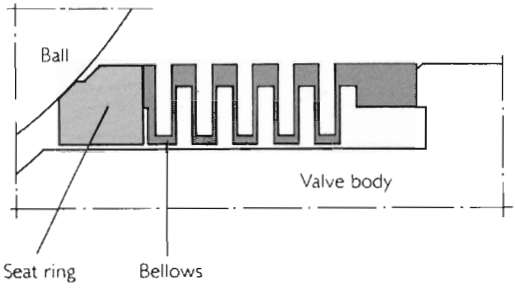


Figure 6. The bellows seat for a typical trunnion-mounted ball valve.

valve. The high velocity creates low pressure, which is led behind the ball seat through the hole located in the vena contracta. The seat will thus be unloaded.

The sealing principle of the floating-ball valve example shown in Figure 8 is effected at the downstream seat where the ball is pressed against the opposite seat by the medium pressure. In doing so the seat rings have a double function. They seal off and at the same time serve as a bearing. The seal at the upstream seat can be relieved in order to avoid a build-up of pressure.

The sealing principle of the fixed-ball valve example shown in Figure 9 is one where the sealing is effected at the upstream seat where the spring-supported seat is pressed against the fixed ball by the medium pressure.

The ball itself can be fixed by bearing pads in the body, by trunnions or by bearing stems. A pressure build-up is prevented by the spring-supported seats in connection with the fixed ball. To summarise, effective sealing depends on:

- the contact pressure
- the contact surface of the seat
- the accuracy of the surface finish on the ball and ball seat
- the sealing design and the sealing material

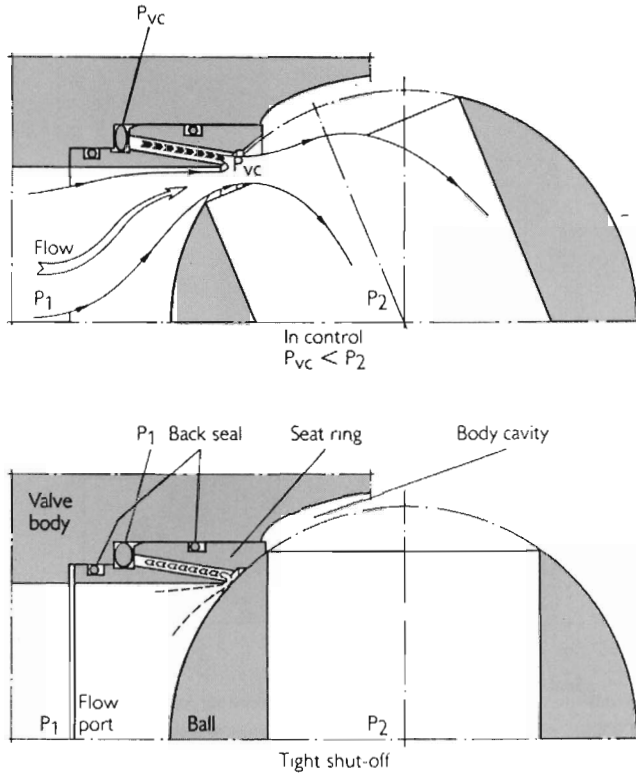


Figure 7. The special control seat.

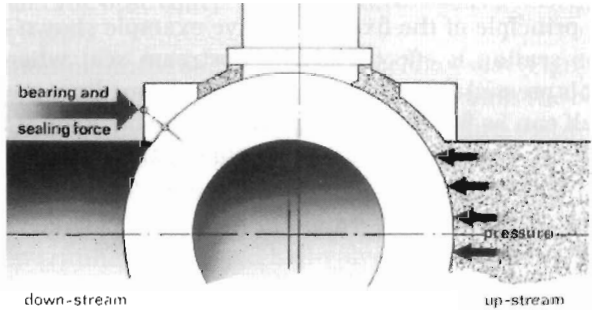


Figure 8. The sealing principle of the floating ball.

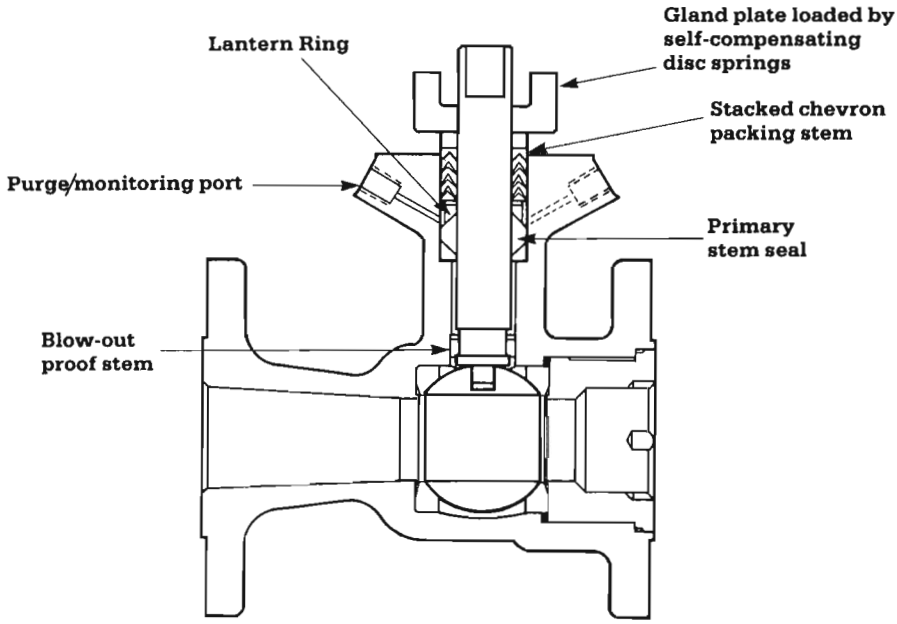


Diagram showing the dual-stem sealing arrangement in a high-integrity ball valve.

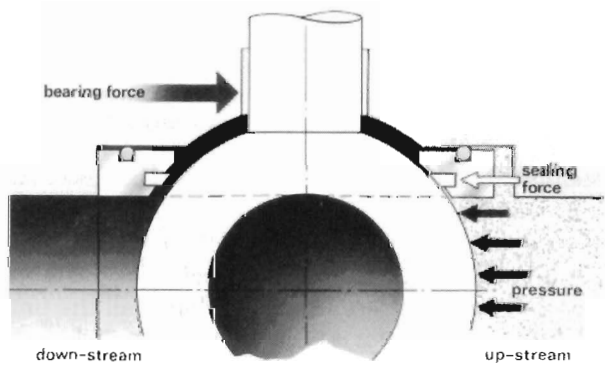


Figure 9. The sealing principle of the fixed ball.

Generally, ball valves are sealed by applying a load to a soft seating material between the valve body and ball to create localised yielding.

Seals of plastic material usually depend on localised yield to achieve bubble-tight sealing. The problem with a jam seat is that increasing the shut-off pressure can increase plastic deformation. As long as pressure remains at a

high level this is not a problem; leakage may occur if the shut-off pressure is decreased. A jam seat has no pressure compensation. Another area to consider about jam seats is temperature swings.

With increasing temperatures, metallic ball and valve casings expand. PTFE valve seats expand at a much higher rate and if the temperature change is high enough, the jam seat will tend to generate a 'self stress' above its yield strength and deform plastically beyond its initial state. When the valve is cooled, shrinkage of the additionally deformed seat may result in leakage.

A possible way of overcoming this is to employ valves with flexible lip seats (Figure 10) or seats that incorporate a separate double block and bleed design. Another aspect to consider with soft-seated ball valves is built-in body-cavity pressure relief. Ordinary water trapped in a valve cavity without air will increase in pressure by about 100 lb/in^2. The pressure/temperature relationships of most common liquids are in the order of 90–110 lb/in^2 per °F (11.2—13.7 bar per °C).

The cavity area created by the two soft seats of a ball valve is a typical area for pressure increases. While the valve is open, any pressure in the cavity zone created by the ball, seat and body can be vented via a hole from the bottom of the stem slot to the ball waterway.

In the closed position, relieving cavity pressure is more difficult. Some valves have a vent hole in the ball.

Cavity-pressure increases derive from the differential thermal expansion rates of incompressible fluids and typically a venting of one hundredth of a cc of trapped liquid will bring cavity pressure back to normal.

The key to ball-valve performance is the sealing (seating) structure, regardless of whether the seats are metal or plastic.

Pressure–temperature ratings

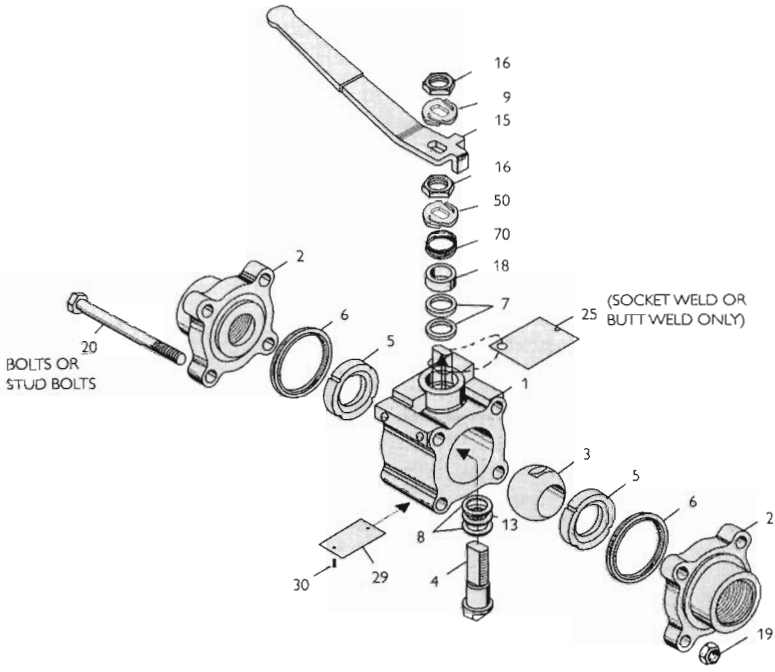
The pressure–temperature ratings of soft-seated ball valves are determined not only by the valve body materials, but also by the sealing material used for ball seats. Sealing materials for seats may be PTFE, 15% or 25% glass-filled PTFE, FPM, Celastic, N.R.G., POM, Lyton and steel.

New and improved polymers are being developed all the time for coating and sealing and the use of ceramics is becoming widespread.

It is very difficult to pre-determine exact pressure–temperature ratings for all kinds of media under all imaginable conditions. The chart shown in Figure 11 gives a typical general overview.

Pressure–temperature seat ratings indicated by the solid lines on the chart are based on differential pressure with the ball in fully-closed position and refer only to seats. The dotted lines indicate the maximum working pressures for carbon-steel valve bodies made from TstE 355N (equal to ASTM A350 LF2). For ratings of other body materials refer to ANSI B 16.34.

Pressure–temperature seat ratings for metal-seated valves are the same as the body ratings.



Standard parts list

Item no.	Part name	Body material	
		Carbon steel	**Stainless steel**
1	Body	ASTM A105N, ASTM A216 WCB (0.25% C Max) or BS970 070 M20	ASTM A812 F 316, ASTM A351 CF8M or BS970 S316
2	Body cap	ASTM A105N, ASTM A216 WCB (0.25% C Mac) or BS970 070 M20	ASTM A812 F 316L ASTM A351 CF8M/CF3M or BS970 S316
3	Ball	316 stainless steel	
4	Stem	316 stainless steel or 17-4 PH stainless steel	
5	Seat	PTFE (T), filled PTFE (M) or acetal resin (R) (Delrin*)	
6	Body seal	Spiral-wound 316 stainless steel and graphite	
7	Gland packing	PTFE	
8	Stem-thrust bearing	Carbon-filled PTFE or acetal resin	
9	Stem-tab washer	Stainless steel	
13	Stem-thrust seal	Graphite	
15	Handle	Stainless steel with PVC sleeve	
16	Stem nut	316 stainless steel	
18	Gland	316 stainless steel	
19	Nut	ASTM A194 grade 2H or ASTM A194 grade 2HM, 7M	ASTM A194 grade 8B, 8Cb, 8TB or ASTM A453 grade 660
20	Body bolt/stud	ASTM A193 grade B7 or ASTM A193 grade B7M, L7M	ASTM A193 grade B8, B8C, B8T class 2 or ASTM A453 grade 660
25	Weld warning tag	—	
29	Identification plate	Stainless steel	
30	Drive pin	Stainless steel	
50	Stem-tab washer	Stainless steel	
70	Anti-static spring	Stainless steel	

Figure 10. Soft-seated ball valve, exploded view.

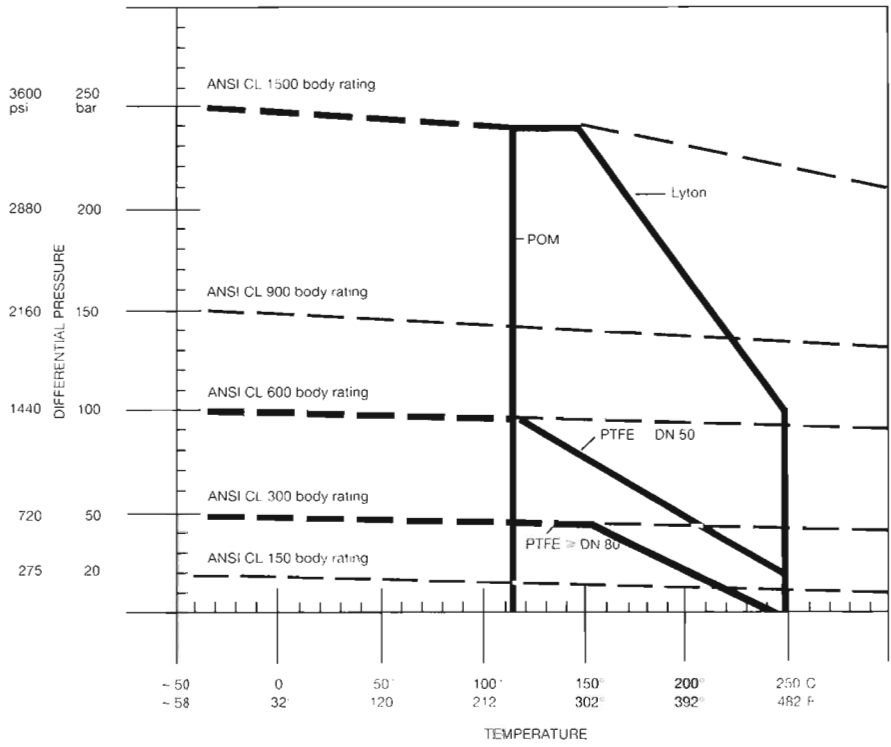


Figure 11. Pressure–temperature ratings.

Flow data

Typical flow data is shown in Table 1. The flow rates were determined for ball valves in fully-open position and a water temperature of 15°C (59°F).

Typical major application areas for ball valves include:

Refineries

- shut-off and isolation valves for tower bottom lines and thermal-cracking units with coke problems
- gas/oil separation
- gas distribution including measuring, metering and pressure regulation stations
- controlling oil loading
- pumping and compressor stations
- emergency shut-down
- refining units

Table 1. Flow data

Full bore
Nominal flow rate

Nominal size		Kv m^3/h	Cv US gallons per min
mm	in		
15×15×15	1/2×1/2×1/2	19.4	22.6
20×20×20	3/4×3/4×3/4	45.6	53.2
25×25×25	1×1×1	71.5	83.4
40×40×40	1 1/2×1 1/2×1 1/2	170	198
50×50×50	2×2×2	275	321
80×80×80	3×3×3	905	1056
100×100×100	4×4×4	1414	1650
150×150×150	6×6×6	3674	4288
200×200×200	8×8×8	7155	8350
250×250×250	10×10×10	12,500	14,590
300×300×300	12×12×12	20,780	24,250
400×400×400	16×16×16	37,000	43,100
500×500×500	20×20×20	70,700	82,500

Reduced bore
Nominal flow rate

Nominal size		Kv m^3/h	Cv US gallons per min
mm	in		
—	—	—	—
20×15×20	3/4×1/2×3/4	14.3	16.7
25×20×25	1×3/4×1	40.1	46.8
40×32×40	1 1/2×1 1/4×1 1/2	89.8	105
50×40×50	2×1 1/2×2	146	170
80×65×80	3×2 1/2×3	484	564
100×80×100	4×3×4	800	934
150×100×150	6×4×6	728	850
200×150×200	8×6×8	3577	4175
250×200×250	10×8×10	6933	8090
300×250×300	12×10×12	11,392	13,294
400×300×400	16×12×16	1600	18,672
500×400×500	20×16×20	33,333	38,900

Kv value is the full-capacity flow rate through the ball valve in cubic metres per hour (m^3/h) with a pressure drop of 1 bar.
Cv value is the full-capacity flow rate through the ball valve in US gallons/min of water at 60°F with a pressure drop of 1 psi.

Chemical and petrochemical complexes

- low differential pressure control
- emission control
- handling highly viscous fluids, abrasive slurries or corrosives as well as non-corrosives in processes and storing facilities

Power industry

- boiler feedwater control
- control and shut-off for steam
- burner trip valves
- sluicing valves for feeding coal into pressurised combustors and for extracting fly ash

Gas and oil production

- subsea isolation and shut-down
- well-head isolation
- pipeline surge control
- secondary and enhanced oil recovery
- processing separation
- transmission and distribution
- storage

Pulp and paper industry

- pulp mill digesters
- shut-off valves
- batch-digester blow service
- liquor fill and circulation
- lime mud (slurry) flow control
- dilution water control

Other common areas for the application of ball valves include: food industry, water supply and transport, marine and solids transport.

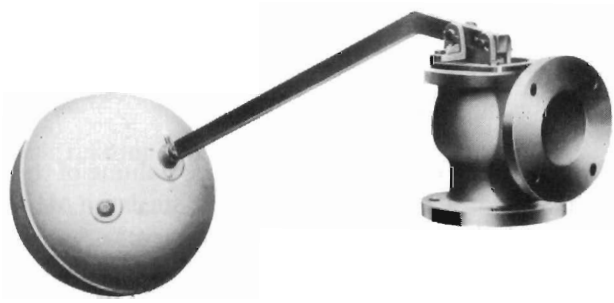
Ball Float Valves

The typical ball float valve consists of a control valve of the piston and disc-type operated by a floating ball and lever mechanism adjusted to open the valve at a predetermined liquid level. It is thus essentially a level-control valve and is used mainly for controlling the supply of make-up water (e.g. in cisterns, water tanks, etc.)

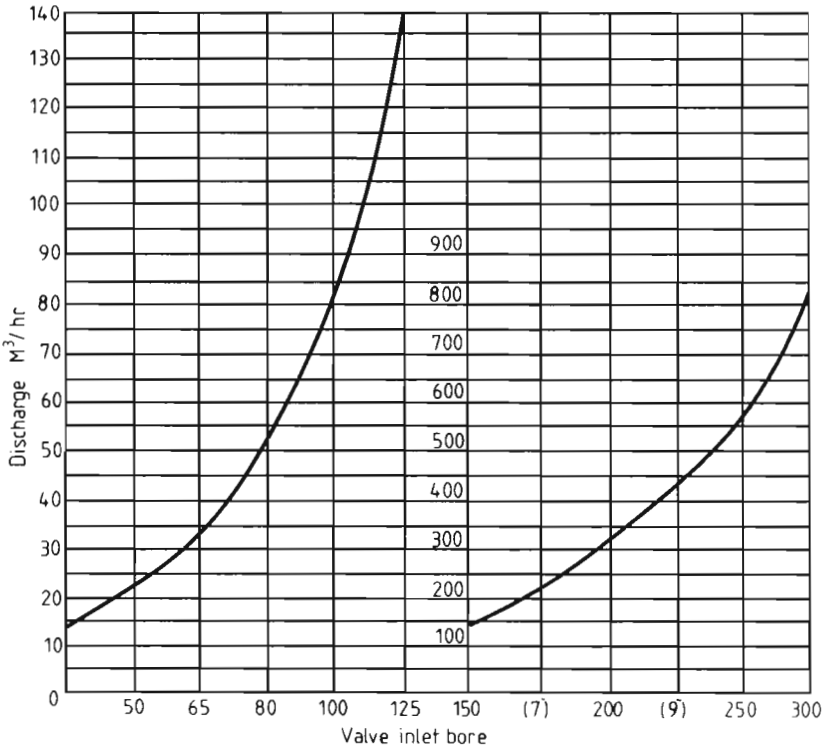
The most effective type is the equilibrium ball float valve (Figure 1), so called because the upward and downward pressure forces are nearly balanced out (leaving just enough unbalance to eliminate hunting). The basic type finds widespread application. The body is usually of angle pattern with the inlet flanged and bolted to the inlet pipe flange with the tank wall sandwiched between.

Design geometry calculation

Design geometry calculations for ball float valves can be tedious. As far as fluid forces are concerned there is an upward force at the valve position due to mains pressure tending to force the float downwards, which will normally be resisted by the displacement force generated by the float under equilibrium conditions (Figure 2). These equilibrium conditions correspond to the valve being held closed by a surplus of 'displacement' force. (In the event of the water level falling, of course, the valve will open to allow inflow of water until equilibrium conditions are restored.)



A typical ball float valve.



Headloss approximately 1.5 m angular and 4.5 m straight through.

Typical ball float valve capacity chart.

Specifically, the valve force (V_F) effective at the ball is given by:

$$V_F = \frac{0.7854\ PN}{L} \times d_2{}^2 - d_1{}^2$$

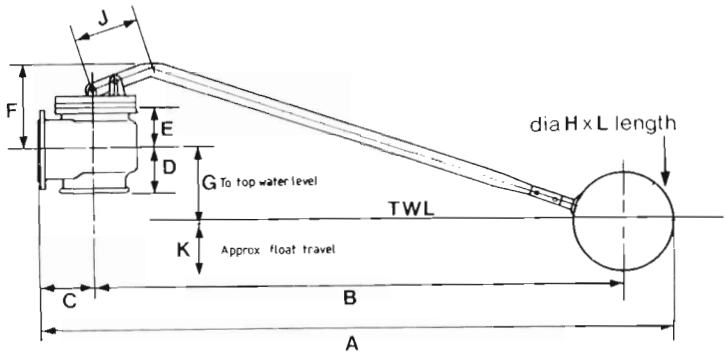
where

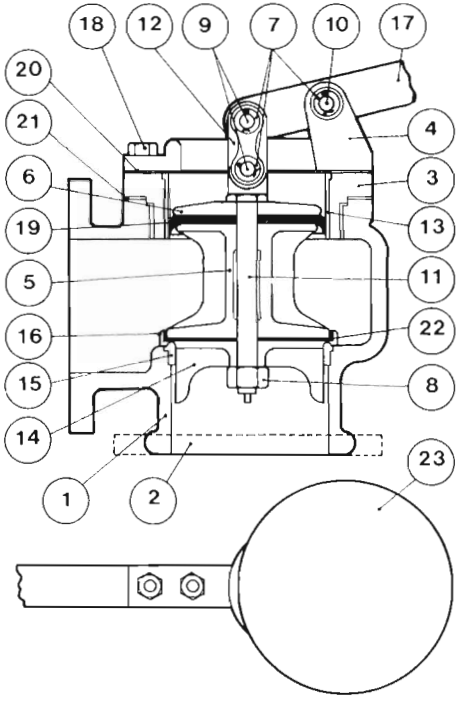
P = supply water pressure
N = fulcrum, distance from valve
L = fulcrum, distance from ball float
d_1 = outside diameter of valve-sealing face
d_2 = diameter of valve piston.

The displacement force (D_F) is governed by the volume of the ball float (or diameter in the usual case of a circular float) and its depth of immersion. It is usual in the case of spherical-ball floats to design for 50% immersion, when:

$$D_F = 0.01\ D^3 \text{ (to a close approximation)}$$

where D is the float diameter.





Item description

1 Body (beaded outlet)
2 Body (flanged outlet)
3 Cover
4 Fulcrum and retaining ring
5 Valve
6 Keep plate
7 Split pins and washers
8 Nut
9 Pins to links
10 Pins to fulcrum
11 Spindle
12 Links
13 Liner
14 Winged-valve plate
15 Seat ring
16 Keep ring
17 Lever
18 Studs and nuts
19 Cup washers
20 Cover joint
21 Body joint
22 Seat washer
23 Float

Figure 1. Angular-pattern ball float valve.

Thus the basic relationship is modified by:

(i) The necessity of maintaining a positive closing force on the valve for fluid tightness. An empirical figure here is to make D_F equal to $1.25 \times V_F$.

(ii) Additional movements introduced by the weight of the lever on both sides of the fulcrum or pivot point and the weight of the float. These can be calculated or eliminated by counterbalancing.

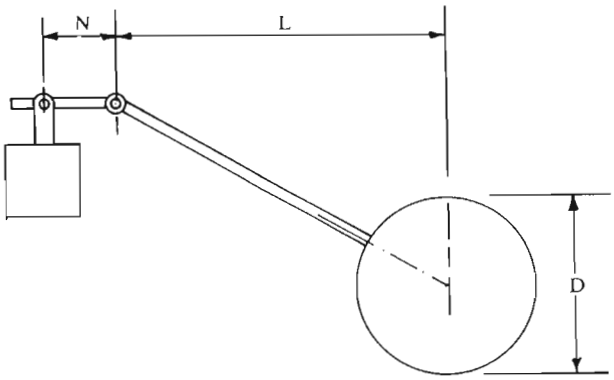


Figure 2. Ball float valve displacement force generated by the float.

(iii) Frictional resistance of the pivot and rising part(s) of the valve. This will call for an additional increase in displacement force. i.e. float size. It is difficult to establish required values except on empirical lines as frictional forces may be subject to change with age.

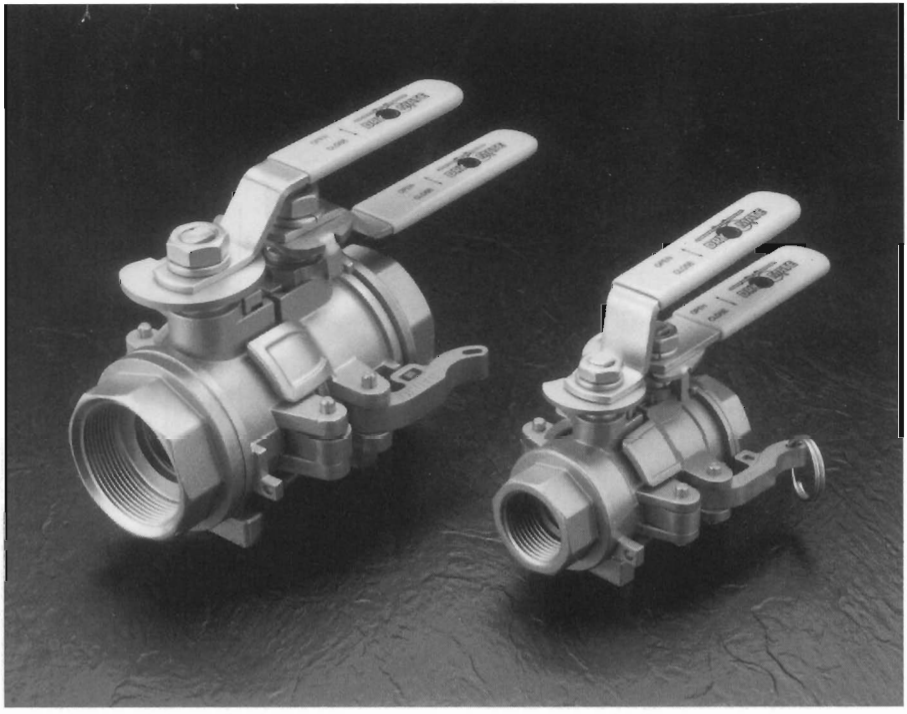
It may be further necessary to evaluate the displacement force with the float fully submerged (when $D_F = 0.02\ D^3$) and the resulting loading on the fulcrum pin. Design should allow adequate sheer strength on the pin to allow for this contingency, particularly in ball float systems used with level controls in large tanks and/or inaccessible positions.

Butterfly Valves

Since it was first introduced well over one hundred years ago, the butterfly valve has come through many development stages to become one of the most successful high-performance valves in use today.

The first butterfly valve was used by James Watt, the Scottish engineer, for his steam engine. It was also used in the Mercedes motor car in 1901 for the fuel intake linked to the accelerator pedal.

Initially, butterfly valves were limited to low pressure drop applications and sizes that were about six inches or more. They also tended not to seal too well.



Butterfly valves for industrial applications.

In basic terms, a butterfly valve uses a flat disc in which the closure device rotates about an axis regulating the flow of liquids with off-centre or in-line sealing. Smaller sizes usually have manual operation, but much larger devices such as penstock control valves are usually motorised.

Butterfly valves can offer attractive cost savings and operating benefits over conventional globe valves. With high flow capacities, butterfly valves enable the use of smaller units which reduces cost, weight and space requirements. With only two wetted parts and a range of valve linings, butterfly valves isolate the body from the media, thus eliminating the need for expensive exotic materials.

The smooth contoured, crevice-free disc produces lower torques, while the butterfly valve design makes it easy to install, maintain and service.

The two main groupings are general purpose butterfly valves and high-performance butterfly valves. Butterfly valves have the disadvantage that they restrict the flow through the pipe and solids catching on the disc can cause a blockage or prevent the valve from closing. Butterfly valves are used in high-temperature, high-pressure applications or those involving toxic or corrosive fluids. Modern butterfly valves are normally of wafer design, fitting

Butterfly valve for the chemical industry.

directly between pipeline flanges. Double-eccentric (offset) design butterfly valves have the sealing plane of the disc offset from the axis of rotation to create an interrupted sealing surface and the axis of the disc is laterally displaced from the true centre of the disc so that the disc will 'cam' away from the seat as the valve is cycled open.

Butterfly valve movement is simple and straightforward, requiring only 90° rotation of the butterfly for full movement (or somewhat less in most designs).

The main technologically significant features of a butterfly valve are the designs of the disc and the seat. Nearly all modern high-performance butterfly valves incorporate some form of double-offset design as previously described.

The two offsets in a typical butterfly disc are shown in Figure 1.

Body construction is normally cast iron, ductile iron, cast steel, bronze and epoxy. Various other materials may be used depending on size and application. Welded materials (e.g. steel, stainless steel and titanium) may be used for certain valves and in particular where percolation of gases through cast components is to be prevented.

Discs are also usually of cast iron, although again alternative materials may be specified for particular services. Profile shapes vary, most having some form of convex streamline shape to minimise head loss.

Valve seats

The seat (closure member) of the butterfly valve is an area where there are as many designs as there are manufacturers of butterfly valves. A single-piece

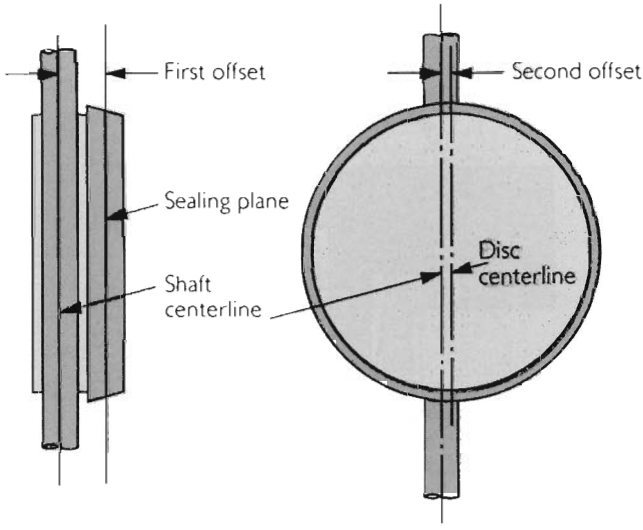


Figure 1. The two offsets in a butterfly disc.

Butterfly valve for the water industry.

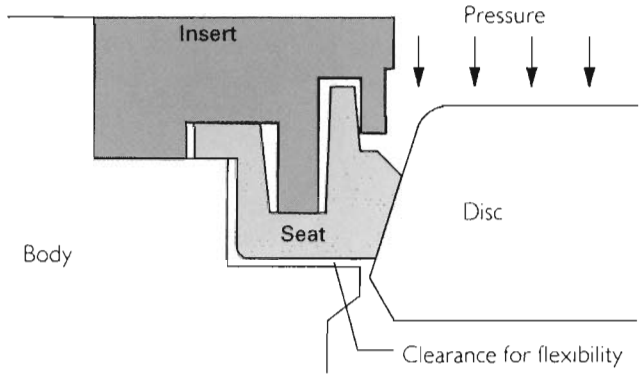


Figure 2. Wafer-sphere sealing principle with the disc downstream of the seat.

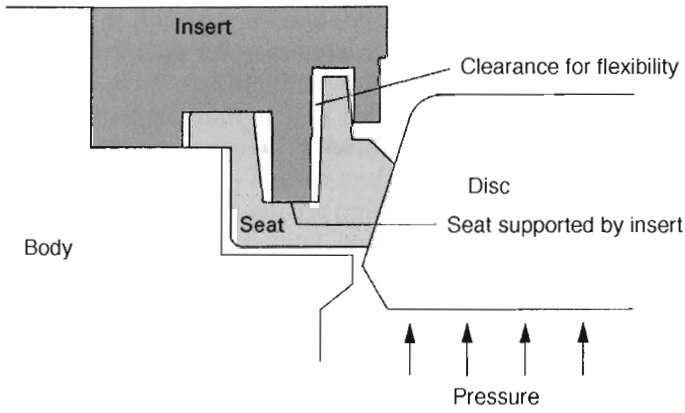
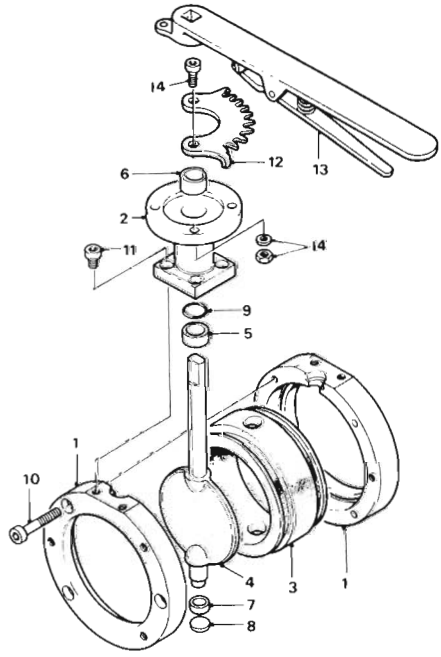


Figure 3. Wafer-sphere sealing principle with the seat downstream of the disc.



1	Body cartridges	8	Plus
2	Top adaptor	9	'O-ring'
3	Seal	10	Body securing screws
4	Disc/Stem	11	Top adaptor securing screws
5	Centre bush	12	Notch plate
6	Top bush	13	Lever
7	Bottom bush	14	Notch plate fixings

Figure 4. A wafer-type butterfly valve.

flexible PTFE seat has proved to be a popular choice, with thick cross-sections throughout the seat, pre-compression of the seat for low-pressure sealing and clearances surrounding the seat to allow flexibility.

The significance of the single-piece seat is that there are no O-rings or metallic springs to limit the temperature or corrosive conditions that the PTFE seat can be exposed to.

A typical example of PTFE seat design is shown in Figure 2 where the disc is downstream of the seat.

As line pressure is applied, the full cross-section of the seat is pressurised, which causes the seat to follow the natural deflections of the disc under pressure. Pressure activation of the seat enhances sealing with increasing line pressure, despite the fact that the disc is moving away from the seat due to the same pressure.

With the flow in the opposite direction, with the seat downstream of the disc, the seat is supported by the seat retainer (Figure 3). The disc is deflected by pressure into the seat, enhancing the sealing as the pressure increases.

A wafer-type butterfly valve is shown in Figure 4. Typically the valve consists of a stainless steel disc/stem in a polymer seat, fastened by two half-body cartridges. This particular valve has three side thrust-absorbing bushes, one top and bottom and one directly above the seat with a secondary O-ring seat adjacent.

Elastomer-lined centred-disc butterfly valve for water supply.

Fully rubber-lined butterfly valves, similar to the type shown in Figure 5, incorporate a rubber lining that is bonded and integral with the valve body. The main advantage here is that there is little or no deformation of the lining or corrosion to the body.

Ebonite-lined butterfly valves are designed for use in systems which carry seawater and other moderately aggressive liquids. Ebonite is a hard natural or synthetic rubber.

Ceramic- and fluoropolymer-lined valves are gaining in popularity for controlling highly corrosive and abrasive liquids, gases, slurries and powders.

Another basic arrangement is a corrosion-resistant seat (e.g. bronze or stainless steel), into which a continuous rubber-ring seal is fitted. Others include flexible metal-seal rings (for high-temperature services) (Figure 6). Detail design may provide automatic adjustment to any eccentric motion of the disc and/or automatic compensation for seal wear. Drop-tight closure of

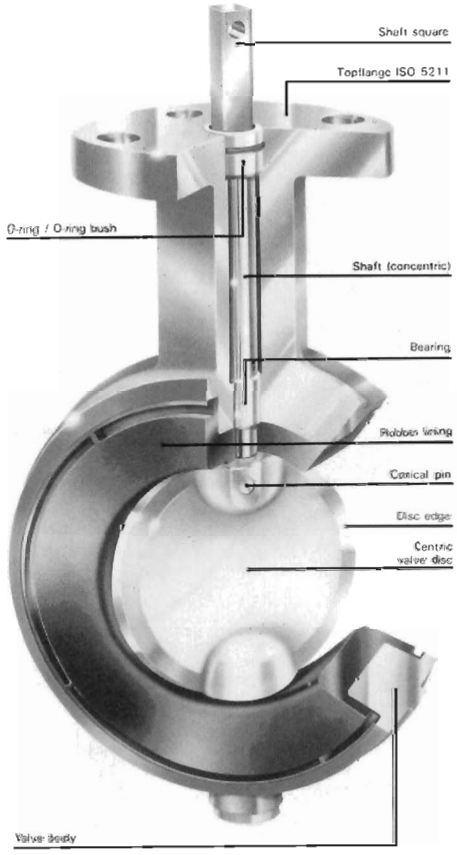


Figure 5. Fully rubber-lined butterfly valve.

any butterfly valve is normal and can be retained for a considerable time before seal replacement is necessary.

Metal seats in butterfly valves have particular advantages and should incorporate the following:

- good tightness—to ANSI B 16.104 Class V and higher
- no jamming
- smooth control—low- and constant-friction load in the control position
- low torque
- high cycle service
- wide temperature range
- good corrosion resistance
- low cavity relief

The metal-to-metal seated valve shown in Figure 7 is designed for bi-directional zero-leakage service. A double-offset (eccentric) shaft together with an offset conical seat achieves the 'camming' action of the disc into the seat. This keeps the sealing ring clear of the seat except in the final shut-off position and provides for non-rubbing rotation.

SEATING PRINCIPLE

The disc of the valve is machined to close tolerances to create an elliptical shape similar to an oblique slice taken from a solid metal cone. When the valve is closed, the elliptical disc at the major axis displaces the seat ring outward, causing the seat ring to contact the disc at the minor axis. When the valve is opened, the contact is released and the seat ring returns to its original circular shape.

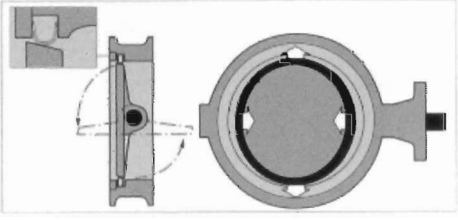
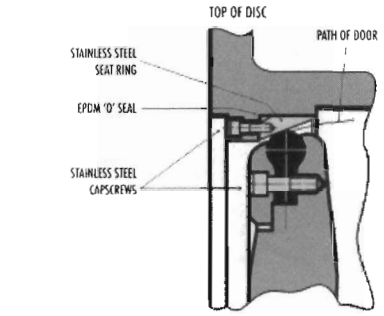


Figure 6. Metal-seated wafer-type butterfly valve.



Stainless steel-seated butterfly valve.

The cone angle allows the seal ring to touch the seat with a contact angle that is uniform and allows a slight amount of wedging.

This type of valve is particularly suited for process and steam duties from cryogenic to high-temperature applications.

Another novel butterfly valve is shown in Figure 8. This valve is designed specifically for dry solids processing. The valve has an inflatable seat that has only 'casual' contact with the valve disc during opening and closing. In operation, air and electric controls operate the valve. They automatically inflate and deflate the seat, allowing a single control input to operate the valve. When supplied with air, the control assembly moves the disc to the closed position and then automatically inflates the seat. When the control signal is received, the seat is instantly deflated and the valve disc moves to the open position. When the control signal is dropped, the assembly returns the disc to the closed position and automatically inflates the seat (Figure 9).

Actuation

All types of control mechanisms can be used to operate butterfly valves—manual by lever or handwheel with reduction gear, electrical by actuator or reduction gear, hydraulic actuator or pneumatic actuator. Choice largely

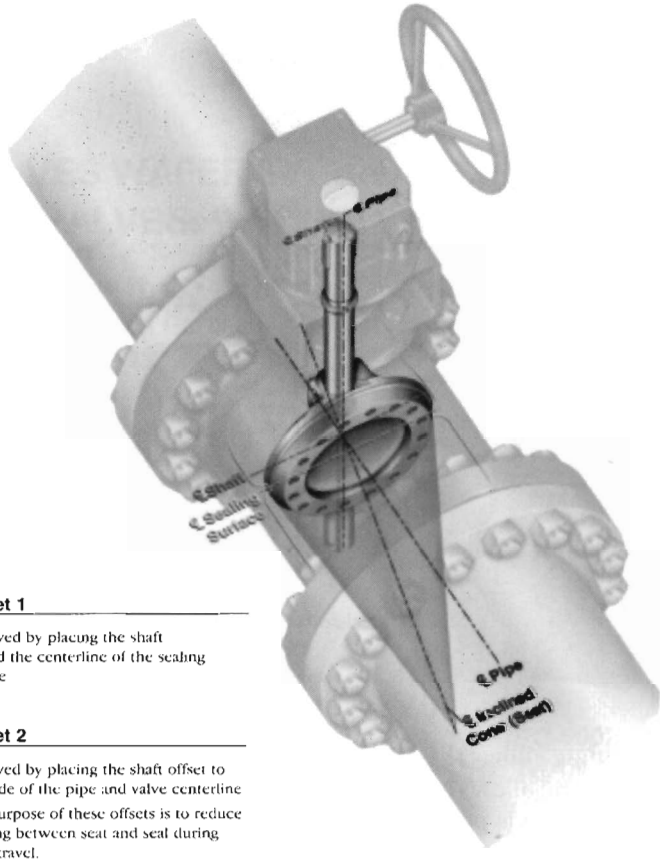


Figure 7. Triple-offset metal-seat butterfly valve.

depends on the size of the valve and the specific application. Special control systems can also be used for automatic closing, e.g. see Table 1.

Fieldbus control

Butterfly valves have now become a viable alternative to conventional control valves due to development in sophisticated controls instrumentation and communications technology.

A major milestone in flow control is the introduction of fieldbus control systems.

Fieldbus systems take advantage of developments in low-cost microchip technology, allowing intelligence to be built into each device in the loop. Each device communicates via a protocol developed for rapid control information, with the ability to adjust a valve's position and enable the speed of the valve stroke to be altered using programmable, menu-driven communications devices.

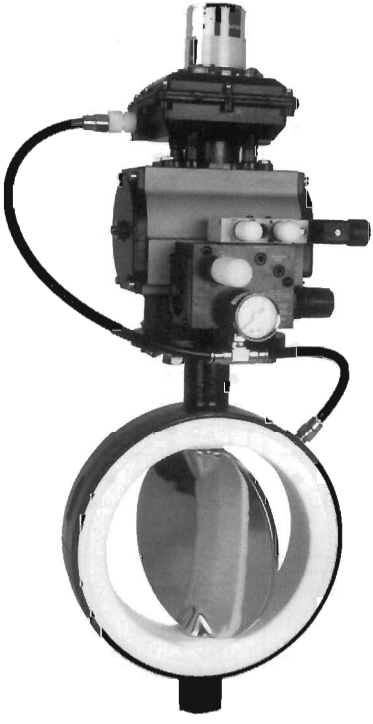


Figure 8.

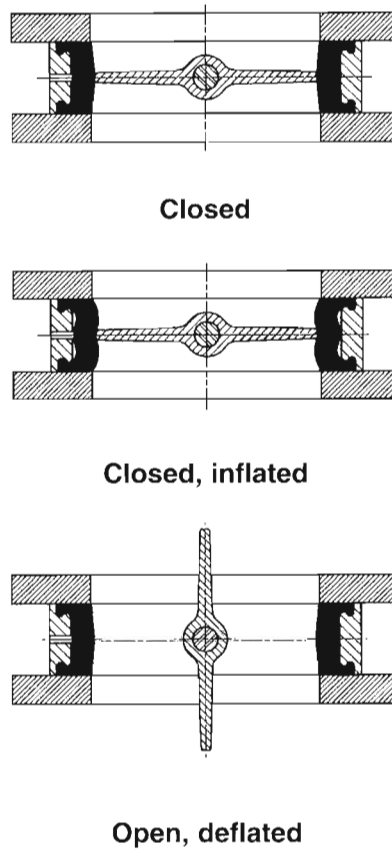


Figure 9.

The diagnostic role of a fieldbus system means it can give advance warning of potential problem areas so that corrective action can be taken. This instrumentation technology has resulted in a new breed of valve controls instrumentation.

See also the chapter on Valve Actuators.

Inherent flow characteristic

The inherent flow characteristic of a valve has been defined so as to keep the differential pressure across the valve constant. When the differential pressure across the valve is constant, the flow rate (q) through the valve is proportional to the valve flow coefficient (C_v). Because the valve flow coefficient (C_v) reflects the effective flow cross-section of the valve, the valve inherent flow characteristic

Table 1. Selection table for automatic-closing butterfly valves

	Is power available? ... During emergency closing? ... Any voluntary remote control?	No		Yes				
	Electrically motorised valve							●
Control device	Hydraulic jack	●	●	●	●	●	●	
	Counterweight	●	●	●	●			
	Oleopneumatic accumulator					●		
	Mechanical locking Manual resetting Automatic resetting	●	●	●				
	Automatic leakage recovery				●	●		
	Motorised pump		●	●	●	●	●	
	Hand pump	●						
Control signal	Defect transmission Mechanical Electrical Optional	●	●	●	●	●	●	●
	Electrical remote control			●	●	●	●	●

shows how the effective flow cross-section changes as a function of the relative travel (h).

Figure 10 shows the most common valve inherent flow characteristics as a function of the relative flow coefficient (N) and the relative travel (h).

Valve sizing

The size of butterfly valves to be used for control purposes should not be dictated by the nominal diameter of the pipe, but should be calculated on the basis of the operating characteristics in order to achieve the correct control characteristics.

To determine the size of a control valve, the opening angle characteristics need to be considered. Typically, some butterfly valves are designed with approximately equal percentage characteristics over an opening of 60°.

The example in Figure 11 shows how to calculate the K_v (flow coefficient) from liquids and gases.

Pressure/temperature ratings

The maximum working capability of a valve is either the body rating or the seat shut-off capability, whichever is the lower.

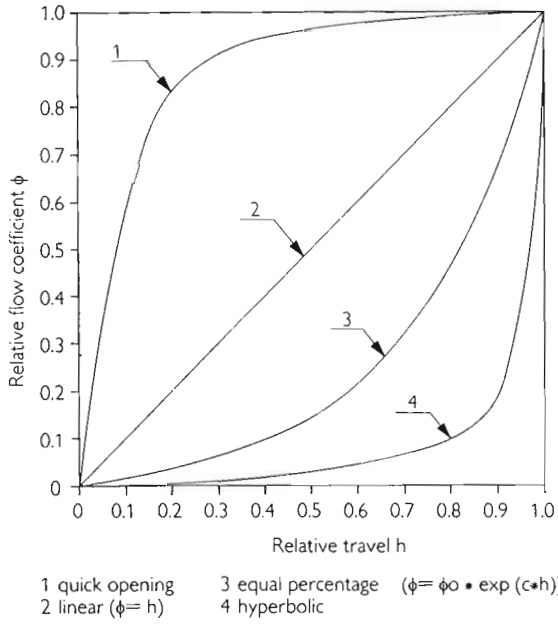


Figure 10. Valve inherent flow characteristics.

▼ METHOD

Calculate the Kv (flow coefficient) from:

a) Liquids

$$Kv = Q\sqrt{\frac{\gamma}{\Delta p}}$$

Liquid sizing formula is only applicable for subcritical flow

b) Gases

$$Kv = \frac{Vn}{514}\sqrt{\frac{G.T}{\Delta p.P_2}}$$

Gas formula only applicable if the ratio Δp to P^1 (upstream pressure absolute) is less than 0.10

Where

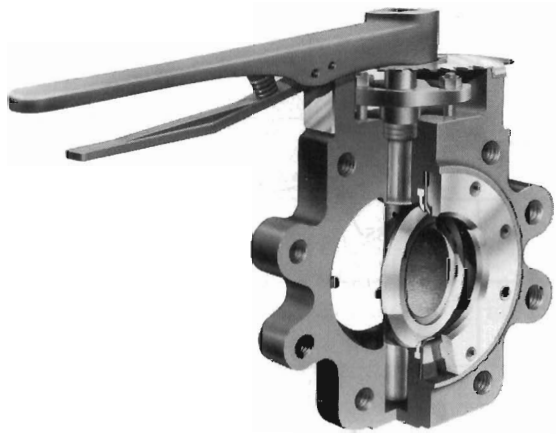
- **Kv** = Flow coefficient (Metric Units)
- **Cv** = Flow coefficient (Imperial Units)
- **Q** = Max. Flow volume in m^3/h
- γ = Specific weight in Kg/dm^3
- **F** = Cross section of pipe in cm^2
- Δp = Pressure drop in bar
- **Vn** = Max flow volume in Nm^3/h
- **G** = Specific weight in Kg/Nm^3
- **T** = Absolute Temperature in °K
- P_1 = Absolute pressure upstream in bar
- P_2 = Absolute pressure downstream in bar

Having calculated the Kv, the figure obtained should be compared with these below and the normal diameter determined.

DN	Cross-section of pipe in cm^2	Opening Angle 90° Kv	90° Cv	80° Kv	80° Cv	75° Kv	75° Cv	70° Kv	70° Cv	60° Kv	60° Cv	50° Kv	50° Cv	40° Kv	40° Cv	30° Kv	30° Cv	25° Kv	25° Cv
50	19.6	111	130	89	104	76	89	59	69	45	53	23	27	14	16	7	8	5	6
65	33.2	170	198	136	159	111	130	89	104	70	82	35	41	22	26	12	14	8	9
80	50.3	256	299	205	239	175	204	136	159	106	124	53	62	32	37	18	21	12	14
100	78.5	470	548	405	473	341	398	260	303	200	233	102	119	62	72	35	41	23	27
125	123	961	1121	854	996	709	827	534	623	418	488	213	249	132	154	75	88	51	60
150	177	1666	1944	1410	1645	1153	1345	880	1027	683	797	350	408	213	249	123	144	83	97
200	314	2777	3240	2329	2718	1880	2194	1495	1744	1111	1296	598	698	359	418	213	249	145	169
250	491	4273	4986	3675	4288	3076	3589	2350	2742	1837	2144	982	1146	572	667	333	389	222	259
300	707	6410	7480	5170	6033	4273	4986	3461	4039	2649	3091	1367	1595	854	996	470	548	324	378
350	962	8547	9973	6923	8078	5726	6683	4359	5085	3504	4089	1880	2194	1111	1296	641	748	427	498
400	1257	10683	12466	9230	10770	7692	8975	5555	6482	4358	5085	2264	2642	1452	1694	769	897	555	648
450	1590	14957	17453	11985	13961	10256	11967	7863	9175	6068	7081	3162	3690	1965	2293	1068	1246	769	897
500	1962	18803	21940	14957	17453	12820	14959	9829	11469	7435	8676	3931	4587	2393	2792	1367	1595	961	1121
600	2827	23931	27924	20512	23955	17521	20445	14102	16455	10042	16455	5213	6083	3247	3789	1880	2194	1282	1496

Figure 11. Example method for calculating flow coefficients K_v/C_v.

Ceramic-lined butterfly valves have provided a long-term, low-maintenance solution to controlling abrasive and acidic titanium dioxide slurry flows.



High-performance butterfly valve.

In Figure 12 the seat ratings shown are based on data from API 609 and the body ratings shown are from ANSI B16.5/BS 1560 part 2.

Butterfly check valves

Butterfly check valves differ from conventional butterfly valves in employing a hinged instead of a pivoted disc, with a sealing ring around the edge of the disc (Figure 13). With forward flow, the two halves of the disc are swung together to trail downstream. With reverse flow, the two halves open to approximately 45° each, sealing the bore.

With this mode of working, a butterfly check valve is, in fact, another form of flap valve. It has the advantage of rapid action with a resilient seal.

Butterfly check valves (Figure 14) require only a short length of body which can virtually be a length of standard pipe flanged at both ends (or threaded or plain ends in smaller sizes). It is also produced in wafer form for clamping between two pipe flanges. In this case the body length only needs to be sufficient to accommodate the hinge post and the two valve plates in their closed position.

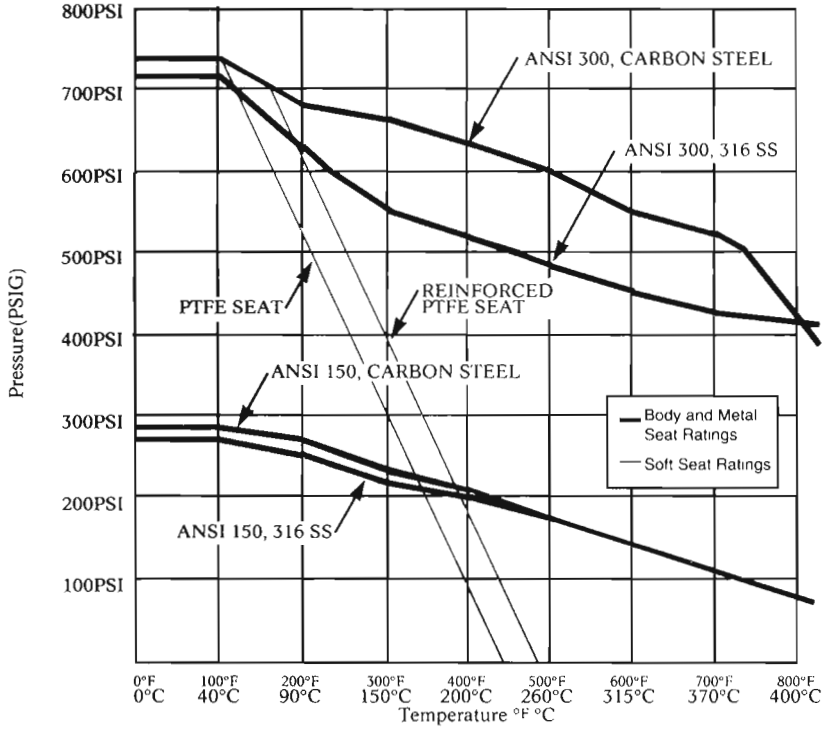


Figure 12. Typical pressure/temperature ratings.

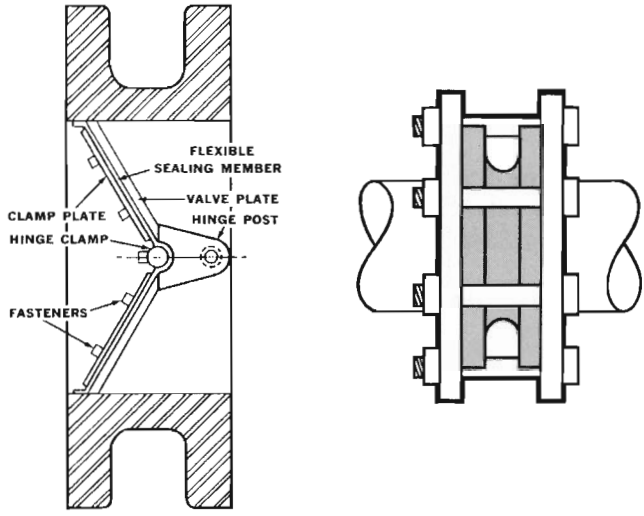


Figure 13. Butterfly check valve.

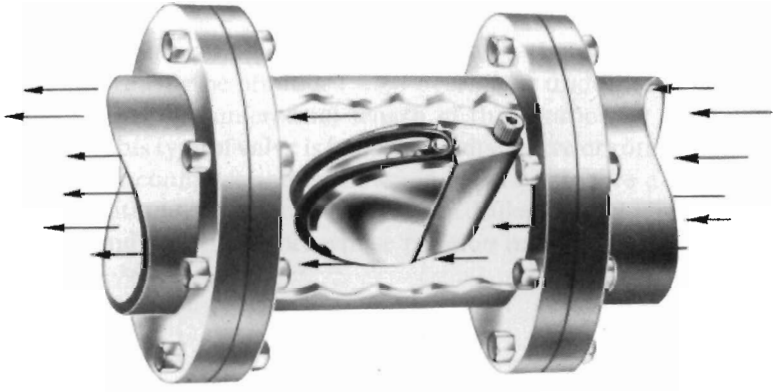


Figure 14. Butterfly check valve.

Advantages of butterfly valves

- Butterfly valves are compact, require less space, less weight, less raw material and are generally less costly than other valve types.
- Butterfly valves are quarter-turn valves, easy to operate by lever, gearbox or actuator. They have excellent gland integrity.
- Butterfly valves have few parts and are generally easy to maintain.
- Butterfly valves are suitable for control purposes with linear flow characteristics between 30° and 70° of opening.
- Butterfly valves offer excellent rangeability from 30:1 to 100:1.

Typical major areas of application for butterfly valves include: liquids, gases, steam, cryogenics, pulpstocks both on control and shut-off services in chemical processing, waterworks duties, oil and gas processing, pulp and paper manufacture, the power industry, refineries and food and beverage processing.

Properly selected and integrated with the latest controls and communications technology, butterfly valves can provide an economical, long-term solution to flow control in large process plants.

Rotary Disc/Rotor Valves

The rotary valve is an obvious configuration, although not widely used. It can be classified as a type of spool valve where the ports run axially instead of circumferentially (Figure 1). Sealing in the closed position, valves are a close fit over a restricted area only. Also friction can be high. In these respects, it is inferior to a conventional spool valve or even a plug valve.

A somewhat better configuration is to employ a 'solid spool' with drilled-through ports (Figure 2); or the rotary plate valve (see the chapter on Spool Valves).

Geometric design is simplified to a degree with these latter types of valves, and both can readily be produced with overlap or underlap as required, e.g. by enlarging the circumferential length of the rotation or stationary port, respectively. This type of valve is known as a disc valve or rotary disc valve.

A third basic configuration is shown in Figure 3, where a spindle or shaft rotates in a stationary housing. The shaft is drilled axially and also vertically at the blind end to form a port whose position matches the inlet port in the

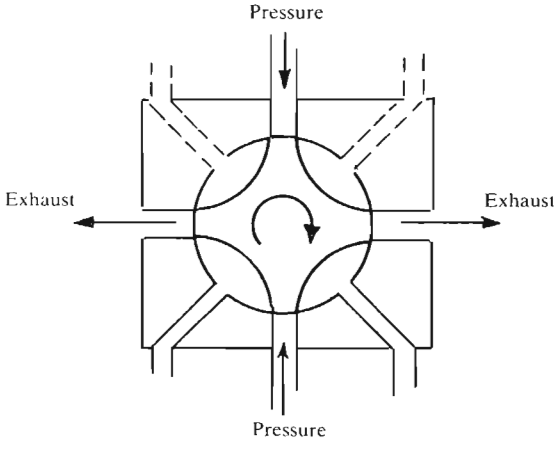


Figure 1.

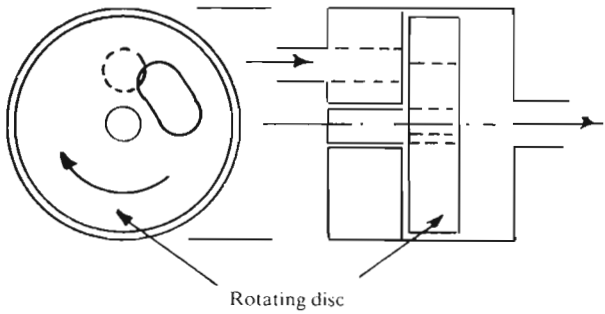


Figure 2.

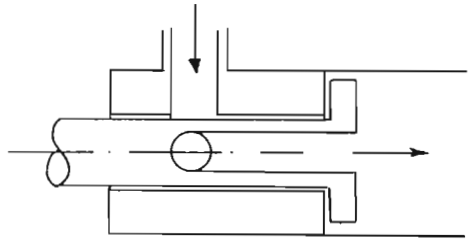


Figure 3.

stationary member. Again, the port opening(s) can be modified in length to provide overlap or underlap as required.

A feature of both rotary valve types shown in Figures 2 and 3 is that they are capable of providing exact timing of port opening with continuous rotation of the rotary element.

The design of rotary valve shown in Figure 4 overcomes the problem of friction and leakage by using shear seal rings in each port and a thrust bearing between rotor and housing. The shear seal rings are grooved to retain O-ring seals and are spring-loaded onto the smooth rotor face by individual disc springs. The flow passages through the valve are made as clear as possible to reduce the pressure drop through the valve.

Rotor valves

This type of valve differs from the typical rotary valve in that the valve design allows for transitional flow to occur when changing valve positions. Transitional flow eliminates dead-heading problems associated with positive displacement pumps.

Typically the rotor valve (Figure 5) consists of four flow types with many flow-pattern combinations and 'piggable' versions. The stem and rotor are

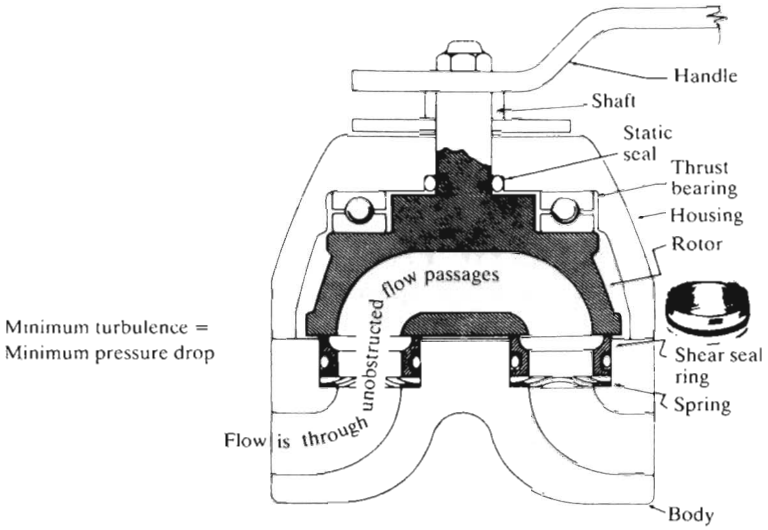


Figure 4.

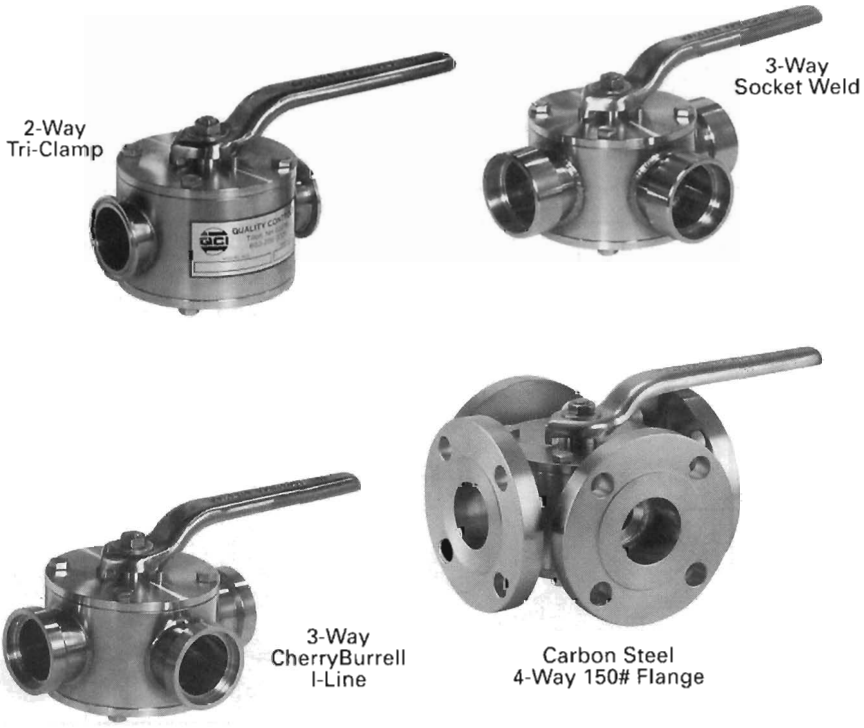
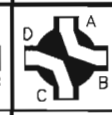
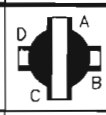
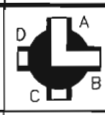
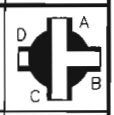
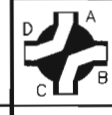
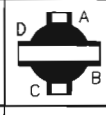
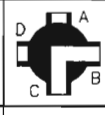
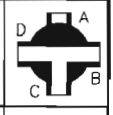
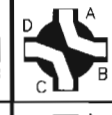
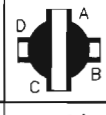
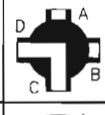
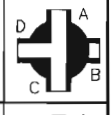
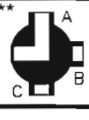
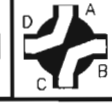
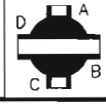
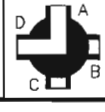
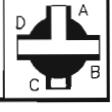


Figure 5. Examples of rotor valves.

usually of a one-piece construction that can eliminate the source of wear and repair common to the typical ball valve design. Full-port diameter reduces the pressure drop across the valve, thereby increasing the flow. An independent leaf seal design eliminates the large cavities common to the ball valve and also the need for cavity fillers, which still create stagnant seams for product to enter.

VALVE FLOW PATTERN COMBINATIONS

PORTING	2-WAY	3-WAY		4-WAY			
	S-	L-	T-	LL	**S-	**L-	**T-
Position 1							
Position 2							
Position 3							
Position 4							

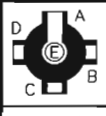
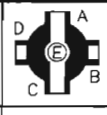
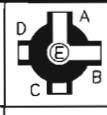
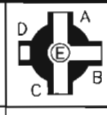
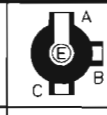
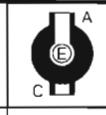
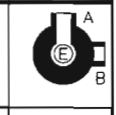
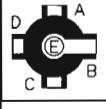
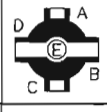
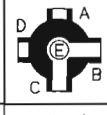
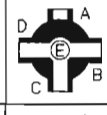
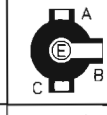
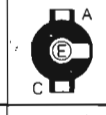
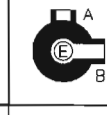
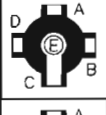
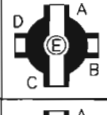
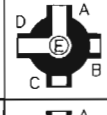
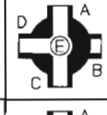
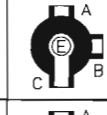
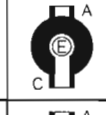
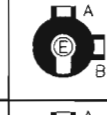
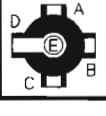
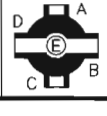
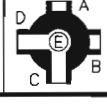
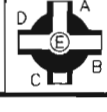
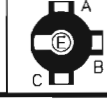
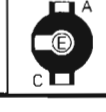
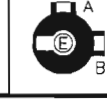
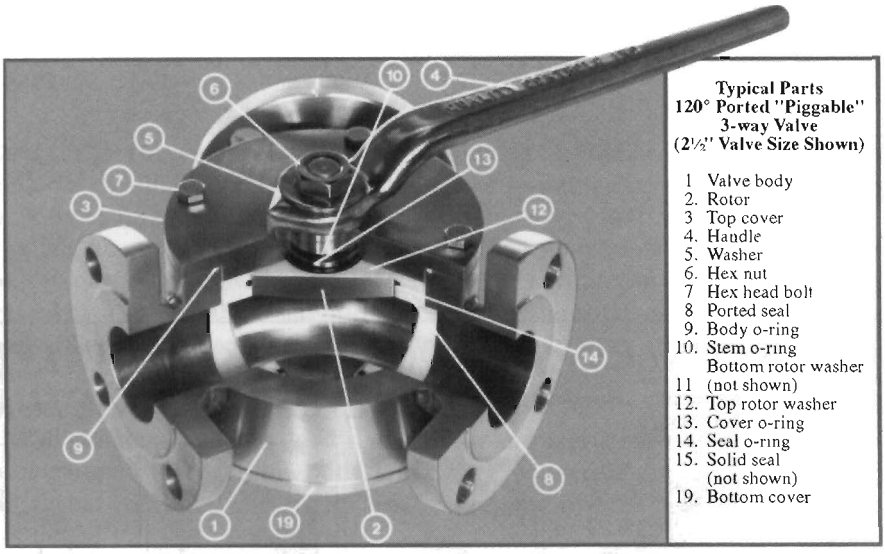
PORTING	5-WAY						
	B-	BS	BL	BT	B- (with special porting)		
					A,B,C&E	A,C&E	A,B&E
Position 1							
Position 2							
Position 3							
Position 4							

Figure 6. Valve flow-pattern combinations.

Rotor valves of this type are favoured by a number of industries including: food and beverage, pharmaceutical, chemical, petrochemical, refining, paper and paint and particularly where quick-couple fittings for sanitary systems are preferred.

Typical flow-pattern combinations are shown in Figure 6.



120° ported piggable 3-way valve.

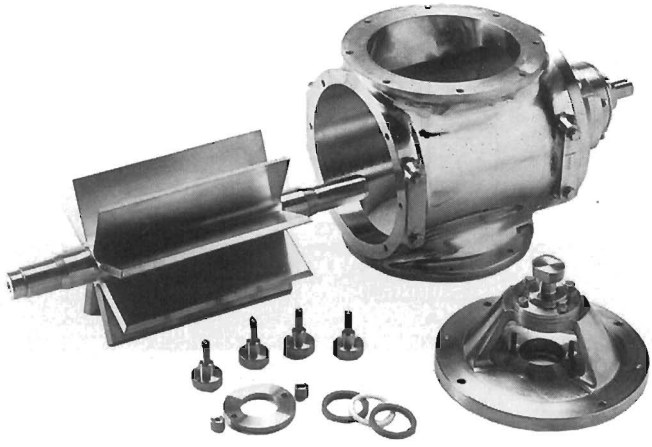


Figure 7. De-mountable rotary valve.

De-mountable rotary valves (Figure 7) are mainly used for sanitary duties in dairy, food, pharmaceutical and chemical applications with powder or granular product. This type of valve is usually produced in 316 stainless steel with the rotor end-plate and shaft seals easily disassembled without tools and the unit capable of being cleaned in place (CIP). Capacities up to 1500 cubic ft/hr in either drop-through or convey-through configurations are common.

Globe Valves

Over the last 60 years, globe valves have been re-appraised in the light of new materials available for use. They are popular as industrial valves because they have fine adjustment and permit unobstructed opening through pipelines.

The globe valve is characterised by a baffle or partition separating the two halves of the body, with an interconnecting part at the centre opened and closed by a screw-down/screw-up disc or plug mounted at right angles to the body (Figure 1). The name derives from the fact that original body shapes were spherical, the more usual modern form being semi-spherical or even substantially parallel-sided.

The globe valve offers good regulation characteristics but high resistance because of the tortuous flow path. This can be reduced to some extent by making the throat area equivalent to that of the pipe (calling for a more bulbous body),

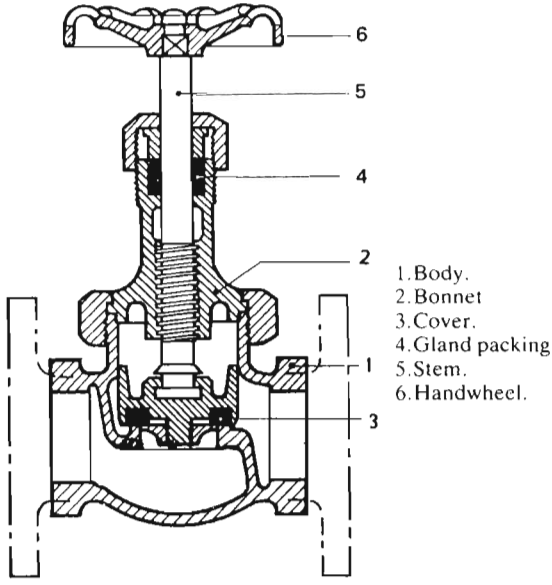


Figure 1. Screw-down globe valve.

Bronze globe valve.

rounding the partition to smooth flow or inclining it to the flow (Figure 2). Reduction of head loss by such treatment is generally minimal and so right-angled partitions are commonly used.

Globe valves are produced with a variety of discs or plugs and seals. Discs provide line contact with the seat which can be broken by solid deposits forming on the seat. They are thus mainly suited only for clean fluids. Disc valves, too, are not as effective as plugs for throttling duties and so are normally used only on shut-off valves. Another limitation of the disc is that it does not provide positive shut-off for air and gases, unless made of a resilient material.

Plugs are used in a variety of configurations, ranging from needle shapes to semi-discs. The plug contour also governs the throttling characteristics, e.g. equal-percentage plugs (percentage flow proportional to valve lift), etc. Needle plugs provide the finest flow control. Globe valves fitted with this latter type of plug are normally referred to as needle valves. Needle valves are normally made only in small sizes.

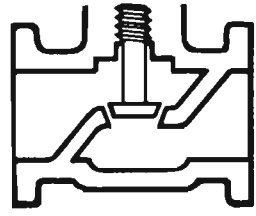
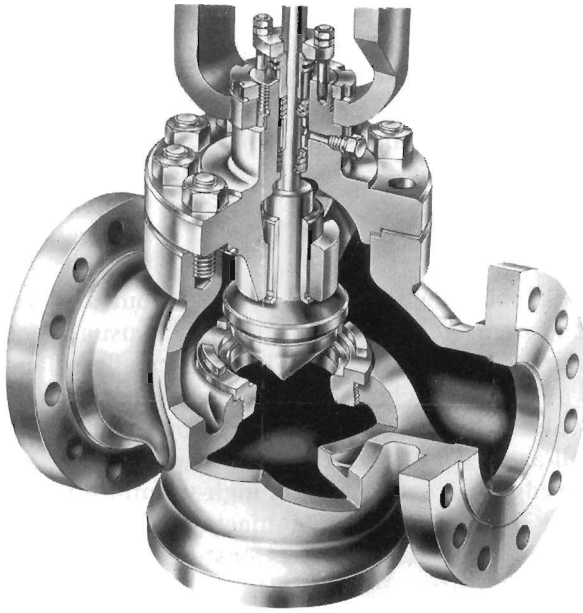
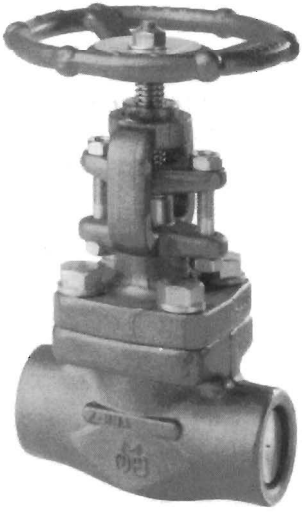


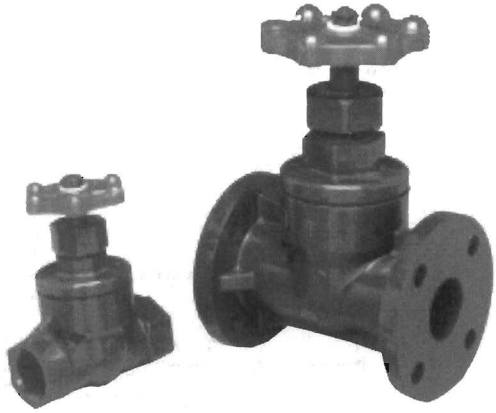
Figure 2.



Cutaway of globe valve.



Forged-steel globe valve.



Plastic globe valves.

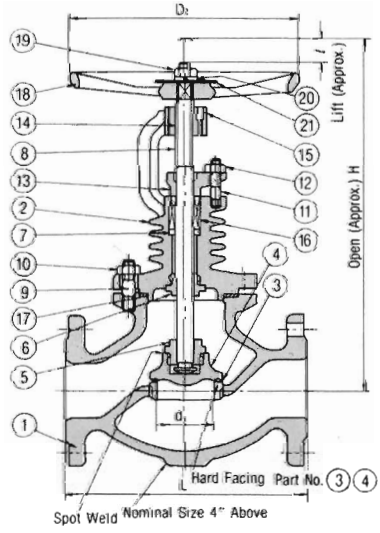
Seats

Globe valve seats may be cast integral with the body or take the form of screwed-in, pressed-in, or spot-welded rings. A variety of materials may be used for seats, depending on the application, including coated seat rings with plastic inserts. Normally only screwed-in seat rings are replaceable.

Stems

Possible stem assemblies include inside screw and outside screw (both rising stem) and sliding stem. Inside stem rising screw is usual. A stem seal (stem gland) is necessary to eliminate leakage. This is normally a gland-type packing or gland rings. A diaphragm bonnet seal or bellows bonnet seal may also be used on globe valves, the former isolating the working parts of the valve from the fluid as well as preventing leakage to the atmosphere. Metallic bellows seals are often used on valves intended for high-vacuum duties.

The valve shown in Figure 3 is manufactured from malleable iron. This valve is widely used on standard pipelines for steam, oil and water.



No.	PART NAME	MATERIAL
1	BODY	Malleable Iron
2	BONNET	Malleable Iron
3	BODY SEAT RING	13 Cr Stainless Steel $2\frac{1}{2}$"~4" Carbon Steel
4	DISC	Carbon Steel
5	DISC STEM RING	13 Cr Stainless Steel
6	BONNET BUSH	13 Cr Stainless Steel + H350
7	PACKING BUSH	13 Cr Stainless Steel
8	STEM	13 Cr Stainless Steel
9	BONNET BOLT	Carbon Steel
10	NUT	Carbon Steel
11	GLAND BOLT	Carbon Steel
12	NUT	Carbon Steel
13	GLAND FLANGE	Malleable Iron
14	YOKE SLEEVE	High Tension Brass
15	SET PIN	Brass

Figure 3. Malleable-iron globe valve.

'Y'-pattern globe valve: bellows seal, inside screw and yoke.

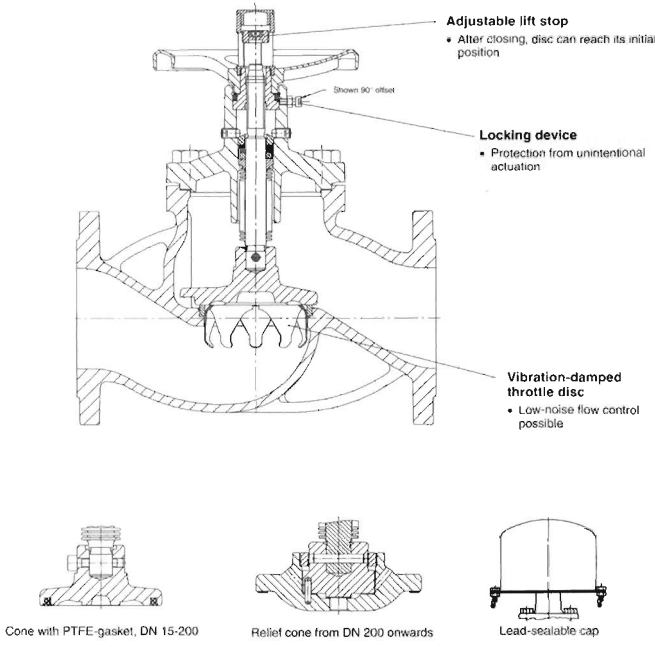


Figure 4. Globe valve with metallic seat.

Malleable iron provides a high yield point, a more important property than tensile strength for valve materials. It is also stable against temperature change. Low-pressure valves of this type generally have PTFE seats. Valves for use at higher pressures have the valve disc and body seat ring made from hard-faced stainless steel. The hard face is an alloy containing cobalt, chromium and tungsten. Valves of this type can also be fitted with replaceable PTFE discs when used with liquefied petroleum gases. The gland packings are usually of a synthetic rubber of butadiene-acryl-nitrile polymer V packing design to provide for good oil and wear resistance. Over time, the V packing will harden; tell-tale signs are: a friction sound when the valve is opened and

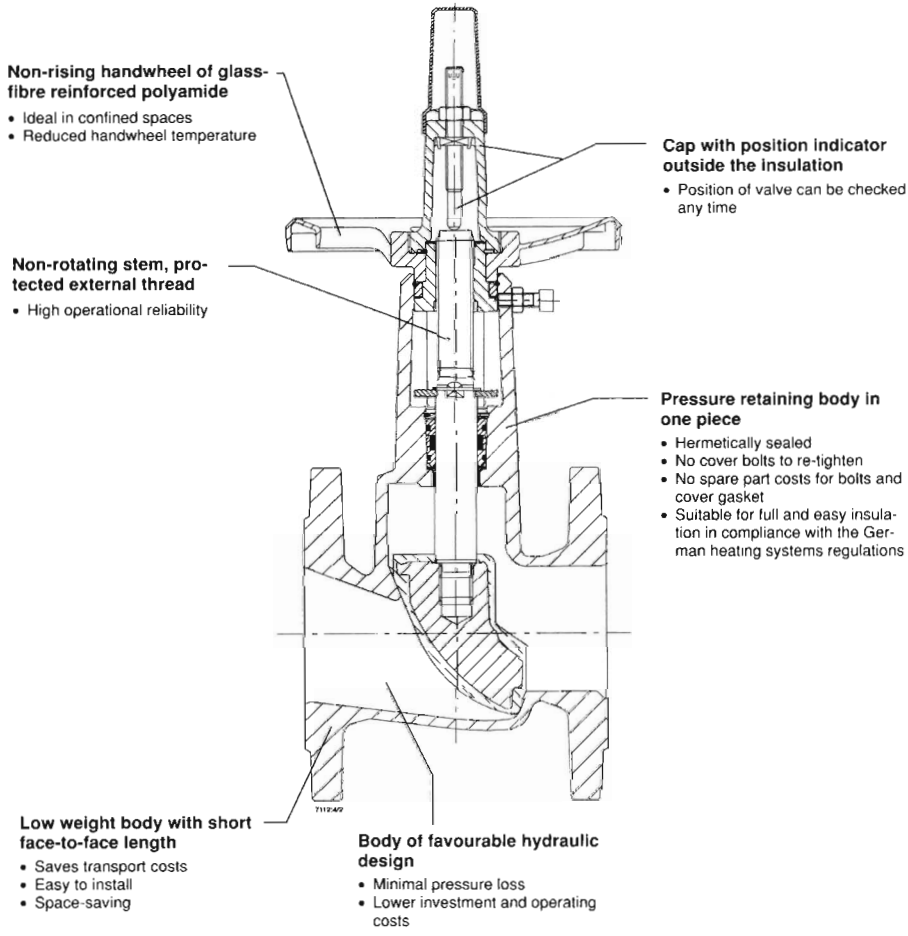


Figure 5. Globe valve with high-temperature soft seat.

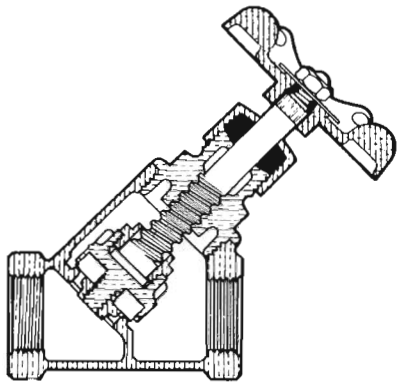


Figure 6. Oblique or 'Y' valve.

closed; the opening and closing operation becomes difficult to operate; and the gland actually leaking. The packing must then be replaced.

An example of a standard globe valve for use in hot- and warm-water heating and boiler installations is shown in Figure 4. This particular valve has a metallic seat. The temperature range is from −10°C up to +350°C, with pressures up to p = 25 bar.

The valve illustrated in Figure 5 is fitted with a soft seat for high-temperature operation from −10°C to +200°C. Typical applications included hot-water heating systems, district heating plants and low-pressure steam plants. The valve has a short face-to-face length which makes it particularly compact. Globe valves are a traditional standard solution for many control applications because of the ability to modify the trim design for different throttling purposes.

Oblique valves

The oblique valve or Y-valve is a hybrid globe valve characterised by the stem being angled (Figure 6). As a consequence the flow path is less tortuous, with reduced pressure drop compared with a conventional globe valve. It retains the same good throttling characteristics as a globe valve and can be fitted with similar types of plugs.

Construction is basically the same as globe valves with the option of integral or fitted seat rings, stem options and stem seal gland treatment.

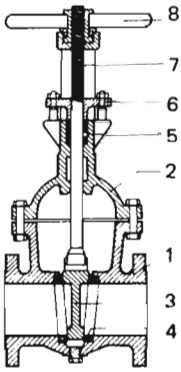
Gate Valves

The main feature that distinguishes a gate valve is the flat face or vertical disc or wedge that slides in a track or seat which can be lifted in a direction at right angles to the valve until clear of the flow path. Generally gate valves are used for on–off non throttling service, i.e. they are intended to be either fully open, when they offer little resistance to flow, or fully closed. For this reason, they are the principal valves used in bulk pumping practice.

Large gate valves tend to be power operated. Throughout the water industry, for example, automation with actuated valves has been introduced in response to the requirement for lower manning levels.

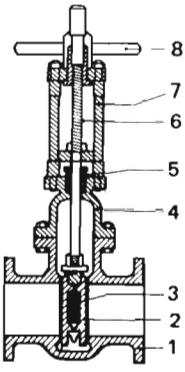
Gate valves are divided into a number of classes, depending on the design of the 'gate' and its seating faces.

Gate valves.



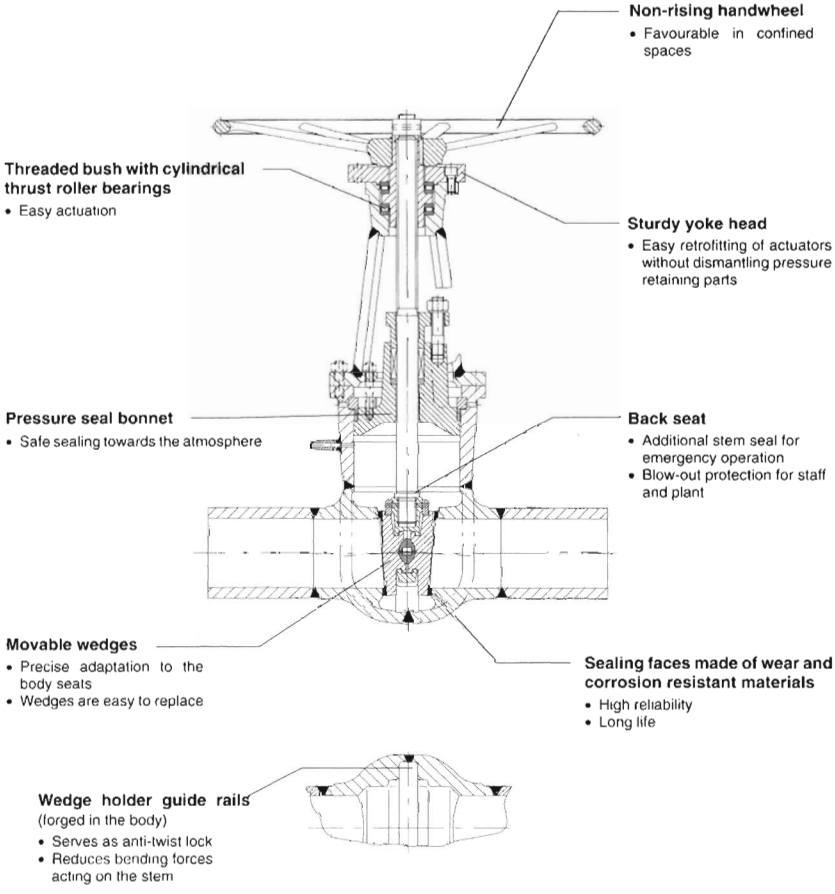
1. Body.
2. Bonnet.
3. Wedge.
4. Seat ring.
5. Gland packing.
6. Gland follower.
7. Stem.
8. Handwheel.

Solid wedge gate valve.



1. Body.
2. Disc.
3. Spring.
4. Bonnet.
5. Gland.
6. Stem.
7. Yoke.
8. Handwheel.

Parallel slide gate valve.



Gate valve with pressure seal bonnet.

Wedge-gate valves

The gate is wedge-shaped and seals on corresponding faces in the faces of the valve body. Wedges and seats can be made of, or coated with, resistant material or faced with plastic such as PTFE. The plastic is often contained in a groove to prevent it spreading. Figure 1 shows a wedge-gate valve with external screw, and Figure 2 one with internal screw.

Flexible-wedge valves and split-wedge valves are similar to the aforementioned, but with provision for slight seat misalignment.

Wedge-gate valves can be further described as inside-screw or outside-screw patterns (see Figure 3). They are widely used for oil, gas and air services, and also for handling slurries, etc.

Double-disc valves

In these valves the gate is in the form of two discs which are forced apart against parallel seats by a spring. This provides tight sealing without relying on fluid pressure, making this type of valve particularly suitable for steam duties as well as handling gases and light oils.

Parallel-slide valves

In 1886, Joseph Hopkinson introduced the parallel-slide valve where sealing of the valve relies on the upstream pressure acting on a flat parallel gate valve.

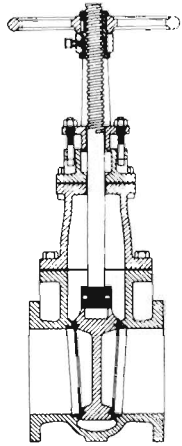


Figure 1. External screw.

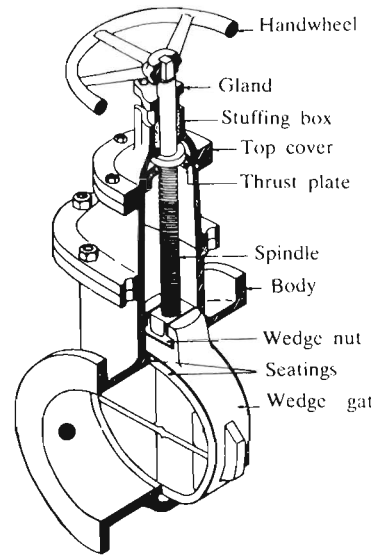


Figure 2. Internal screw.

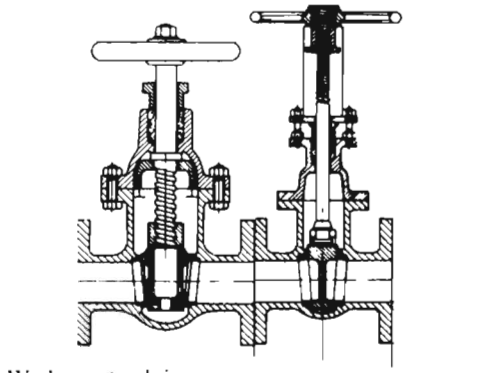
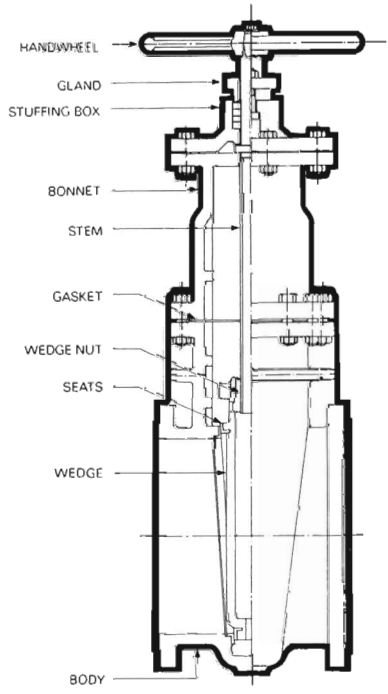
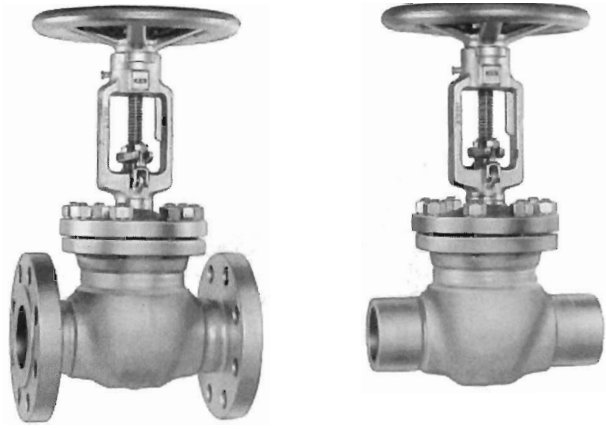


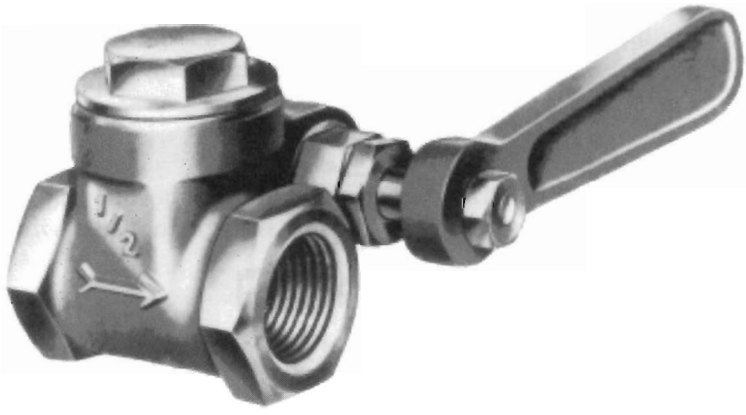
Figure 3.



Inside-screw gate valve.



Flanged and butt-welded gate valves.



Bronze double-disc lever gate valve.

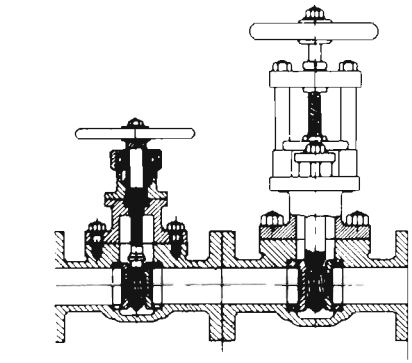
The system is still popular today and the simplest (and probably most effective) layout employs two discs as valve members initially separated by a spring (see Figure 4). The function of the spring is to prevent the discs from rattling and to encourage a wiping action on the downstream disc when under pressure and on both discs when there is virtually no pressure in the line.

This is to avoid—as far as is possible—grit or scale becoming trapped between the vulnerable seating faces which might impair their sealing properties.

Parallel-slide valves are used extensively in the pulp and paper industry.

Sluice valves

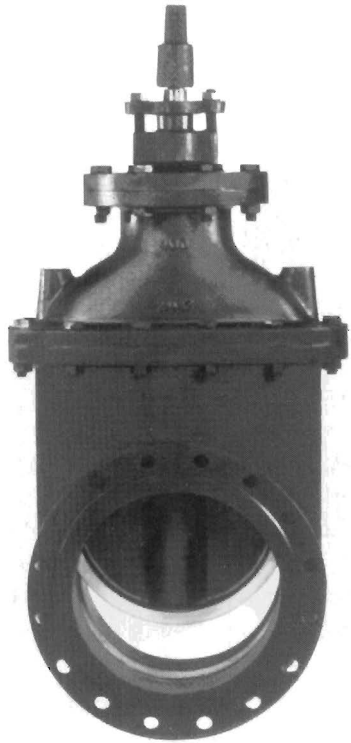
This is a name applied to solid-wedge valves for waterworks.



Parallel slide valve inside screw pattern

Parallel slide valve outside screw pattern

Figure 4.



Metal-seated gate valve.

Bellows seal-gate valves

Environmental protection is a major concern and the bellows seal valve is designed to minimise exposure to dangerous or harmful substances through valve-stem leakage.

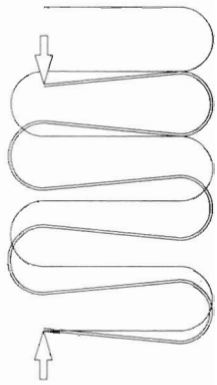


Figure 5.

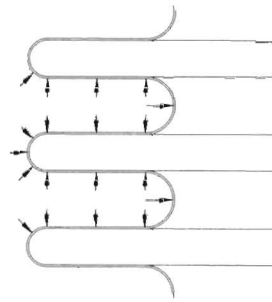


Figure 6.

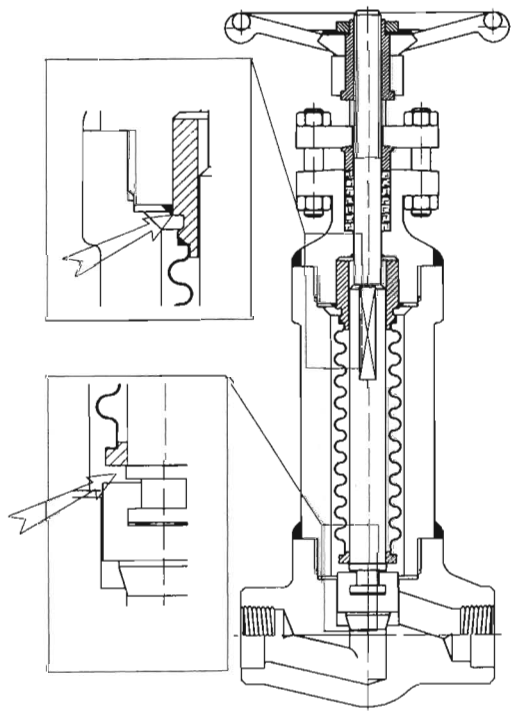
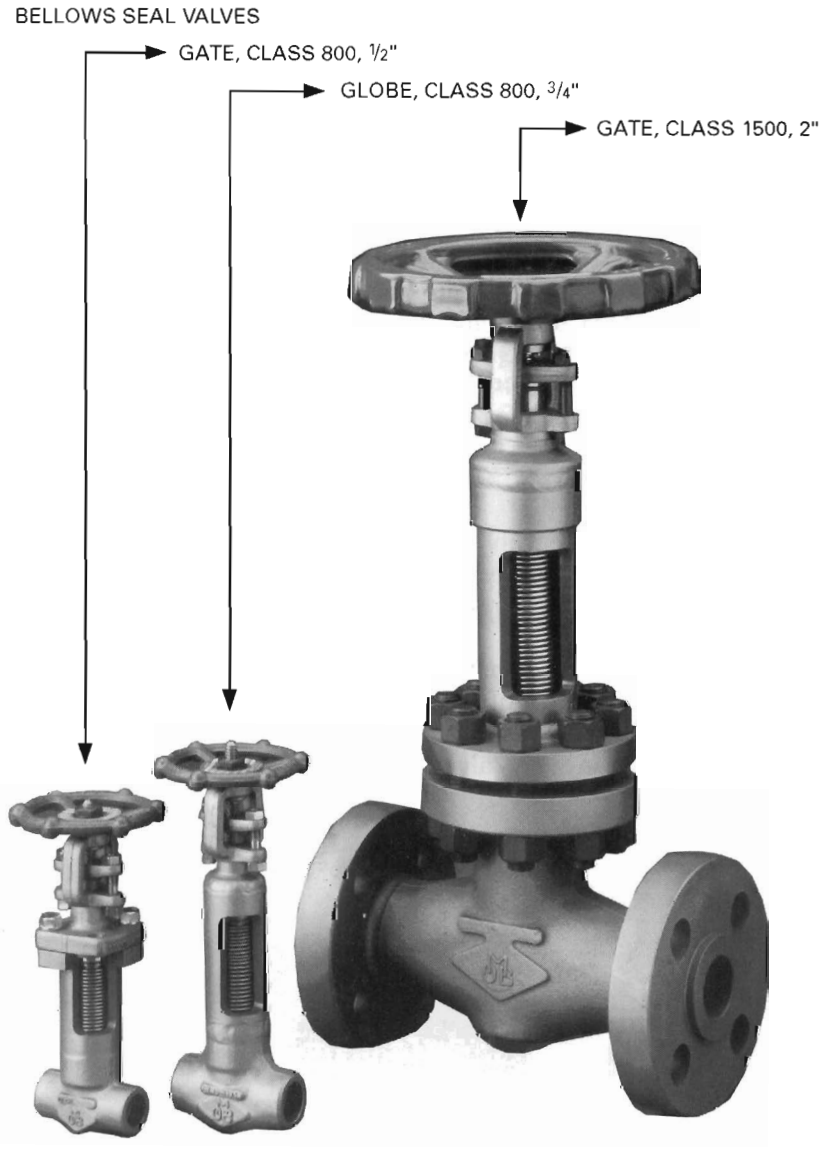


Figure 7. Construction details.

The bellows is a metallic device capable of sealing between the valve stem and the bonnet to prevent escape of the system fluid to the atmosphere. The bellows take the form of convolutions that can move linearly. A hermetic seal is achieved by welding the bellows to the valve stem at one end and to the



Bellows seal valves.

bonnet at the other end (Figure 5). The structural shape of the bellows provides resistance to high pressure, even with thin wall thicknesses (Figure 6).

In operation, the bellows eliminates a leak path to atmosphere. The stem/packing area is sealed from the medium being processed and the bellows becomes the primary seal since the bellows assembly is welded to the stem and to the bonnet as shown in Figure 7.

Replaceable bellows are gaining popularity with valve users in process plants.

In replaceable bellows valves, the bellows is not welded to the bonnet; instead, it is welded to a transition piece that is clamped between the body with standard gaskets to seal the joint. The lower end of the bellows assembly is welded to the disc which is attached to the stem by a threaded connection. The gasket on the media side is generally a spiral-wound gasket. The gasket at the top of the bellows assembly only comes into operation if the bellows fails.

Where maintenance is difficult, the welded bonnet valve may be the better choice.

Gate valves are used mainly in general industry, power stations, process engineering, pulp and paper and marine engineering for water, steam, gas, oil and non-aggressive media.

Actuation

Manual actuation of gate valves is invariably by screw and handwheel. The screw mechanism may be exposed or protected and the screw 'rising' or 'non-rising'. A variety of materials for the working parts is offered by some makers.

Power actuators are very often fitted, especially where valves are difficult to access and are operated frequently. Automation and semi-automation control schemes also make extensive use of actuators.

See also the chapter on Slide Valves.

Needle Valves

Small sizes of globe valves fitted with a finely tapered plug are known as needle valves. This description also applies to any type of valve incorporating a tapered needle having axial movement relative to the axis of a concentric orifice and thus controlling the effective opening of the orifice.

Three basic configurations are shown in Figure 1: (A) is a simple screw-down valve; (B) is an oblique version, offering a more direct flow path; (C) is another form where the controlled outlet flow is at right angles to the main flow (and may be distributed through one or more passages). In these basic

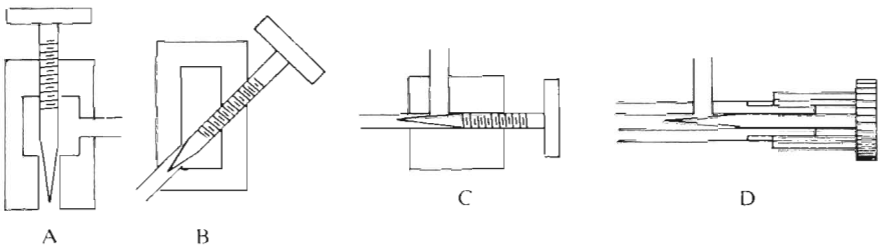
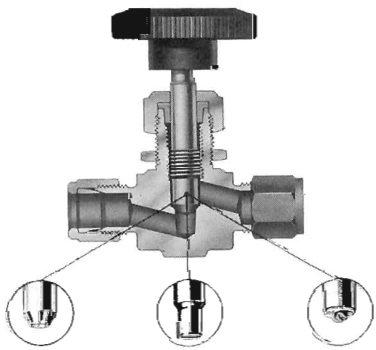
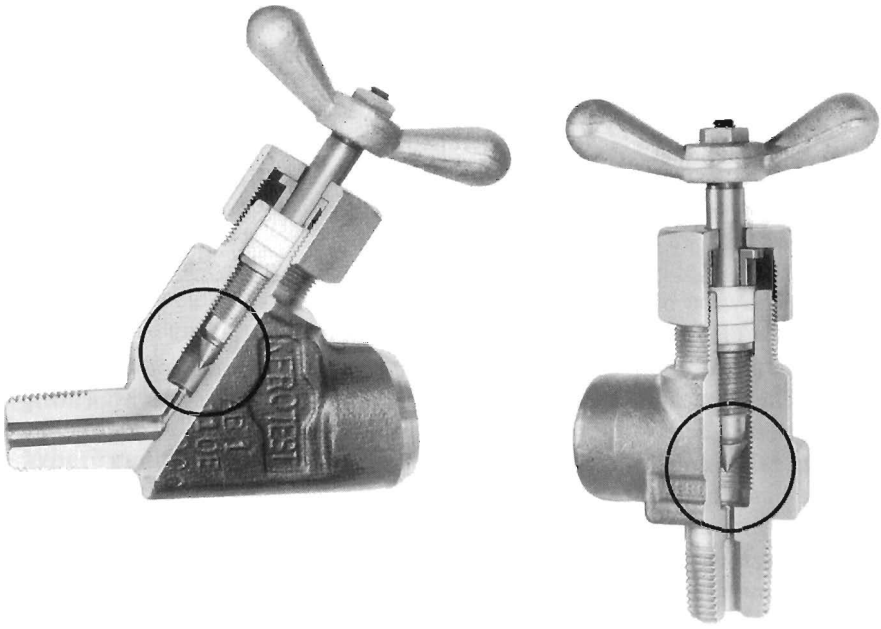


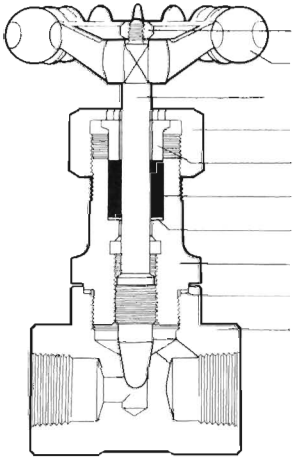
Figure 1.



Needle valve with interchangeable stem.



Oblique and 'T'-type needle valves typically used for process duties.



Part	Material	B S	A S T M
Handwheel Nut	Carbon Steel	1768	
Handwheel	Malleable Iron	309	
Stem	Stainless Steel	1506 713	A182 GR F6
Gland Nut	Carbon Steel	1506 111	
Gland	Carbon Steel	1506-111	
Packing	Valvas..s and Plastic Non Metallic		
Steel Packing Ring	Mild Steel	970 ENIA	
Bonnet	Carbon Steel	1506 111	
Bonnet Gasket	Armco Iron		
Body	Carbon Steel Forging	1503 161 GR 32	A105 GR 2

Typical needle-type meter valve.

versions a threaded needle is shown, the thread itself acting as a seal to eliminate leakage past the needle. This is normally quite satisfactory in very small sizes of needle, although a more leak-tight arrangement is to mount the needle in an externally threaded end piece [Figure 1 (D)]. This end piece can also act as a grip for adjustment of the needle. Sealing in this case can be further improved if necessary by incorporating an internal seal, such as an O-ring. The other common form of needle valve is the float-controlled, carburettor-type valve.

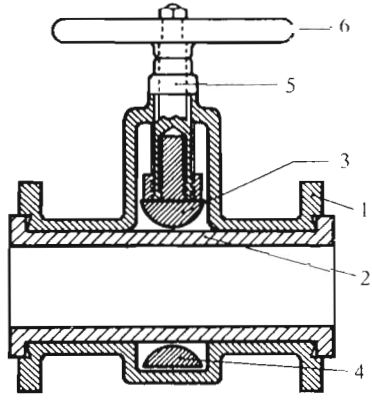
See also the chapter on Globe Valves.

Pinch Valves

The 'working' element of a pinch valve, also known as a clamp valve, is an elastomeric tube or sleeve which can be squeezed at its mid-section by some mechanical system until ultimately the tube walls are pinched or clamped together producing full closure of the flow path.

In its simplest form it can consist merely of a length of elastomeric tube fitted with a pinch bar mechanism incorporating a closure stop to prevent over-pinching of the tube. More usually the moulded rubber tube is housed in a metal body which also incorporates the pinching mechanism (Figure 1). This can be a simple screw-operated mechanism, where the pinch is applied only to one side of the tube, or a differential screw controlling two pinching mechanisms working in vertical opposition. The latter produces lower-stress working of the tube.

Other types of pinch valves dispose with mechanical mechanisms entirely, the tube being squeezed shut by air or hydraulic pressure injected directly into the body of the valve (Figure 2). With a regulated fluid pressure the valve may



1. Body.
2. Flexible tube.
3. Upper pinch bar
4. Lower pinch bar
5. Spindle.
6. Handwheel.

Figure 1. Pinch valve—basic components.

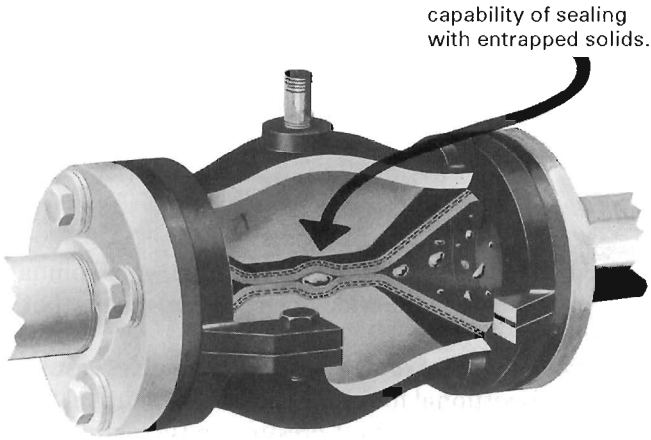


Figure 2. Hydraulic pressure-operated pinch valve.

be used for throttling as well as shut-off (full closure) (Figure 3). The particular advantage of the fluid-operated pinch valve is that it will still close tight over entrapped solids (making it particularly suitable for handling products with solids in suspension). Also, because the tube is flexed under uniformly distributed pressure, its life should be much longer than that of a similar tube working with a mechanical pinching system.

In common with the diaphragm valve, the operating mechanism is not in contact with the working fluid at any time, and nor is the body. In this respect, pinch valves have the advantage over diaphragm valves, unless the latter are rubber-lined or otherwise surface-protected. This exclusion of the working fluid from all parts excepting the sleeve itself makes it ideal for the handling of aggressive fluids and those which readily attack metal; and its straight-through characteristics mean it is suitable for the handling of slurries, pastes and semi-fluids generally, even those containing sizeable solid lumps in suspension.

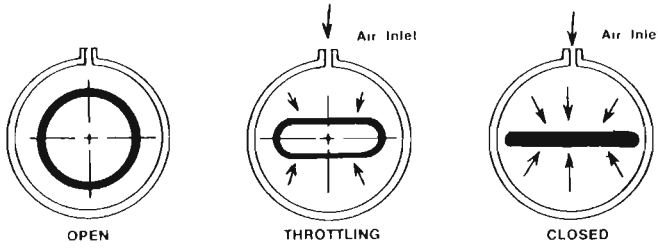


Figure 3.

Pinch valves with mechanical pinching mechanisms are normally operated by a handwheel and screw mechanism, but may equally well be driven by a powered actuator in larger sizes. Bodies are normally split horizontally to facilitate changing the tube when necessary without removing the complete valve from the pipeline.

Flow pattern

The flow pattern of a pinch valve is streamline and laminar. The non turbulent flow pattern even in the wide-open position means that wear on the valve sleeve is minimised.

The linear characteristics of some control pinch valves result in flow rates which are directly proportional to the amount of sleeve travel throughout the stroke of the valve while under constant-pressure and pressure-drop conditions.

Typical valve sleeves are shown in Figure 4. These include standard, double wall for very abrasive conditions, cone sleeve for throttling control and variable orifice sleeve for improved flow characteristics where a high pressure drop is required.

Another form of pinch valve is shown in Figure 5. In addition to a resilient sleeve this also incorporates a streamlined core on to which the sleeve closes to seal. This valve can be operated in a variety of modes. In mode 1, the valve

Figure 4. Typical control pinch valve sleeves.

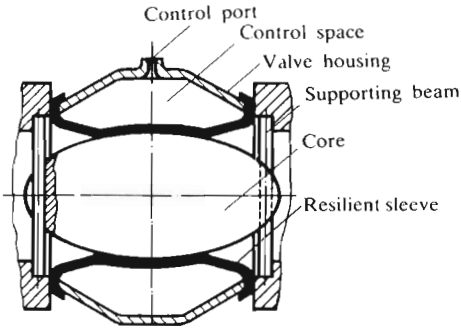


Figure 5.

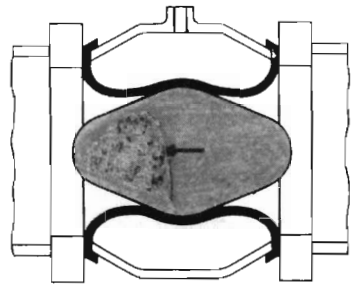


Figure 6.

remains closed when no pressure is present, due to the resilience of the sleeve (Figure 6). In the presence of pressure in the pipeline, the valve opens and remains open (Figure 7). It closes again in the absence of flow pressure. Line pressure of about 1 bar (14 lbf/in^2) is sufficient to hold the valve in the fully open position.

In mode 2, inlet pressure is tapped and fed to the control space between the sleeve and body, closing the valve. The valve opens when the operating pressure is relieved from the control space (Figure 8). At extremely low line pressures, circa 0.5 bar (7 lbf/in^2), the valve remains closed and drop-tight, even when operating pressure is relieved from the control space.

In mode 3, the operating principle is the same, except that the control space is pressurised from an independent source, e.g. compressed air or a hydraulic supply.

In mode 4, the flow is tapped to feed the control space which is only partially filled and then isolated, holding the sleeve in a partially closed position (Figure 9). In this mode the valve operates as a throttling valve or pressure-regulation valve.

Various low-hardness, high-tensile elastomeric compounds are used for the tubes, choice being made on chemical resistance and/or abrasion resistance required and service temperature. Typical materials used are:

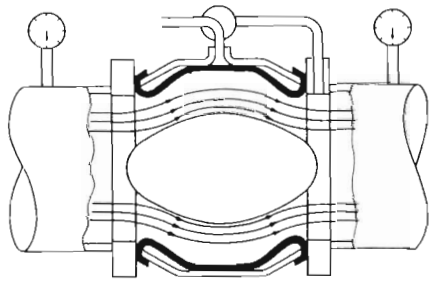


Figure 7.

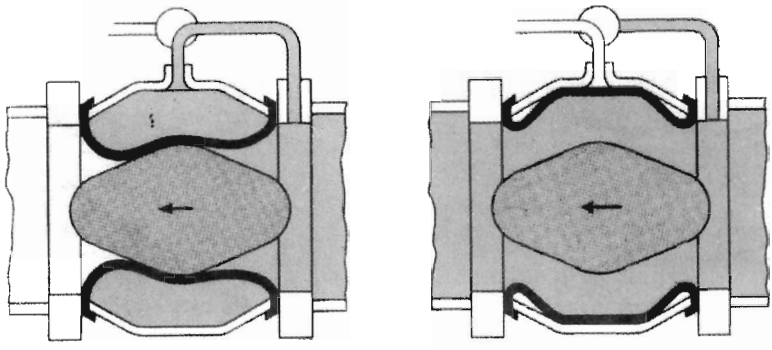


Figure 8.

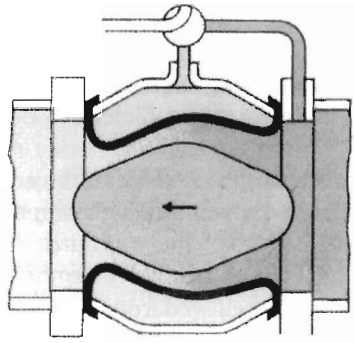


Figure 9.

GRS	excellent abrasion resistance.
BunaN	good resistance to solvents and hydrocarbons.
Neoprene*	good chemical and hydrocarbon resistance; in white compound also suitable for fast and dry application.
Butyl	good combination of chemical and temperature resistance; in white compound has good resistance to animal and vegetable oils.
Hypalon*	excellent chemical and temperature resistance.
PTFE	outstanding chemical and high-temperature resistance.
Silicone	good combination of high- and low-temperature resistance.
FDA	excellent abrasion resistance; suitable for many foods and dairy applications.
EPDM	excellent heat and chemical resistance.

*Neoprene and Hypalon are registered trademarks of DuPont Dow Elastomers.

Fluid performance

A pinch valve presents full-bore flow in the open position, with a straight, uninterrupted flow passage. Pressure drop or head loss under such conditions is thus minimal, related only to flow velocity and tube length, for a given fluid. There is no slamming when the valve closes against back pressure and the elastic nature of the tube tends to eliminate hammer (although this feature is absent in a hydraulically-operated pinch valve).

Vacuum services

Pinch valves tend to have limited suitability for vacuum services because of the tendency for the tube to collapse inwards. This is particularly true in the case of pinch valves with simple exposed tubes. Where the tube is enclosed in a body it is possible to adapt the valve for vacuum duties by applying a vacuum within the casing to balance the internal (vacuum) pressure.

Sizes and ratings

Sizes commonly available range up to 300 mm (12 in), with standard bodies suitable for pressures up to 14 bar (200 lbf/in^2), or steel or stainless-steel

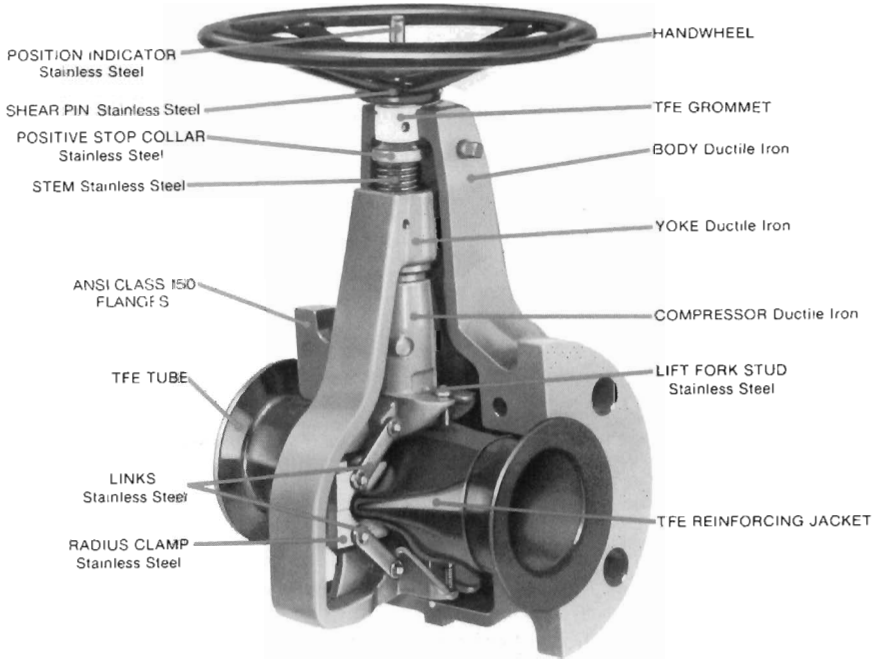


Figure 10. Clamp valve.

bodies for pressures up to 28 bar (400 lbf/in^2). Larger sizes are also available, those over 600 mm (24 in) diameter usually being individually made with fabricated steel bodies.

Clamp valves

This type of pinch valve (Figure 10) consists of a flexible tube and clamp. The flexible tube has a heat-shrunk reinforcing jacket with both made from virgin TFE fluorocarbon resin. The clamping mechanism consists of a compressor which travels down a stem with rotation of a handwheel or power operator, and a yoke which travels up the stem at the same time.

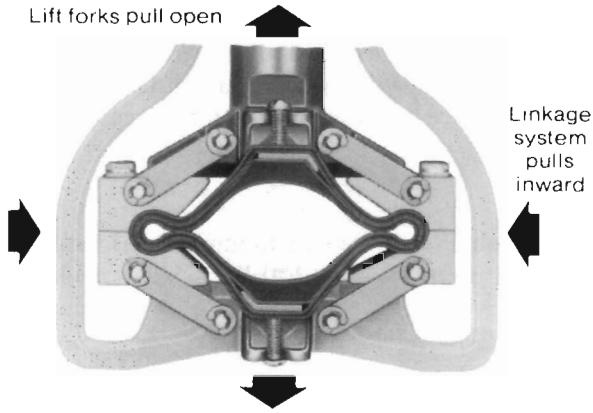


Figure 11.

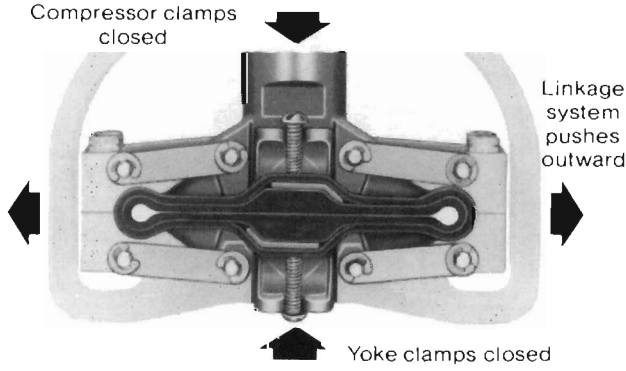


Figure 12.

Radius clamps are connected to the yoke and to the compressor by means of links and pins. Working together, they provide a 'scissor-jack' action which pushes the tube element inward during the opening cycle and pulls it outward during closing. The actions of the valve mechanism are shown in Figures 11 and 12.

Pinch valves are ideal for use in many industrial applications including:

- Chemical plants—where there are corrosive chemicals and for pump isolation.
- Power industry—FGD systems, ash handling and wet lime scrubbers.
- Mining industry—centrifuge control, solids separation, tailings systems, coal washing.
- Waste water treatment—flow equalisation, polymer feed systems, sludge control, grit systems, carbon slurry and raw sewage.

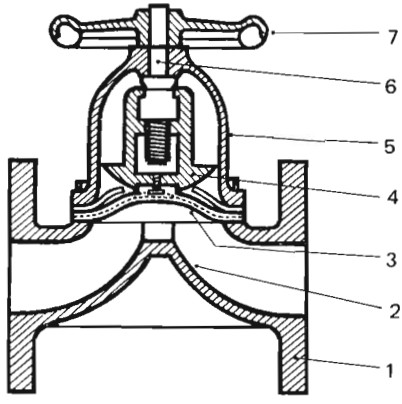
Diaphragm Valves

The distinguishing feature of a diaphragm valve is the closure device. This is usually an elastomeric diaphragm or tube which acts as a flexible seal when compressed against a ridge in the valve body. The diaphragm valve handles corrosive and erosive materials.

Diaphragm valves fall into two main types—weir valves and straight-through valves. In the former geometry (Figure 1), the body has a dividing weir, above which is mounted an elastomeric diaphragm. In the closed position the diaphragm sits on the weir. In the open position, it is fitted to provide a streamlined flow through the valve body. The amount of lifting is variable, so the valve can act both as a flow controller or a stop valve.

The straight-through diaphragm valve (Figure 2) may have a parallel, top-tapered or venturi-pattern body with closure provided by a wedge-shaped projection of the diaphragm. Because of the full-bore opening, it offers minimum resistance to flow in the open position, can pass suspended solids, and is capable of being rodded through for clearing any blockage.

Because the diaphragm isolates the moving parts, these valves are particularly suitable for handling aggressive fluids, as well as for 'clean fluid'



1. Body
2. Weir
3. Diaphragm
4. Diaphragm movement
5. Bonnet
6. Spindle
7. Handwheel

Figure 1. Weir-type diaphragm valve.

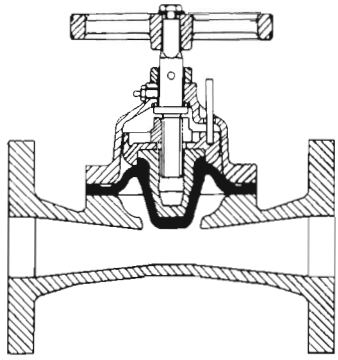
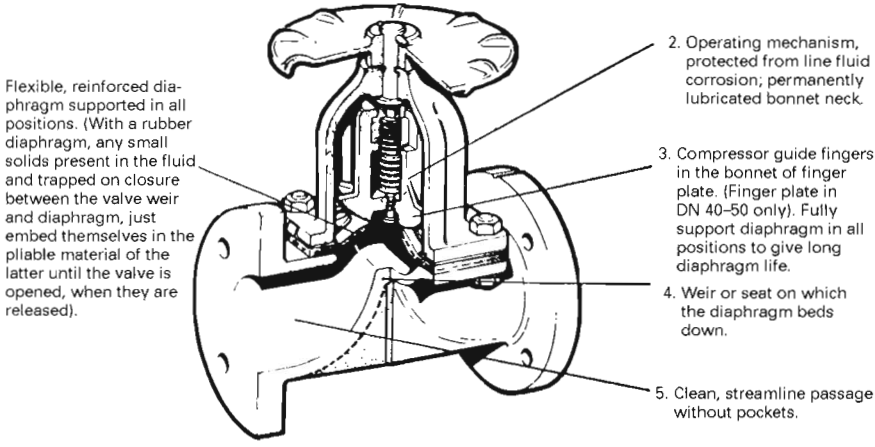


Figure 2. Straight-through diaphragm valve.



Standard diaphragm valve.

applications, the type of elastomer being chosen accordingly. The body itself can also be lined for corrosive duties.

Particular advantages of the diaphragm valve are the glandless construction and absence of seating problems. Its main limitation is that the maximum service temperature and pressure are limited by the temperature/pressure rating of the elastomeric material.

Typical body materials are cast iron, malleable iron, bronze, gun-metal and stainless steel. Lined diaphragm valves normally have cast-iron bodies lined with rubber, neoprene, polypropylene, PTFE or glass. Typical diaphragm materials and their main uses are summarised in Table 1. Reinforced diaphragm materials may be used for more arduous duties and are virtually standard for vacuum services.

Typical flow coefficients for weir-type and straight-through diaphragm valves are given in Tables 2A and 2B.

Table 1. Diaphragm materials

Material	Size		Temperature		Main uses
	mm	in	°C	°F	
Butyl rubber	15 to 350	0.6 to 14	−30 to 90	−22 to 134	Acids and alkalis
Nitrile rubber	15 to 350	0.6 to 14	−10 to 90	+14 to 134	Oils, fats and fuels
Neoprene	15 to 350	0.6 to 14	−20 to 90	−4 to 134	Oils, greases, air and radioactive fluids
Natural/ synthetic rubber	15 to 350	0.6 to 14	−40 to 90	−40 to 134	Abrasives, brewing and dilute mineral acids
White natural rubber	15 to 125	0.6 to 5	−35 to 90	−31 to 134	Foods and pharmaceuticals White diaphragm
White butyl	15 to 150	0.6 to 6	−30 to 100	−22 to 212	Natural colour, foodstuffs plasticisers and pharmaceuticals
Viton*	15 to 350	0.6 to 14	+5 to 140	+41 to 284	Hydrocarbon acids, sulphuric and chlorine applications
Hypalon*	15 to 350	0.6 to 14	0 to 90	+32 to 134	Acid- and ozone-resistant
Butyl rubber	15 to 350	0.6 to 14	−20 to 120	−4 to 248	Hot water and intermittent steam services, sugar refining

*Du Pont Dow Elastomers Registered Trademark.

Operation

Of the standard forms of manual operation available, the handwheel is preferred for most purposes. The design of handwheel and operating mechanism (spindle, compressor, bush or nut) varies according to the size and type of valve. Various-shaped handwheels are also available. This facility, for instance, greatly assists the operator in identification in dark conditions or where the handwheel becomes slippery.

Various bonnets are applicable to handwheel-operated valves. Extended spindle valves are readily available but existing valves can be simply converted by use of adaptor and extension. Other variants of bonnet assembly can be substituted for the handwheel-operated design.

Normal bonnet assembly material is cast iron but alternative materials are offered by most manufacturers, e.g.:

(i) All iron and steel construction (for handling acetylene, ammonia and other similar fluids).
(ii) All stainless steel (where there is severe atmospheric-corrosion conditions).
(iii) Gun-metal (for medical oxygen, turbine oils and certain water services).
(iv) Cast steel with rising spindle fitting (mainly used in oil refineries).

Table 2A. Typical flow coefficients for weir-type valves

Valve size	Cast iron		Rubber-lined		Halav/glass-lined	
DN	C_v	K_v	C_v	K_v	C_v	K_v
15	5.8	1.6	1.3	4.4	6	1.7
20	11.5	3.2	9.4	2.6	12	3.4
25	17.4	5	14.5	4	18	5.6
32	26.5	7.5	22	6	28	8
40	43	12.2	35	9.8	45.5	12.8
50	84	21.4	70	17	88	22.5
65	126	30.5	102	24.4	132	32
80	180	44.4	147	35.5	185	46.6
100	320	77.7	264	62	336	81.6
125	420	108	348	86.4	444	113
150	600	147	504	117.6	630	154
200	1260	305	996	244	1320	320
225	1630	388	1320	310	1680	407
250	1990	500	1620	400	2076	525
300	2580	625	2088	500	2700	656
350	3840	833	3060	666	4020	875.7

Table 2B. Flow coefficients for typical straight-through valves

Valve size	Cast iron		Rubber-lined		Halav/glass-lined	
DN	C_v	K_v	C_v	K_v	C_v	K_v
15	8.6	1.8	—	—	9	1.9
20	—	—	—	—	—	—
25	37.8	7.9	30.6	6.5	39	8.2
32	55.8	12.5	45.6	10.1	58.2	12.9
40	75	20	66	18	79	21
50	128	34	107	28	138	36
65	238	68	195	55	254	72
80	330	90	264	73	342	92
100	588	150	480	123	618	158
125	924	235	720	184	960	274
150	1680	385	1260	293	1800	545
200	2580	789	2196	665	2724	825
250	4020	1050	3420	900	4296	1100
300	6060	1510	4884	1221	6204	1550
350	10.300	2800	9950	2360	—	—

(v) Silicon aluminium (for lightness and low temperature).
(vi) A variety of plastic materials (for general corrosion resistance).
(vii) Epoxy-coated cast iron (for corrosion resistance, attractive appearance).

For quick closure and/or opening, lever-action valves can be used. A quarter-turn movement is preferred when the liner can also act as a valve

position indicator, e.g. parallel with the pipeline in the fully open position and at right angles to the pipeline in the fully closed position.

Diaphragm valves are particularly suited for rapid closure/opening because the cushioning action of the flexible diaphragm minimizes the shock throughout the pipeline, compared with equally rapid but less resilient types of valve movement.

Double-diaphragm valves

A double-diaphragm valve is a basically simple design consisting of two flexing diaphragms on an axial stem. There is no metal-to-metal contact, O-rings or sliding seals, making lubrication unnecessary, as shown in Figure 3. The valve requires no special filtration and is tolerant to dirt-laden media as well as scrubbed instrument air.

Designed for compressed air and inert gases, the self-purging non-lubricated design is also suitable for vacuum applications. A cartridge-insert version is manufactured for direct integration into finished products. Typical areas of application include food processing and medical equipment. In fact, a double-diaphragm air valve has performed over two billion cumulative cycles, an equivalent of 50 years of human life, in various heart systems. The valves are located in the mechanical control system, which is attached to the patient by plastic tubes, and control the flow of compressed air through the tubes to the artificial heart, causing it to pump.

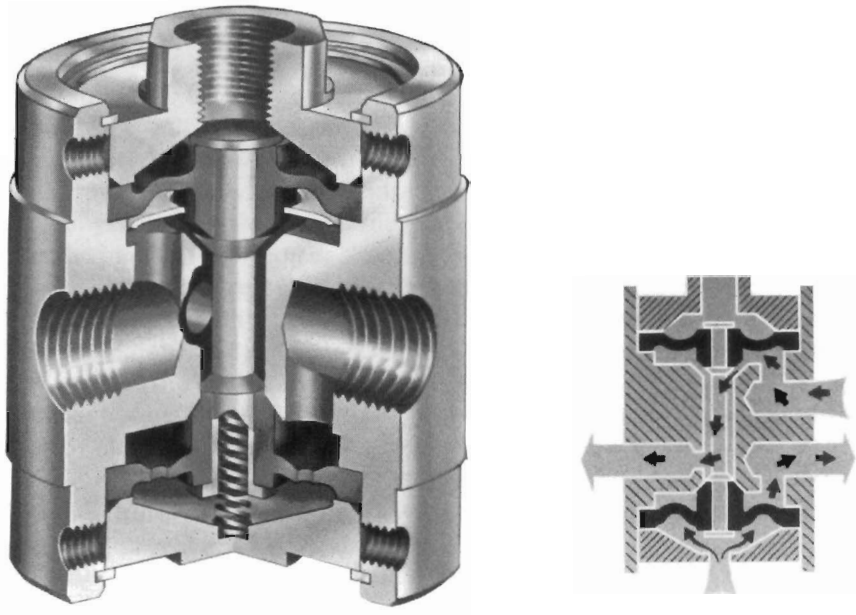


Figure 3. Double-diaphragm air valve.

Plastic diaphragm valves (Figure 3) are becoming increasingly popular. Manufactured from PVC-U, PVC-C, ABS, PP and PVDF plastics, the main advantages are lightweight and compact construction, corrosion resistance and a long maintenance-free working life.

Typical pressure–temperature charts are shown in Figures 4 and 5. Miniature air-operated diaphragm valves are designed for pressure applications for

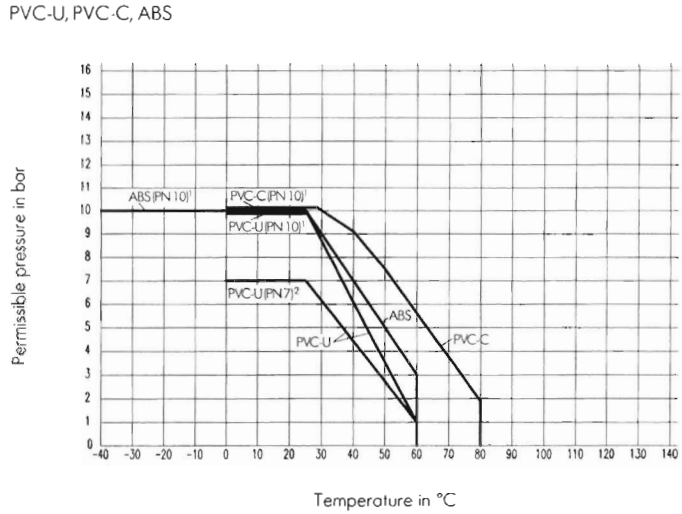


Figure 4. and 5. Typical pressure–temperature diagrams for diaphragm valves.

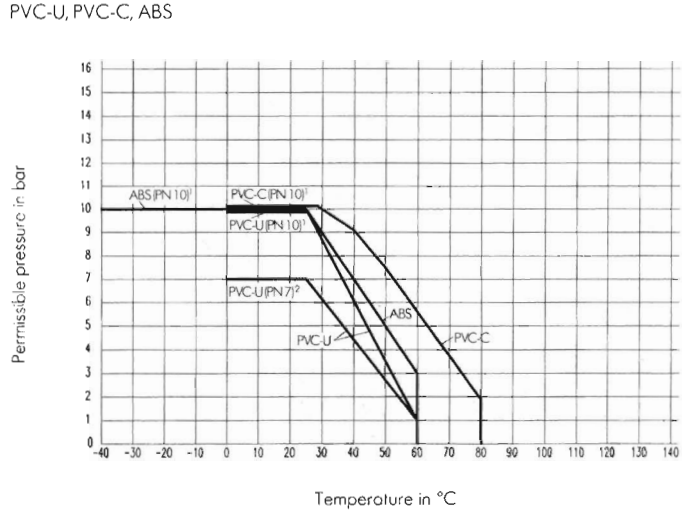


Figure 4. and 5. Typical pressure–temperature diagrams for diaphragm valves.

Figure 6. Iris-type diaphragm valve.

highly corrosive or ultra-pure liquids, when space is critical. This type of valve has numerous applications in the electronics/semiconductor industry for use with concentrated etchants and ultra-pure water.

Generally, the valves open with air pressure and close with a return spring.

Diaphragm valves play a significant role in air-pulse jet-dust control equipment and valve performance has a great influence on the cleaning efficiency of the generated air pulse.

Air-pulse diaphragm valves need to open and close very rapidly at high flows. Fluttering of the diaphragm during opening and closing increases air consumption and will affect valve performance. The opening time of the pulse valve must be as short as possible, i.e. between 8 and 14 ms to achieve best performance. Long closing times increase air consumption.

Iris-type diaphragm valves

The diaphragm valve shown in Figure 6 is designed specifically to control the flow of dry bulk solids and is used for food, chemical pharmaceutical and general processes. Essentially the valve consists of a tube of flexible material, fixed rigidly at each end. This tube is held in a mechanism which rotates one end through 180° relative to the other. When twisted in this way, the tube closes completely, creating a diaphragm visually resembling the iris of a camera.

Iris-type diaphragm valves have a variable area concentric orifice so that the flow can be accurately controlled. They can open or close irrespective of size to the smallest of orifice sizes, regulating the flow of even the finest of powders. Power-operated models can open or close to pre-set "dribble-feed" positions.

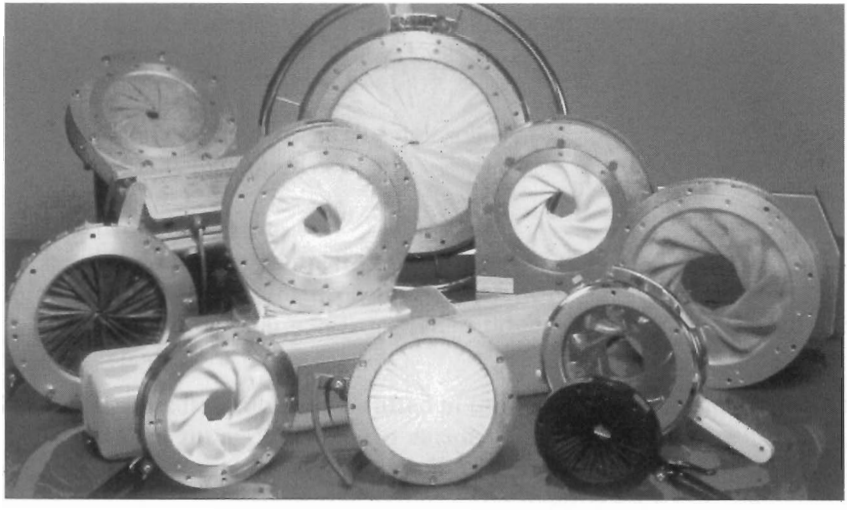


Figure 7. Iris-type diaphragm valve membranes.

Central to the performance of the iris-type diaphragm valve is the correct selection of diaphragms.

The diaphragms are usually made from either (i) elastomers—natural and synthetic, (ii) fabrics and (iii) coated fabrics (Figure 7).

Typical applications include discharge valve to cake-mix mixer, discharge valve for rail tankers carrying bulk sugar, packing herbs and spices, controlling the flow of finished tablets and capsules, general purpose flow-control valves for silos and hoppers, filling fertilizers into 1 tonne bags, gland around telephone cable to remove excess grease, valve on salt silo for motorway gritting, weighing out of abrasive ingredients, and controlling the flow of pigments.

Slide Valves

Slide valves are one of the many variations of the gate-type valve and were originally designed for use in the pulp and paper industry to overcome the problems in handling wet and dry fluidized solids in pipelines.

The slide valve, or knife or plate valve as it is sometimes called, in its original form was a simple rattle-fit plate in a fabricated body. Opening or closing was achieved by pushing or pulling the plate to give a crude shut-off. Although design improvements have been made, this simple form of valve is still commonly used as a diverter or hopper outlet valve on dry powders or solids where a pressure seal is not required. In such applications the body of the valve will probably be of square or rectangular bore to suit the hopper outlet or duct on which it is fitted.

The logical advancement from this design was the fitting of resilient seals and an operating screw and handwheel to open and close the slide. With the improvement in sealing that this gives, the slide valve is suitable for a much wider range of services and can handle solids suspended in liquids or gases. Although they are simple valves, there are a variety of designs on the market all sharing, to a greater or lesser degree, the following advantages:

(a) short overall length
(b) no wedging action
(c) thin closing member to cut through solids in the line
(d) substantially full-round bore
(e) lightweight
(f) easy to power-operate
(g) stem/slide connection not in contact with line fluid
(h) slide exposed for visual inspection when valve is open
(i) good regulating characteristics when fitted with specially-shaped slide and/or body bore

The resilient seals, which can be fitted in the body or on the slide depending on individual design, are available in various materials to suit the fluid being handled. For most applications they will be in rubber, e.g. Nitrile or Viton*.

*Dupont Dow Elastomers registered Trade Mark.

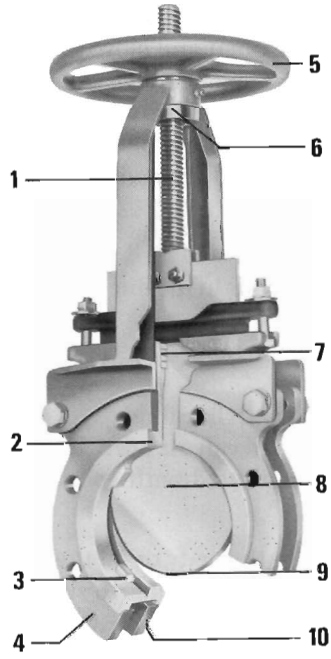
but for higher temperatures or in the food and chemical industries it may be necessary to specify PTFE or other special elastomers.

There are many individual designs of slide valve on the market. In some ways, this is advantageous as it gives the valve user more scope for finding a valve specifically designed to overcome a unique problem. Generally speaking, slide valves are used on services such as:

(i) viscous media
(ii) dry powder
(iii) dry solids of small and large particle size
(iv) slurries and sludges

These applications are commonly found in the waterworks, sewage, mining, chemical, power generation, food, cement, brewing and other process industries as well as the pulp and paper industry for which the valve was originally designed. But this does not necessarily mean that slide valves are only used on difficult applications. They are equally successful when put on less arduous duties where the benefits of leak-tightness, space-saving, price, etc., need to be considered.

Figure 1 shows a typical design of slide valve. It will be noted that the bore is clear of obstructions and that there are no pockets in which solids can collect,



1. Stainless steel stem.
2. Cast body.
3. Gate guides and jams.
4. Raised face flanges.
5. Handwheel.
6. Yoke.
7. Packing.
8. Full round port.
9. Stainless steel gate.
10. Welded on steel flanges.

Figure 1. Knife-edge slide valve.

in addition to which the seal is housed in the body of the valve and shrouded by the body to avoid damage from solids in the line. In this design the seal seats on the edges of the slide, which means that the valve will seal equally well with flow in either direction and the slide has a chamfered leading edge which enables it to slice through any obstruction and seat effectively against the body seal (Figure 2). These features ensure bubble-tight shut-off against pressure or vacuum.

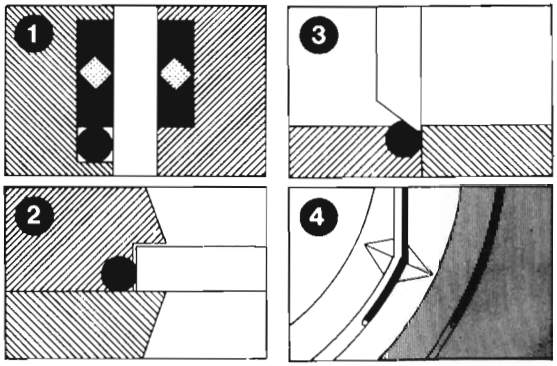


Figure 2. Features of the slide valve shown in Figure 1. 1. Built-in horizontal seal; 2. internal seal located in valve body; 3. valve slide with chamfered end; 4. internal contours designed to ensure that deposits are flushed into the flow.

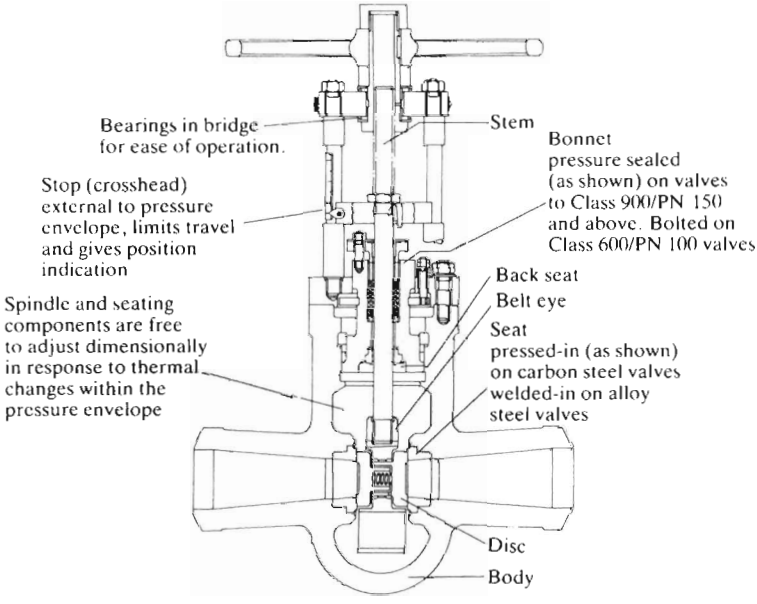
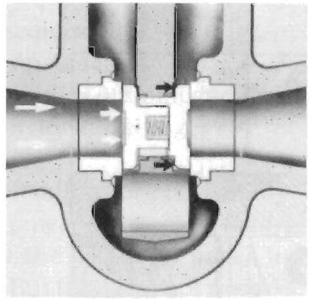
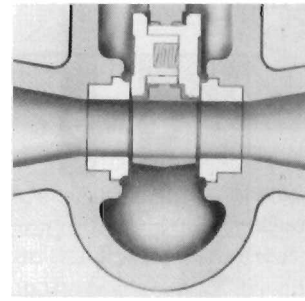


Figure 3. Venturi parallel-slide valve.

Unlike conventional gate valves, the slide passes through the body and a standard gland packing cannot therefore be used. In the design shown here, profiled transverse seals are employed. These comprise two lengths of V-section rubber with the open sides of the V facing each other. During assembly, the diamond-shaped opening is filled with an oiled-fibre packing which is forced



Valve closed
Fluid pressure (indicated by arrows) holds disc on outlet side in contact with seat.



Valve open
Gives unobstructed flow. 'Eye-piece' bridges gap to complete venturi form passage and protect seat faces.

Figure 4. Parallel-slide action.

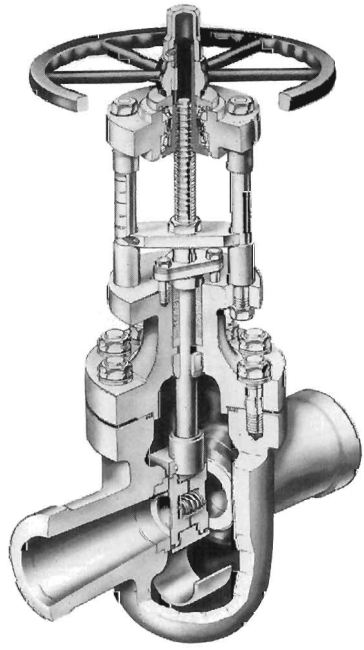


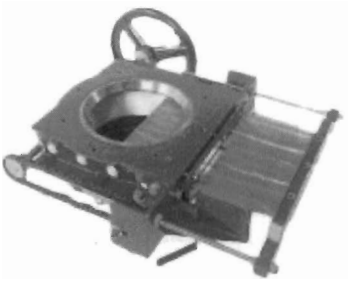
Figure 5. Parallel-slide valve.

in and pushes the lips of the transverse seals into contact with the body and the slide. In this way, leakage to atmosphere is prevented. Also, by removing the screws on the sides of the body, more packing can be inserted at a later date to maintain a tight seal even if the valve is on-stream and under pressure or vacuum. An optional extra on this design of valve is a set of scraper blades set below the transverse seals. During the opening phase, this enables the slide faces to be scraped clean over their whole width before they are drawn through the transverse seals, and damage to the seals is thereby prevented. This is particularly important when handling sugar, sticky media such as honey, chocolate compound, glues, tenacious powders, etc.

A venturi parallel-slide valve is shown in sectioned form in Figure 3. This valve incorporates a pressure-sealed bonnet design and is used as a general purpose stop valve for main steam and feedwater isolation on power station boiler plant. The parallel-slide action is shown in Figure 4.

A cutaway view of the internal cross-section of the valve is shown in Figure 5.

When power operation is required, slide valves are particularly easy to operate pneumatically as the pneumatic cylinder can be mounted directly on



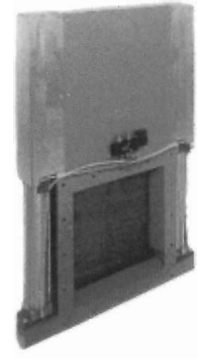


Figure 6. Slide valves used in (top left) brewing, (top right) food processing and (bottom) dust control.

the valve pillars and the end of the piston rod connected direct to the valve slide. Electric actuation is also widely used on slide valves and, to a lesser extent, hydraulic actuation. In addition, a very useful alternative to handwheel operation is the lever-operated slide valve which gives a very quick open/close operation.

When powders and granular materials are stored in silos or conveyed by belt and screw conveyors, actuated rectangular valves are often required, as shown in Figure 6. This is particularly true for pulverised fuels, ash and grain, as well as brewing, food processing and dust control.

See also the chapter on Gate Valves.

Screw-down Valves

The general classification "screw-down valve" is taken to refer to all types of valves sealing by a disc or plug, etc., and in which the sealing element is lifted from and lowered on to the valve seat by rotation of a threaded stem, the axis of which is perpendicular to the valve seat. Mainly this embraces various types of stop valves, e.g. globe valves, oblique or Y-valves, gate valves, lift-type plug valves and angle valves. Much of this has been covered in other chapters. It also includes certain types of throttling valves, i.e. needle valves in particular.

Screw-down valves are also categorised as:

(i) Inside screw, where the threaded portion of the stem is fully enclosed within the bonnet.

(ii) Outside screw, where the threaded portion of the stem is exterior to the bonnet and (usually) carried in a yoke (see Figure 1).

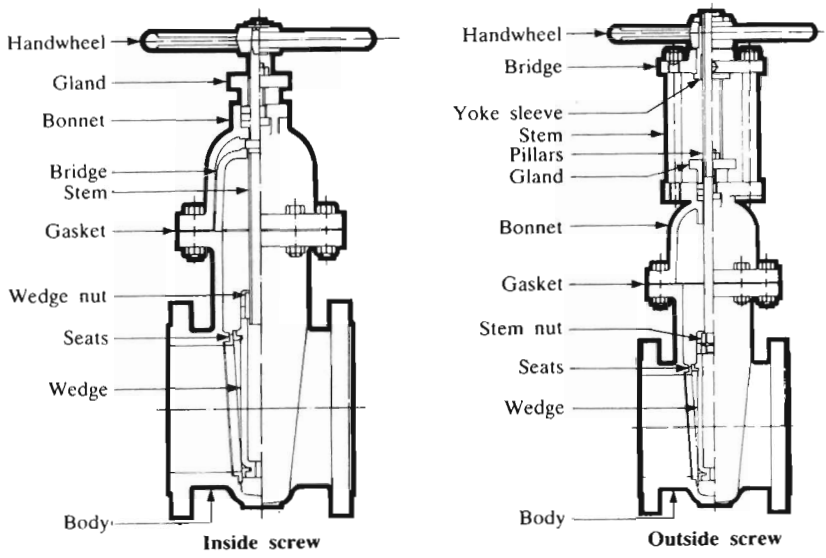


Figure 1. Outside- and inside-screw gate valves.

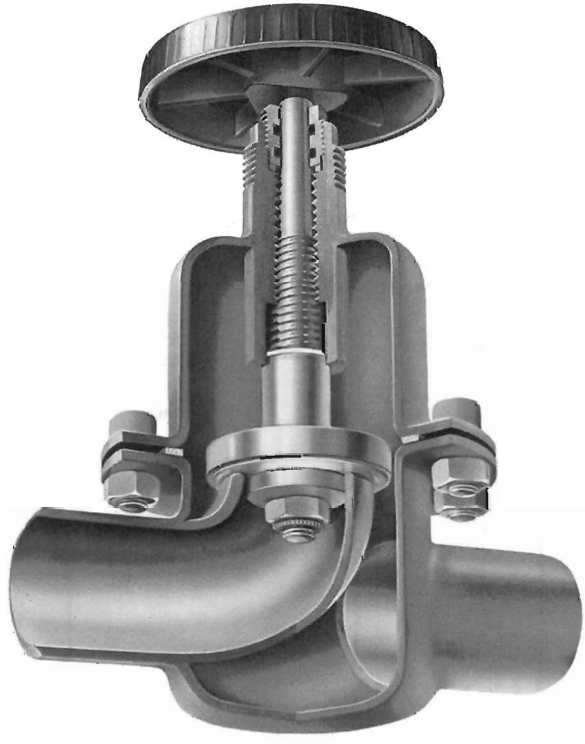
A further distinction is made between:

(a) Rising-stem valves, where the stem moves in or out of the bonnet as the stem is rotated by a handwheel, lever or actuator.
(b) Non-rising stem valves, where there is no displacement of the stem along its axis when rotated.

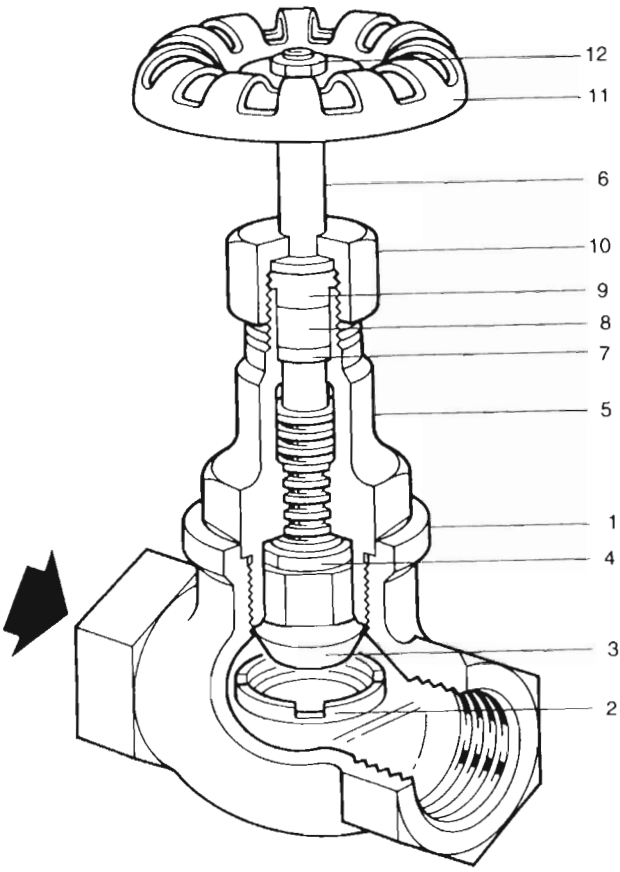
Both inside-screw and outside-screw valves can be of rising-stem or non-rising-stem type.

Principal differences between these categories are:

(i) Inside-screw valves have the threaded length of the stem protected from dirt, etc. However, the stem is fully exposed to the fluid being handled. Also it is more difficult to provide lubrication for the thread where the fluid handled is not itself a lubricant.
(ii) Outside-screw valves have the threaded length fully exposed to the surroundings, hence they can readily collect dirt and/or be subject to corrosion. Lubrication is easier because the threaded length is fully

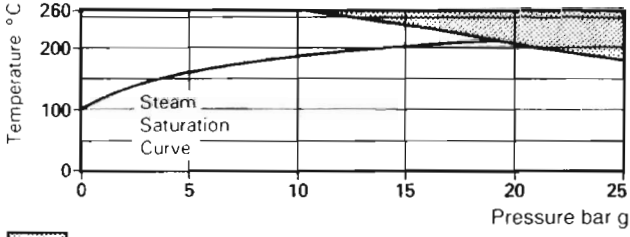


Inside screw-down valve.



No	Part	
1	Body	
2	Valve Seat	
3	Valve	
4	Locknut	
5	Bonnet	
6	Stem	½" - 1"
		1¼" - 2"
7	Washer	
8	Gland Packing	
9	Gland	
10	Packing Nut	
11	Handwheel	
12	Handwheel Nut	

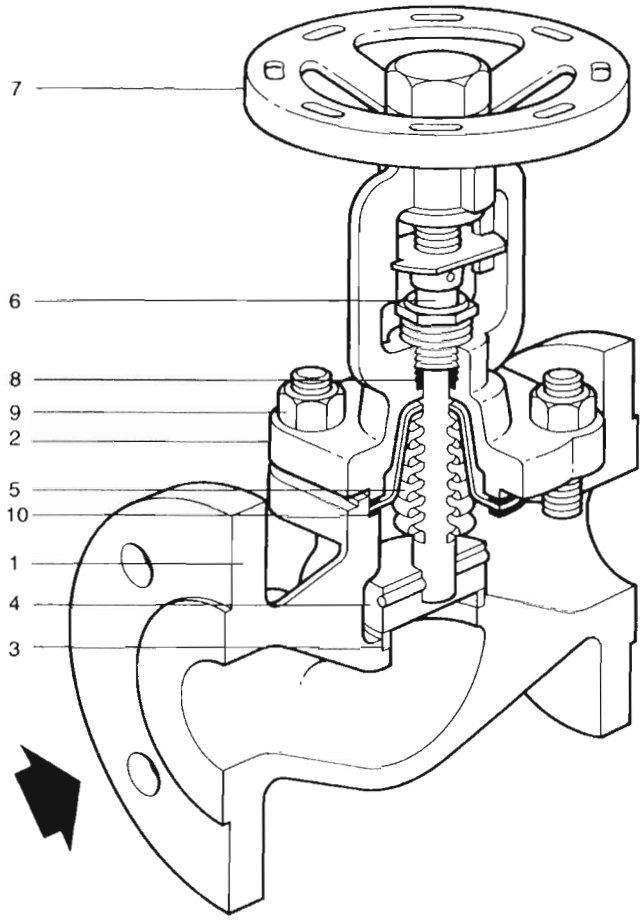
Operating range



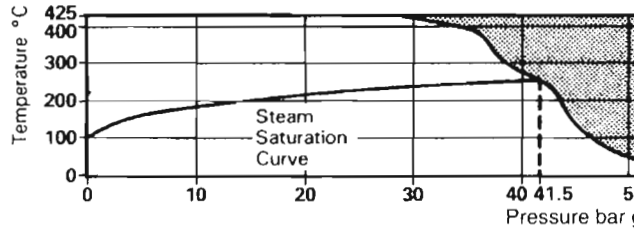
The product must not be used in this region.

Typical industry standard stop valve.

No	Part
1	Body
2	Bonnet
3	Seat
4	Disc/Plug
5	Bellows
6	Stem
7	Handwheel
8	Stem Packing
9	Bonnet Studs Bonnet Nuts
10	Body/ Bonnet Gasket



Operating range (ANSI 300)



This product must not be used in this region.

ANSI bellows-sealed stop valve.

Outside-screw rising-stem stop valve.

accessible, but again lubricant will promote collection of dirt on the threads. The threaded length of the stem is isolated from the fluid being handled by the stem glands, hence this type is more suitable for handling corrosive media, slurries, etc.

(a) Rising-stem valves provide a visual indication of the position of the valve disc or gate and thus the degree of valve opening. On the other hand, adequate clearance is needed above the valve to accommodate the rising-stem movement.

(b) Non-rising-stem valves have the advantage that they can be installed in positions where headroom is limited. Stem wear is also minimised, although there may be increased wear on the threaded length which lifts and lowers the valve disc or gate.

For corrosive duties, stem protection may be provided by a bellows seal applied either to an inside screw (usually) or an outside screw.

Spool Valves

Spool valves embody two basic elements: a cylindrical barrel in which slides a plunger or spool. Port blocking is provided by glands or full diameter sections on the spool, with intervening waist sections which provide port interconnection through the barrel. This makes it easy to provide multi-way and multi-position switching.

Sliding-spool valves are generally used in hydraulic and pneumatic fluid power systems for directional and flow-control purposes. There must be an annular clearance between the spool and the body, so there is always some leakage flow across the spool and this must be taken into consideration.

Spool valves are relatively simple and economic to manufacture, although for adequate sealing a fine surface finish is required on both the spool and the barrel bore, with close tolerances to ensure practical minimum clearances. Glandless spool valves thus normally require a lapped fit between spool and body.

Pneumatic-spool valves with static seals offer simpler construction in this respect and also rather more flexibility in design with seals positioned between valve spaces so that a seal is situated between each subsequent port and one seal on the outside of each of the two outer ports (see Figure 1).

Spool valves operate on a sliding principle, so design normally follows the basic requirement of all slide valves, i.e.:

(i) Pressure-balanced ports are required so that there is no net pressure force acting axially on the spool.
(ii) The valve diameter should be a minimum consistent with suitable stiffness.

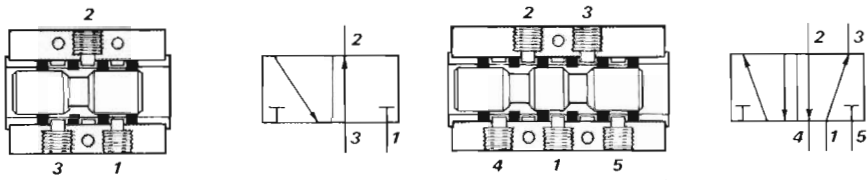


Figure 1. 3-way and 4-way spool valves.

(iii) The valve body or sleeve must have adequate rigidity.
(iv) Friction forces must be minimised and are largely controlled by material selection for rubbing/sliding parts.
(v) Annular flow should be symmetrical in order to avoid radial unbalanced forces which could increase friction.
(vi) Bernoulli forces, arising from changes in fluid momentum, must be minimised.

Parameters (v) and (vi) are largely controlled by the detail design of the spool.

Spool-cushioning passages can be built into the valve as shown in Figure 2. These equalise hydraulic forces on the ends of the spool and cushion the spool shift. When the spool is shifted, the fluid displaced from one end of the spool is transferred to the other end through the passage which is designed to provide a cushioning effect and balance the spool.

Forces may also be set up due to the changes in fluid momentum through the valve, generally described as Bernoulli forces. Thus, typically, there may be a reduction in pressure on the valve spool at the controlling edge, leading to a force being generated producing unbalance or tending to close the valve. At the same time, if backlash is also present in the system, Bernoulli forces may produce high frequency 'chatter' of the valve spool.

The hydraulic unbalancing effects of fluid momentum between the cylinder and tank ports of a vale can be minimised by contouring the spool shape as shown in Figure 3. Flow forces that are developed at the conventional square land orifice (P to B) are partially compensated for by the force-balancing contour on the outer spool lands (A to T).

Accurate sequencing of land opening and closing also provides maximum axial stability, as shown in Figure 4. In this example, it is important that flow path A to T is opened before the path P to B to prevent pressure intensification which could upset axial balance and limit valve function.

The spool can be moved manually, mechanically, by pilot pressure or by an electric solenoid. Directional-control valves usually have finite spool positioning to change the direction of flow from one port to another.

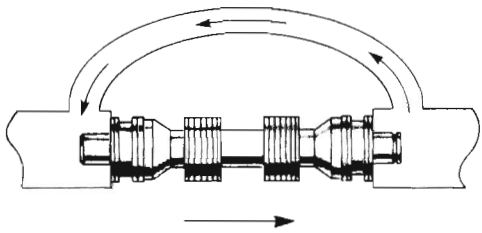


Figure 2.

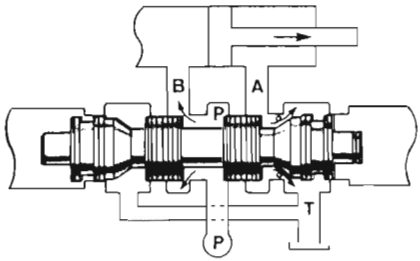


Figure 3.

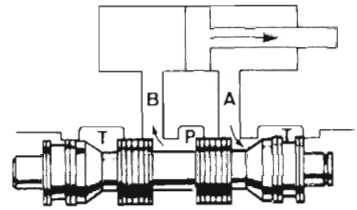


Figure 4.

Proportional-control valves and servo-valves have infinitely controllable spool positioning so that the flow rate of the fluid as well as the direction of flow is controlled.

Servo-valves

A servo-valve is capable of providing continuously variable flow with changing input signal. The latter is normally an electric signal to a torque motor, but feedback signals may also be derived hydraulically or mechanically.

The simplest form of spool valve to control both the direction of flow and flow rate is the three-way valve, but this will control the flow to only one side of the load and a differential-area spool must be used. A more common design, shown in Figure 5, is the four-way valve whose symmetry results in improved linearity. However, there are three critical axial dimensions of the spool and the sleeve. To reduce some of the manufacturing difficulties, designers have used the following different designs.

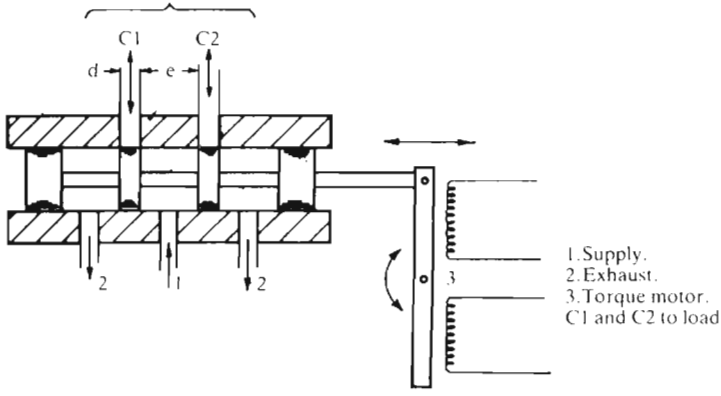


Figure 5. Spool-type valve.

Split-spool valves

To reduce the number of critical axial dimensions of the four-way valve, two separate three-way valves may be linked together, as shown in Figure 6, and a means of zero adjustment can be provided in the links. Although manufacturing problems associated with porting are reduced, further difficulties are introduced in that two parallel bores have to be made, and there may be additional backlash in the linkage. Furthermore, its weight is usually more than that of the simple four-way valve.

A design in which manufacturing difficulties associated with axial tolerances are eliminated is the Elliott adjustable lap valve. This is a split, three-way valve in which the two spools are mounted back-to-back and are actuated by a central ram against restraint. The correct valve lap is obtained after assembly by axial adjustment of the sleeves.

Sliding-plate valves

This design, shown in Figure 7, may be likened to an unwrapped spool (that is, two-dimensional), or even to the original D-type steam valve. It overcomes the difficulties associated with the manufacture of the bores in spool valves, and hole-and-plug porting techniques may be used. However, some manufacturers consider, the difficulties associated with the production of flat and parallel plates greater than those of making spools and sleeves. Various methods are used to reduce friction forces; in some valves the sliding member is suspended on spring plates to prevent metallic contact, and others achieve hydrostatic pressure balance.

Rotary-plate valves

An alternative form of the plate valve is the rotary type shown in Figure 8. Reaction-force compensation may be fairly easily introduced by the use of deflector vanes which have the added advantage of being adjustable.

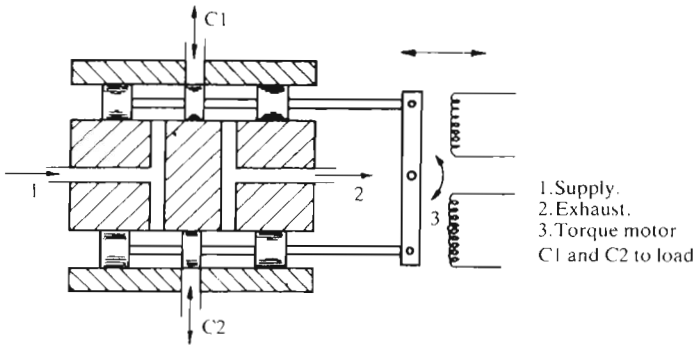


Figure 6. Split-spool valve.

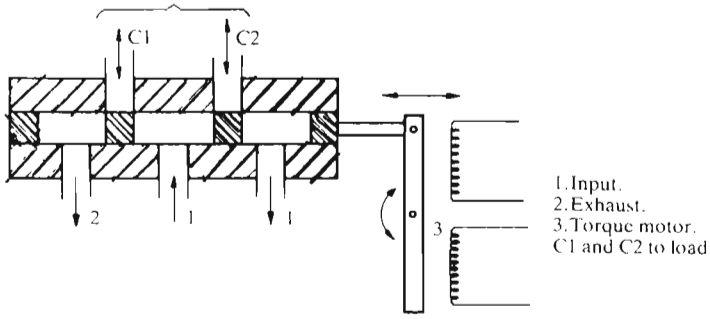


Figure 7. Sliding-plate valve.

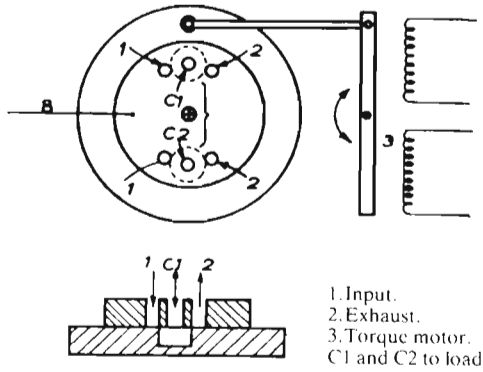


Figure 8. Rotary-plate valve.

Askania-type valves

The main advantages claimed for this type of valve, shown in Figure 9, are that it is less susceptible to contamination clogging, and the ease of manufacture. Although it has been fairly extensively used for control purposes in low-pressure applications, its design for medium- and high-pressure systems presents a far more difficult problem because it is based on empirical methods. A comment has been made that large reaction forces leading to serious instability can occur, although the reasons for this are not known. This valve, whose action depends upon the conversion of kinetic energy of the jet into static pressure at the spool or ram, is referred to in the United States as the 'jet-pipe' design. However, it is probably preferable to avoid this term to prevent confusion with other nozzle or jet designs used in two-stage valves.

Two-stage valves

Two-stage valves were designed to overcome the practical limitations of power and response of single-stage valves. Any of the previously mentioned

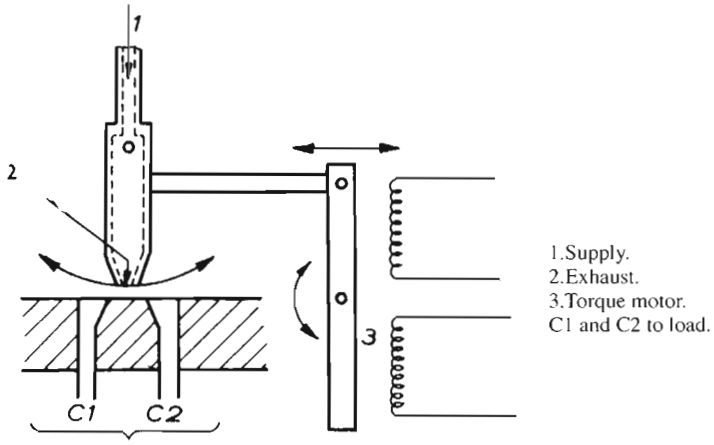


Figure 9. Askania-type spool valve.

single-stage valves may be used as the first stage of a two-stage valve with a spool or a plate as the second stage, of which the following are examples.

Double-spool valves

In this valve, shown in Figure 10, the output from the first stage is used to control the motion of the second stage spool and hence produces delivery to the load. Feedback from the output stage is necessary to avoid the integrating effect of the two spools and is usually accomplished either electrically or mechanically.

Nozzle–flapper spool valves

The basic configuration of the single nozzle–flapper valve is shown in Figure 11, where it can be seen that a movement of the flapper towards the nozzle

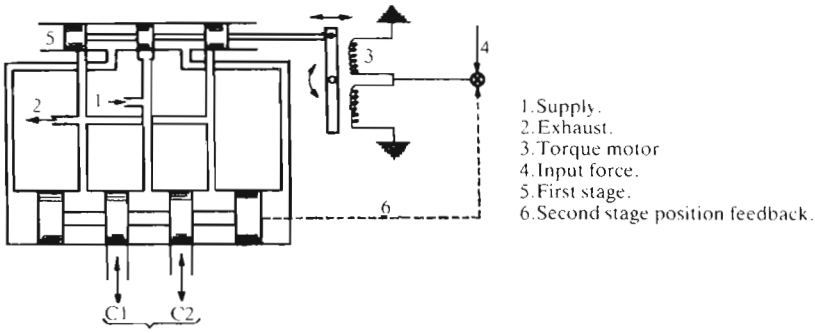


Figure 10. Two-stage valve: double spool.

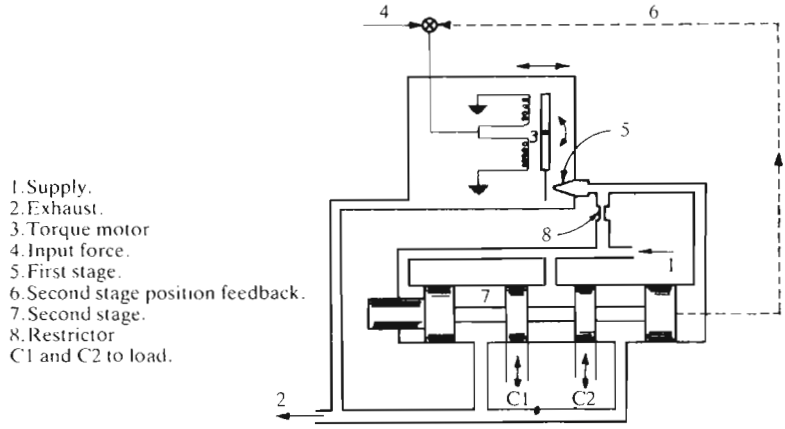


Figure 11. Two-stage valve: nozzle–flapper spool.

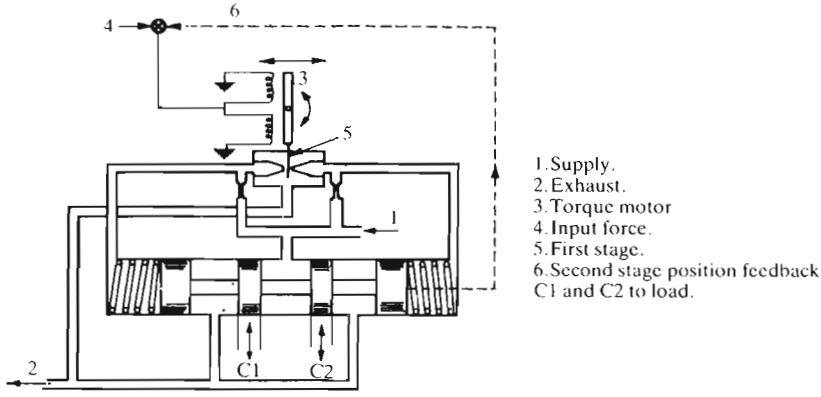


Figure 12. Two-stage valve: double nozzle–flapper spool.

causes an increase in the pressure in the chamber between the nozzle and the restrictor which causes the second stage spool to move and thus deliver oil to the load. Movement of the flapper in the other direction will reduce the chamber pressure, causing the spool to move in the opposite direction and produce reverse motion of the load. Thus the nozzle and flapper act as a variable impedence, and a variable percentage of the supply pressure acts on the right-hand end of the second stage spool.

Double nozzle–flapper spool valves

Representing a further development of the design previously described, this valve is shown in Figure 12. The flapper and nozzle control the pressure at

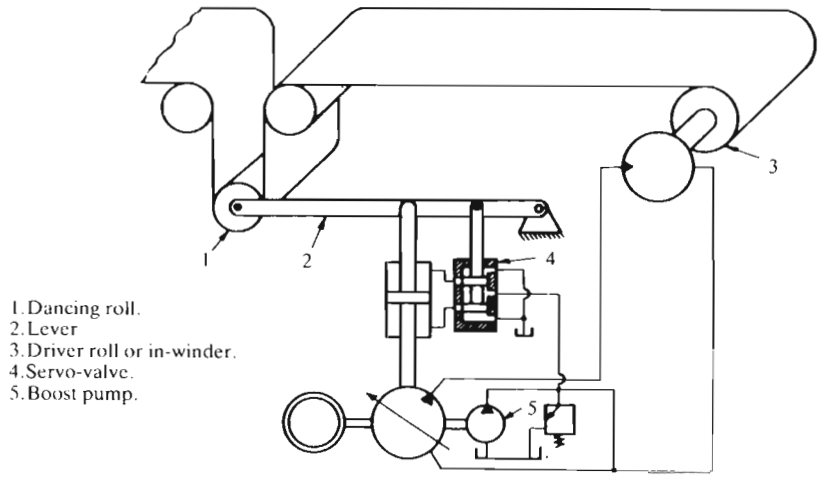


Figure 13. Controlling web tension with hydraulic servo-operated variable delivery pump and hydraulic motor drive.

both ends of the second stage spool and thus the operation of the first stage may be likened to that of the four-way valve. Although a fairly high quiescent flow is inevitable with this design, the power loss is not significant for most applications.

The introduction of the nozzle–flapper device as the first stage, with its low inertia and short stroke, was a major contribution in the field of two-stage valve design. The design shown in Figure 13 is basically one of the earliest of a family of valves having nozzle–flapper as the first stage.

For more detailed information on spool valves, refer to the Pneumatic Handbook also published by Elsevier Science Limited.

Solenoid Valves

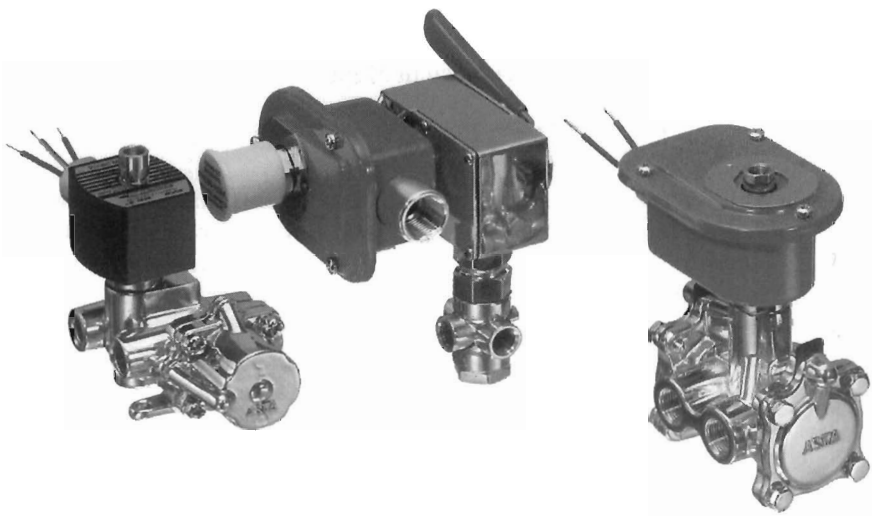
A solenoid valve is basically a valve operated by a built-in actuator in the form of an electrical coil (or solenoid) and a plunger. The valve is thus opened or closed by an electrical signal, being returned to its original position (usually by a spring) when the signal is removed. Solenoid valves are produced in two modes—normally-open or normally-closed (referring to the state when the solenoid is not energised).

The solenoid itself may be operated by d.c. or a.c. A d.c. supply may be provided by a battery, d.c. generator or through a rectifier. An a.c. supply is normally taken from a.c. mains voltage, through a transformer if necessary.

Valve types and classifications

Basically there are nine different valve types to be distinguished, as shown in Figure 1.

Solenoid valves are also classified by type as follows:



Solenoid valves.

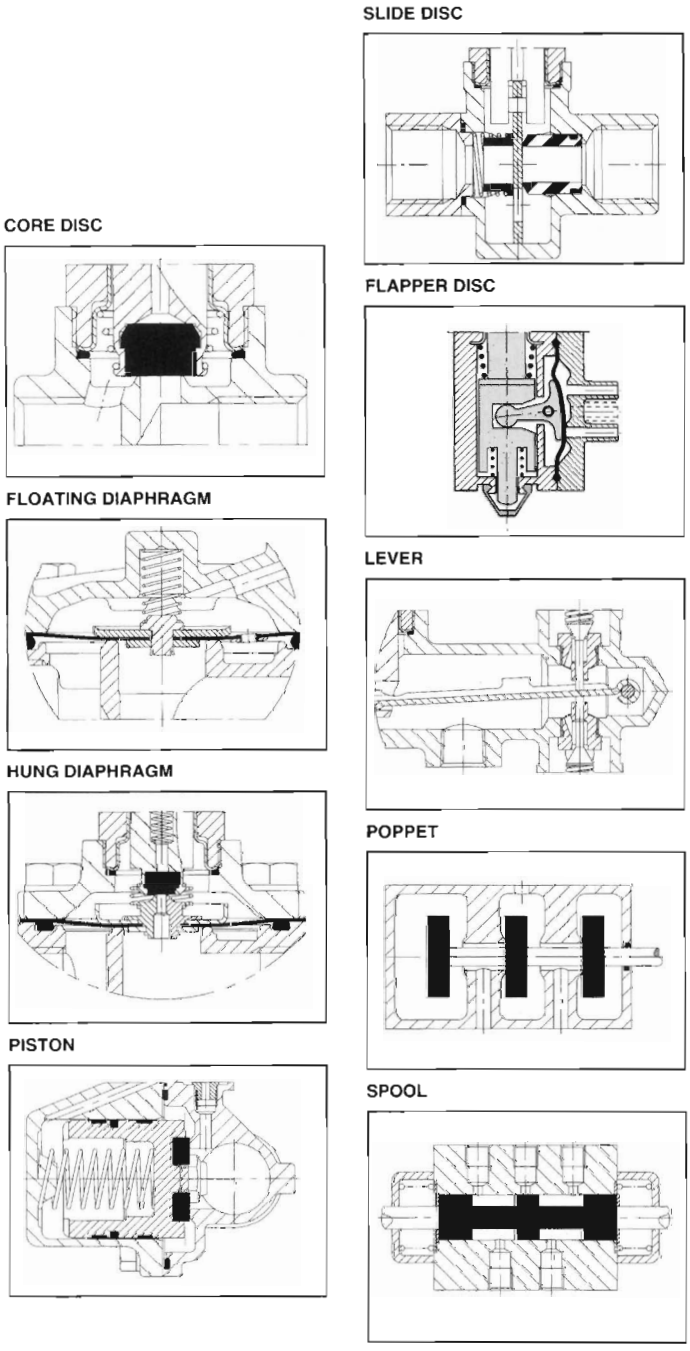


Figure 1. Solenoid valve types.

2/2 (2-way valves)

Two-way valves have one inlet and one outlet pipe connection (see Figure 2). They are of either

- normally-closed construction—valve is closed when de-energised and open when energised, or
- normally-open construction—valve is closed when energised and open when de-energised.

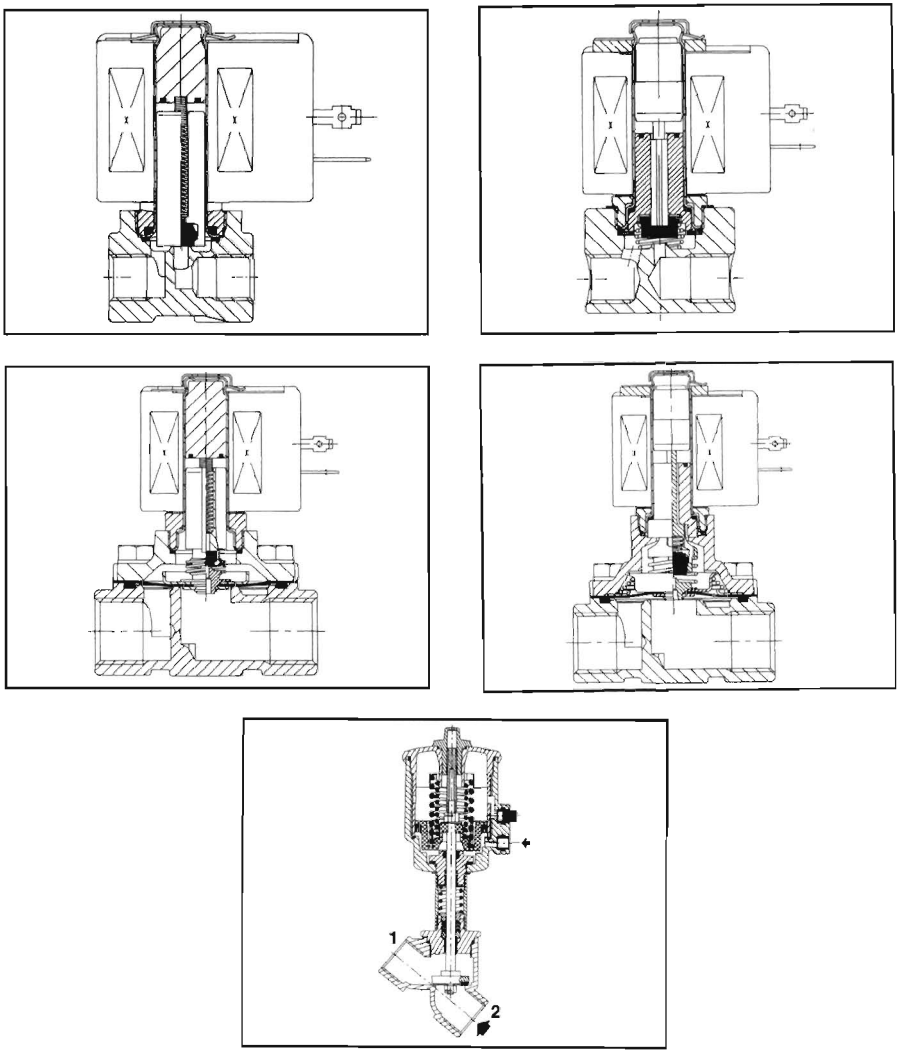


Figure 2. 2/2 (2-way valves).

3/2 (3-way valves)

Three-way solenoid vales have three pipe connections and two orifices (when one is open the other is closed and vice versa). They are commonly used alternately to apply pressure to and exhaust pressure from a diaphragm valve or single acting cylinder (see Figure 3). Three modes of operation are available.

- Normally-closed construction—with the valve de-energised, the pressure port is closed and the exhaust port is connected to the cylinder port. With the valve energised, the pressure port is connected to the cylinder port and the exhaust port is closed.
- Normally-open construction—when the valve is de-energised the pressure port is connected to the cylinder port and the exhaust port is closed. When the valve is energised, the pressure port is closed and the cylinder port is connected to the exhaust port.
- Universal construction—this allows the valve to be connected in either the normally-closed or normally-open position. In addition, the valve may be connected to select one or two ports (selection) or to divert flow from one port to another (diversion).

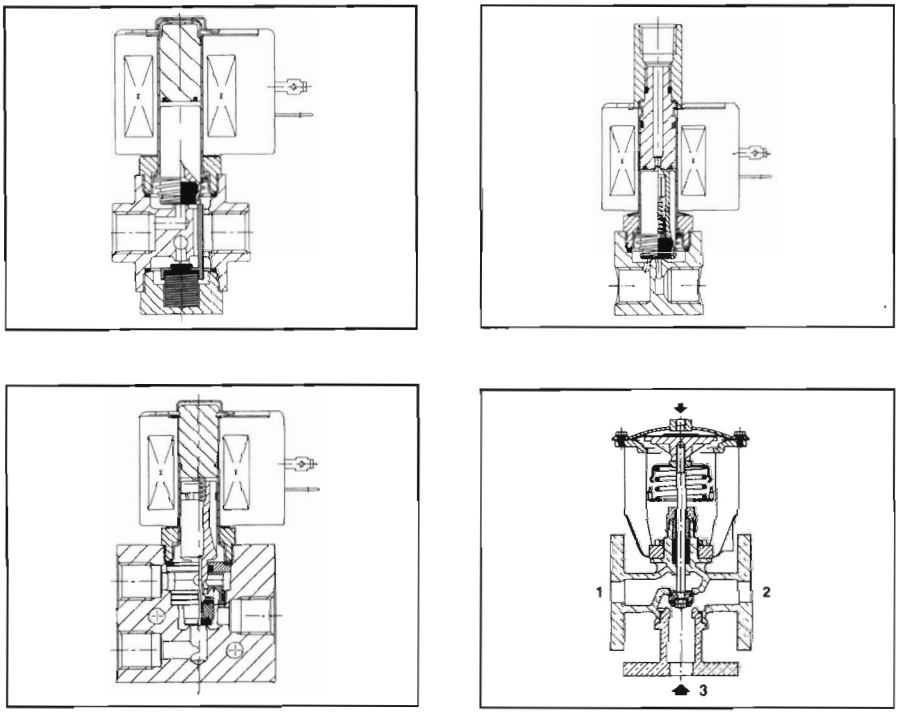


Figure 3. 3/2 (3-way valves).

4/2 and 5/2 (4-way valves)

Four-way solenoid valves are generally used to operate double-acting cylinders. These have four or five pipe connections—one pressure, two cylinder and one or two exhausts (Figure 4). In one valve position, pressure is connected to one cylinder port; the other is connected to the exhaust. In the other valve position, pressure and exhaust are reversed at the cylinder connections. Single-solenoid and dual-solenoid types are commonplace.

Manual reset valves

Manual reset valves must be manually latched into position and will return to their original position only when the solenoid has been energised or de-energised depending on construction (Figure 5). Four modes of operation are possible:

- electrically tripped—latched open
- electrically tripped—latched closed
- no voltage release—normally-closed
- no voltage release—normally-open

Valve classifications

- General purpose valve—a normally-open or normally-closed valve intended to control the flow of a fluid but not depended upon to act as a safety valve.
- Safety shut-off valve—a normally-closed valve of the 'on' or 'off' type, intended to be actuated by a safety control or emergency device to prevent unsafe fluid delivery. It may also be used as a general purpose valve. A multiple-port valve may be designated as a safety shut-off valve only with respect to its normally-closed port.

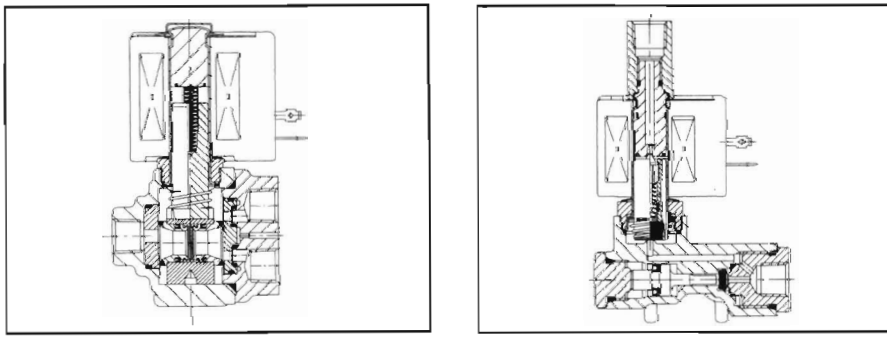


Figure 4. 4/2 and 5/2 (4-way valves).

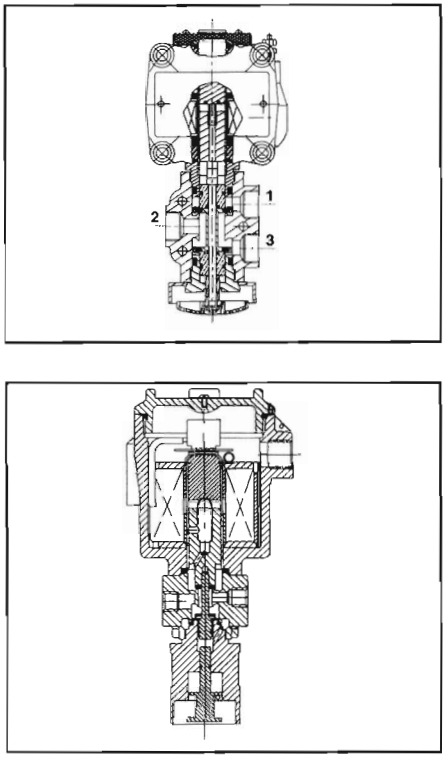


Figure 5. Manual-reset valves.

- Process-control valve—an approved valve (FM) to control flammable gases, but not to be relied upon as a safety shut-off valve.

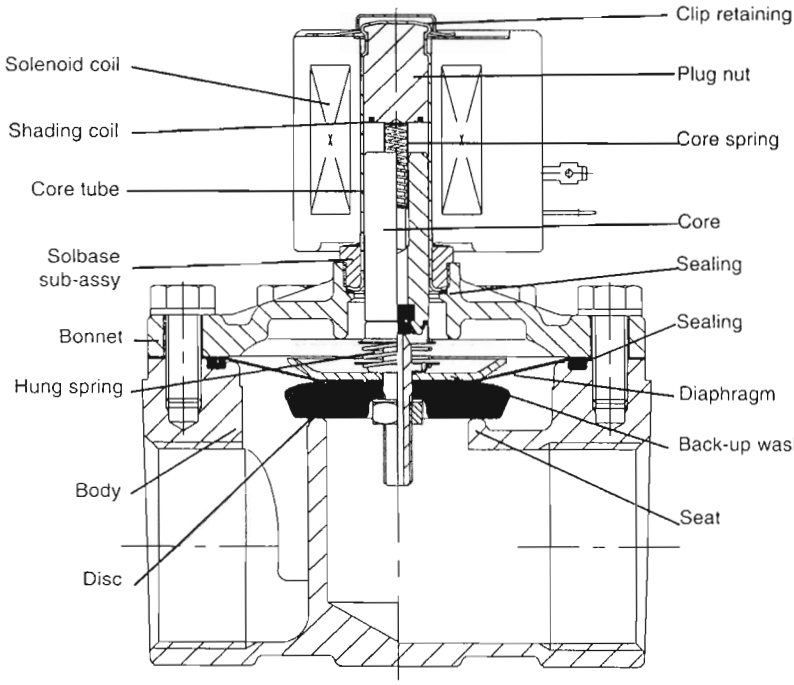
Direct-acting valves

When the solenoid is energised in a direct-acting valve, the core directly opens the orifice of a normally-closed valve or closes the orifice of a normally-open valve (Figures 6a and 6b).

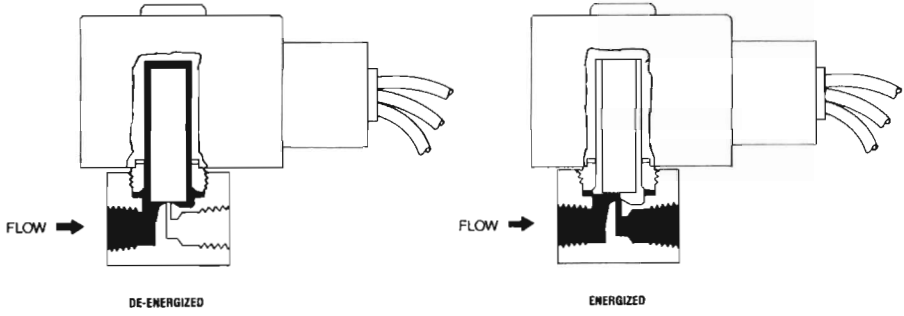
The force needed to open the valves is proportional to the orifice size and fluid pressure. As the orifice size increases, so does the force required. To open large orifices while keeping the solenoid size small, internal pilots are used.

Pilot-operated valve

This type of solenoid valve is equipped with a pilot and (smaller) (bleed) orifice and utilises the line pressure for operation. When the solenoid is energised, the pilot orifice is opened and releases pressure from the top of the valve piston or diaphragm to the outlet of the valve.



Direct-acting hung-diaphragm solenoid valve component parts.



Figures 6a and 6b. Direct-acting solenoid valves.

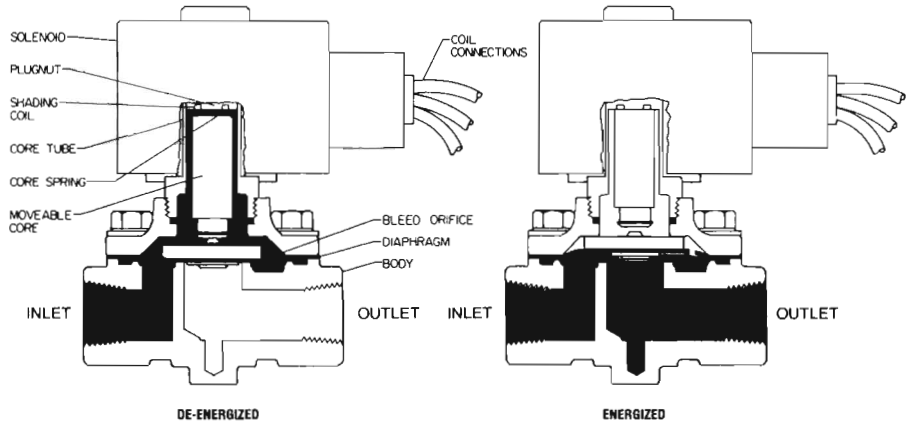
This results in an unbalanced pressure which forces the line pressure to lift the piston or diaphragm off the main orifice and open the valve.

When the solenoid is de-energised, the pilot orifice is closed and full line pressure is applied to the top of the piston or diaphragm through the bleed orifice, producing a sealing force for tight closure. There are two common types of construction:

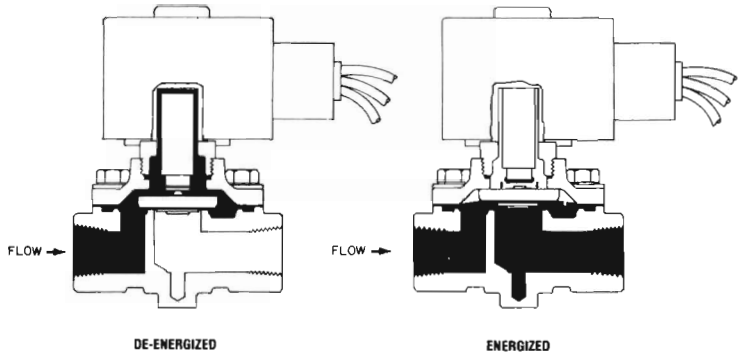
(i) floating diaphragm or piston which requires a minimum pressure drop to remain in the open position (Figures 7a and 7b);
(ii) hung-type diaphragm or piston which is mechanically held open by the solenoid core and operates from zero to the maximum pressure rating (Figures 8a and 8b).

Pressure-operated valve

This is a diaphragm- or piston-operated valve equipped with a 3- or 4-way solenoid pilot which alternatively applies a separate operating pressure to or from the diaphragm or piston to open or close the main valve (Figures 9 and 10).



Figures 7a and 7b. Internal pilot-operated floating-diaphragm valve.



Figures 8a and 8b. Internal pilot-operated hung-diaphragm valve.

Pressure-operated diaphragm solenoid valves.

Air-operated solenoid valves

An-air operated solenoid valve has two basic functional units:

(i) an operator with a diaphragm or piston assembly which when pressurised develops a force to operates;
(ii) a valve containing an orifice in which a disc or plug is positioned to stop or allow flow.

Low and instrument air-pressure range operators usually have a diaphragm for operation and for pneumatic operation the operator is generally a piston.

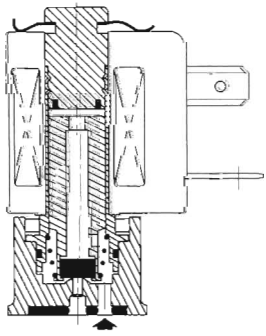


Figure 9. Pressure-operated diaphragm valve.

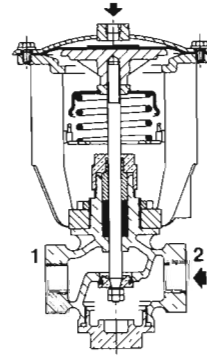
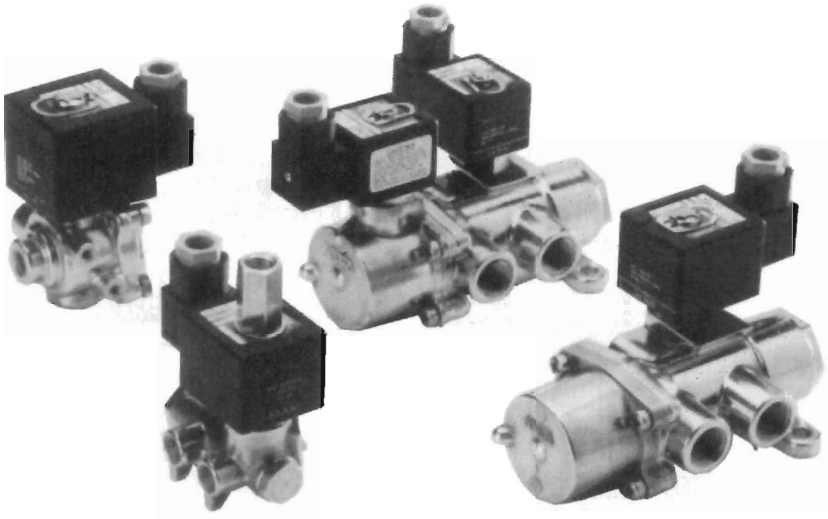


Figure 10. Pressure-operated piston valve.



4/2, 5/2 direct pilot-operated solenoid valves.

In dual-acting valves the operator stem is moved by the diaphragm or piston and directly opens or closes the orifice. In internal pilot-operated valves, the valve is equipped with a pilot and bleed orifice and utilises the line pressure for operation. Figure 11 shows a direct-acting valve flow diagram and Figure 12 an internal pilot-operated valve flow diagram.

Return-spring effect

With a two-way normally-closed valve, both the spring force and the fluid inlet pressure act to close the valve. As a consequence, the return spring can be made relatively weak, and in some designs eliminated entirely. The latter would require mounting the valve so that the solenoid was vertical, return action being by gravity plus fluid pressure.

With a two-way normally-open valve, the spring holds the valve open, assisted by fluid pressure. The solenoid force must be sufficient to overcome both spring pressure and inlet pressure to close the valve.

Three-way valves require an upper and a lower spring. The lower spring presses the valve against its seal opened by inlet pressure. The upper spring acts in a direction to force the valve open. The following are the combination of spring strengths required:

	Lower spring	Upper spring
Three-way normally-closed	Strong	Weak
Three-way normally-open	Weak	Strong
Mixer valve	Medium	Medium
Divider valve	Strong	Weak

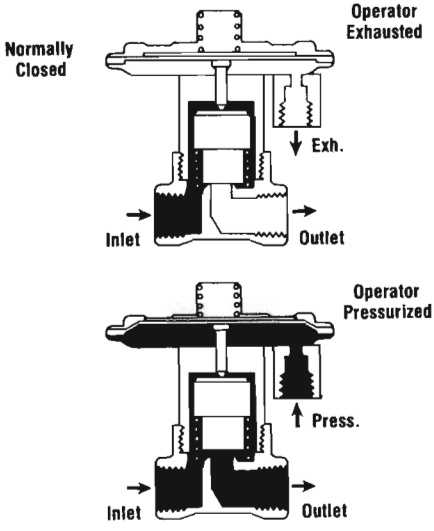


Figure 11. Flow diagram: direct-acting valve.

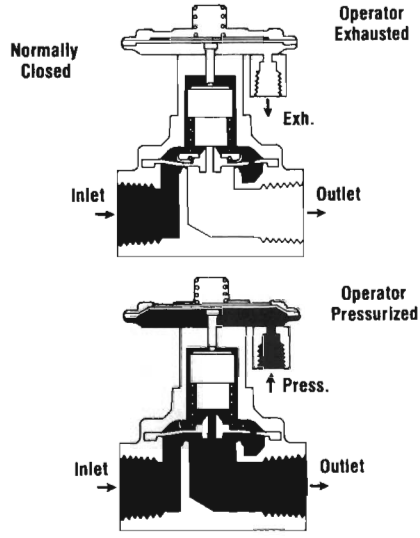


Figure 12. Flow diagram: pilot-operated valve.

Solenoid enclosures

Various types of enclosures may be used for solenoid coils, ranging from general purpose enclosures to protect from indirect splashing and dust, through dust and watertight enclosures to full explosion-proof enclosures. Requirements in this respect are specific to the application and selected accordingly.

Glandless solenoid valves

By arranging the solenoid armature to work in a sealed tube with the solenoid coil enveloping it, the sealing glands can be dispensed with, so simplifying the construction and eliminating one possible point of leakage.

This principle has been applied extensively to smaller valves. A typical type is shown in Figure 13.

This valve is T-shaped with two ports opposite each other, while the third is at right angles to them. The plunger, usually of a corrosion-resistant ferrous material, is spring-biased so that when unenergised it closes the lower orifice while leaving the other open. When energised, the plunger is pulled up so that the lower orifice is opened and the upper closed. If desired, the spring can be arranged to bias the plunger in one direction.

The plunger is provided with plastic valve discs, usually of synthetic rubber or nylon. Because the plunger is unbalanced, the force due to the pressure must be limited and the size of orifice, and therefore the flow and pressure drop, is usually related to the pressure.

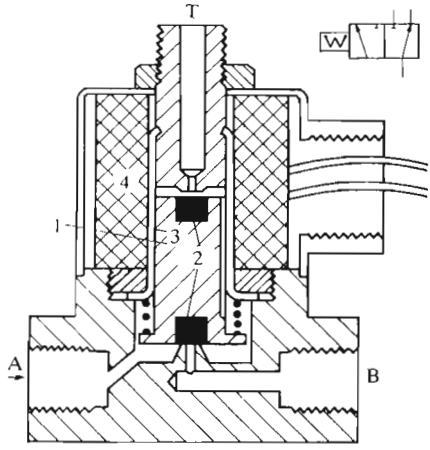


Figure 13. Glandless solenoid valve.

The maximum pressure is also related to the type of valve and may be as high as 210 bar (3000 lbf/in^2) with an 0.85 mm ($^1/_{32}$ in) orifice. Flow depends on the allowable pressure drop and this in turn depends on the orifice size and the fluid.

Sealing is normally 'bubble-tight' but this is to some extent dependent on the cleanliness of the fluid. Lubrication is not essential but if used with air the valve life is increased by air-line lubrication.

Glandless valves can be installed in any position and will withstand appreciable shock loads. Response time is extremely short, 5 ms on a.c. and 10 to 15 ms on d.c. and it is said that speeds of up to several hundred cycles per minute are possible.

For hazardous atmospheres, most manufacturers supply explosion-proof materials which are slightly heavier and bulkier than the standard type.

Although these valves were originally developed for aircraft and missile application, there is no doubt that they have many uses in hydraulics, both as main valves for low-power systems and as pilot valves.

Where pressures do not exceed 17.5 bar (250 lbf/in^2), a 1.6 mm ($^1/_{16}$ in) diameter orifice is suitable and this gives a flow of 2.31 l/min (0.50 gal/min) for 3.5 bar (50 lbf/in^2) pressure drop. On a 50.8 mm (2in) diameter cylinder, this would give a piston speed of 760 mm (30 in) per minute, while when used as a pilot valve for 25.4 mm (1 in) diameter spool with 12.7 mm (2 in) movement, the operating time is about half a second.

When acting as pilot valve, the actual flow would almost certainly be greater than that for a 3.5 bar (50 lbf/in^2) pressure drop, as for a large part of the time the pressure drop will be nearer 14 bar (200 lbf/in^2), until the resistance to piston or spool builds up.

Spool-type solenoid control valves.

Piston-type operator solenoid control valves.

Most of the manufacturers of these valves also supply pilot-operated valves incorporating the basic glandless valve; four-way valves, and two- and three-way valves for larger flows, are made in this way.

These valves may prove useful in acting as pilots to larger valves when the 'pressure release' principle is adopted. Figure 14 shows this applied to a differential-area spool valve. Normally the larger area keeps the spool to the right, with the solenoid valve SC closed. Opening the solenoid valve causes the pressure to drop in the left-hand chamber and the spring, with the excess pressure, causes the spool to move to the left. A two-position springless valve could also be operated in the same way, with jets and solenoid valves at each end.

Glandless solenoid valves—spool type

The construction of a four-way spring-centred closed-centre double-solenoid valve is shown in Figure 15. It has push solenoids with a spool movement of 1 mm (0.040 in) either side of the centre. It is suitable for pressures up to 140

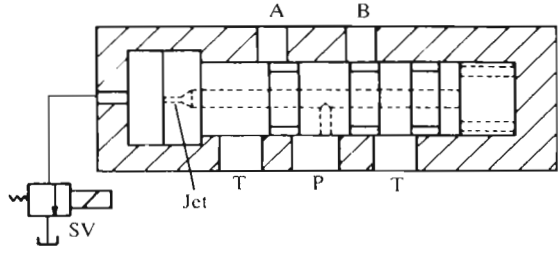


Figure 14. Small solenoid valve used as pilot, employing pressure-release principle.

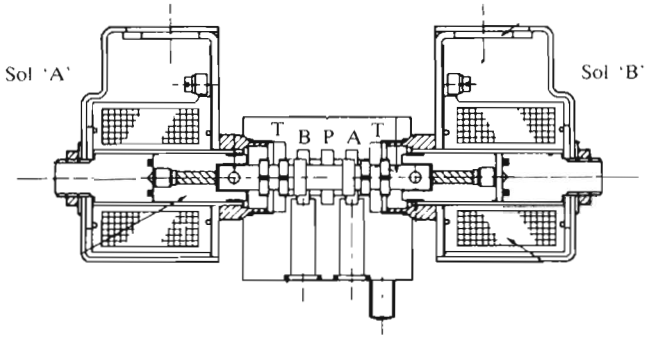
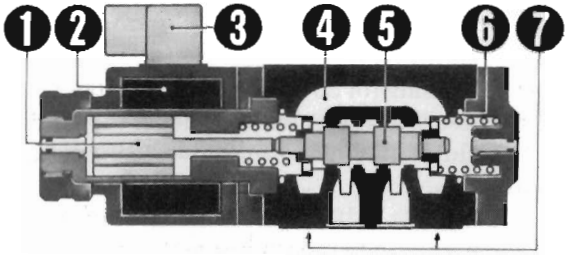


Figure 15. Glandless solenoid spool valve.



1. Wet solenoid.
2. Encapsulated units.
3. Plug and socket connectors.
4. Valve body.
5. Spool.
6. O-ring seals.
7. Mounting surface.

Figure 16. Wet-type solenoid valve.

bar (2000 lbf/in^2) and has a flow of 9 l/min (2 gal/min) for a pressure drop of 2 bar (30 lbf/in^2) on light hydraulic oil at 27 to 38°C (80 to 100°F). It is gasket-mounted and when used as a pilot valve is bolted on top of the main valve.

Another example of a glandless valve with a 'wet' armature is shown in Figure 16. All seals are static O-rings.

Selection

A number of operating and physical parameters must be considered when selecting a solenoid valve. The operating parameters include:

- Pressures
  Maximum operating pressure differential (MOPD), i.e. the pressure the electrical solenoid has to overcome to open the valve and allow flow to occur.

Minimum operating-pressure differential (MinOPD), i.e. the minimum pressure drop that will exist across the valve when it is flowing.

Safe static pressure, i.e. the maximum pressure the valve can be subjected to in normal service.

Proof pressure, i.e. 5 times the safe working pressure.

- Temperatures
  Normal ambient temperature
  Maximum ambient temperature
  Minimum ambient temperature
  Maximum fluid temperature

- Viscosity
  Viscosity is greatly dependent on temperature and to know the actual viscosity of a fluid, the real temperature of the fluid must be considered. Oil grades—both hydraulic and fuel oils are classified relative to viscosity and are roughly distinguished in heavy and light oils.

- Response time
  This is the time lapse after energising (or de-energising) a solenoid valve and depends on the valve size and operating mode, the kind of electrical supply, a.c. or d.c., fluids handled by the valve, temperature, inlet pressure and pressure drop.

Approximate values for a.c. valves on air service under average conditions are:

Small direct-acting valves: 5–10 ms
Large direct-acting valves: 20–40 ms

Internal pilot-operated valves:

(a) small diaphragm-type 15–60 ms
(b) large diaphragm-type 40–120 ms
(c) small piston-type 75–100 ms
(d) large piston-type 100–1000 ms

Operation on liquid media generally has little effect, i.e.

(a) small direct-acting valves: 20–30% higher
(b) large direct-acting valves: 50–150% higher

Response time on d.c. valves is approximately 50–60% higher than on a.c. operation.

- Valve seat tightness
  Valve-seat tightness or leakage depends on the type of valve used, sealing materials, trim and medium.

Valve sizing

It is essential to size a valve properly because both undersizing and oversizing have undesirable effects.

Undersizing may result in:

(1) Inability to pass desired flow requirements
(2) Flashing of liquids to vapours on the outlet side of the valve
(3) Lowering the outlet pressure
(4) Creating a substantial pressure loss in a piping system

Oversizing may result in:

(1) Unnecessary cost in oversized equipment
(2) Variable flow through the valve or erratic control of the flow
(3) Shorter life of some valve designs through oscillating of internal parts
(4) Erratic operation of some designs such as failure to shift position due to lack of required flow in 3- and 4-way valves
(5) Erosion of wire drawing of seats in some designs because they operate at nearly-closed position

The K_v (C_v) method of valve sizing reduces all variables to a common denominator called flow coefficient. Most, if not all, manufacturers provide extensive information and reference data for estimating K_v (C_v) and accurate sizing of solenoid valves. To summarise, the basic factors in valve sizing include:

- Maximum and minimum flows to be controlled
- Maximum and minimum pressure differentials across the valve
- Specific gravity, temperature and viscosity of fluids being controlled

Table 1 gives details of problems, possible causes and solutions in relation to the operation of solenoid valves.

It is recommended that manufacturers' data is referred to and followed carefully when problems occur. It is advisable that the manufacturer is consulted in cases of difficulty.

Table 1. Troubleshooting guide

Problem	Possible cause	Probable solution
Valve will not operate when valve circuit is energised (direct-acting valve)	Low voltage or no voltage to solenoid coil	Check voltage at coil; for most valves, voltage should be at least 85% of name plate rating.
	Burned out coil	See 'Coil failure' below.
	Excessive foreign matter jamming core in core tube	Clean valve; install strainer close to valve inlet.
	Binding core or damaged core tube	Replace parts.
	Excessive fluid pressure	Reduce pressure to valve nameplate pressure rating or install suitable valve.
Valve will not operate when valve circuit is energised (pilot-operated valve)	Same causes and solution as for direct-acting valve, plus:	
	Low pressure drop across valve	Valve might be oversized; replace valve with one having a smaller orifice. Increase pressure if possible.
	Ruptured diaphragm or piston ring	Replace damaged parts.
	Plugged or restricted pilot orifice	Clean valve and pilot orifice.
Valve will not close or shift when valve circuit is de-energised (direct-acting valve)	Coil not de-energised	Check electrical control circuit.
	Excessive foreign matter jamming core in core tube	Clean valve; install strainer close to valve inlet.
	Damaged disc or seat causing internal leakage	Replace with new parts.
	Binding core or damaged core tube	
	Damaged spring	Replace with new spring. Never elongate or shorten.
Valve will not close or shift when valve circuit is de-energised (pilot-operated valve)	Same causes and solution as for direct-acting valve, plus:	
	Plugged bleed orifice	Clean orifice.
	Damaged pilot seat or pilot disc	Replace with new parts.
	Damaged diaphragm or piston	Replace with new parts.

	Damaged pilot spring	Replace with new spring. Never elongate or shorten spring.
	Insufficient pressure drop across the valve	Valve might be oversized; replace valve with one having a smaller orifice. Increase pressure if possible.
Wire drawing	Dirt or foreign matter is lodged on seat	Replace valve body or install new valve; install suitable strainer close to inlet or valve.
Coil failure*	Overvoltage	Check voltage at coil; voltage must conform to nameplate rating.
	Damaged core or core tube causing inrush current to be drawn continuously	Check for damaged core and core tube, or damaged spring. Check for scale or foreign matter on the core or inside the core tube. Clean thoroughly, and replace any damaged parts.
	Excessive foreign matter jamming core in core tube and causing inrush current to be drawn continuously	Check for damaged core and core tube, or damaged spring. Check for scale or foreign matter on the core or inside the core tube. Clean thoroughly, and replace any damaged parts.
	Excessive fluid pressure causing inrush current to be drawn continuously	Reduce pressure or install suitable valve.
	Excessive ambient or fluid temperature	Class A coils are limited to ambient temperatures of 77°F. For temperatures up to 167°F, use Class F coils; for temperatures up to 212°F, use Class H.
	Missing solenoid parts	Install missing solenoid housing and other metal parts or properly install incorrectly assembled metal parts. The housing and other metal parts form part of the magnetic circuit and are required to provide the impedance needed to limit current draw.
	Moisture inside solenoid enclosure	Waterproof the entrance conduit to prevent entry of moisture. If valve is mounted outdoors, check to see that enclosure is weatherproof and that gaskets are in good condition; use appropriate sealant where required. If general purpose enclosure is used in a damp or humid atmosphere, use watertight, moulded coils.

*In explosion-proof solenoids, a binding core, high-input voltage, or excessive ambient or fluid temperature may cause the solenoid's non-resettable thermal fuse to open. If this occurs, the solenoid must be replaced.

Swing Check (Flap) Valves

'Swing check' valves is the preferred description for non-return valves consisting of a hinged disc, although they are also commonly called flap valves because of their geometric action. Their mode of working is obvious. With flow in one direction the disc hinges upwards to permit flow through the valve. With reverse flow the disc is held closed. Equally, spring pressure or mass effect normally holds the disc closed in the absence of flow. In some cases closure is also assisted by the use of a weighted lever.

Small-size swing check valves for low-pressure services may use an elastomeric disc with a square end clamped in position, eliminating any need for a separate hinge. A back-up plate is added to assist closure and also provide rigidity to the unsupported area of elastomer when the valve is closed. Without this the disc would tend to collapse and extrude through the port. Larger versions of flexible (elastomeric) flap valves are made in sizes up to 1500 mm (60 in).

Larger swing check valves are more usually made with discs or flaps of metal or composite materials, hinged at the top and sealing on a metal seal. The sealing surface is inclined at a small angle to the vertical to assist opening, provide more positive sealing under back pressure and reduce shock when closing under high pressure. A typical valve design is shown in Figure 1. In

1. Body in ductile iron FGS 500-7 epoxy coating 250 microns inside/outside
2. Cover in ductile iron FGS 500-7 epoxy coating 250 microns inside/outside.
3. Bolts in dip galvanised steel.
4. Closing disc: DN 65 mm to 150 mm: ductile iron FGS 500-7
   DN 200 mm: steel.
5. Drain plug: dip galvanised steel.
6. Disc coating: NBR (Nitrile).
7. Gasket: NBR (Nitrile).
8. Disc shaft: brass BS.2874 NBR coated.

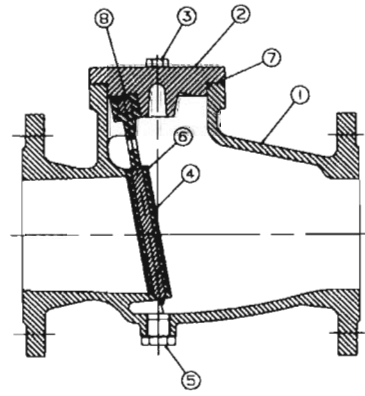
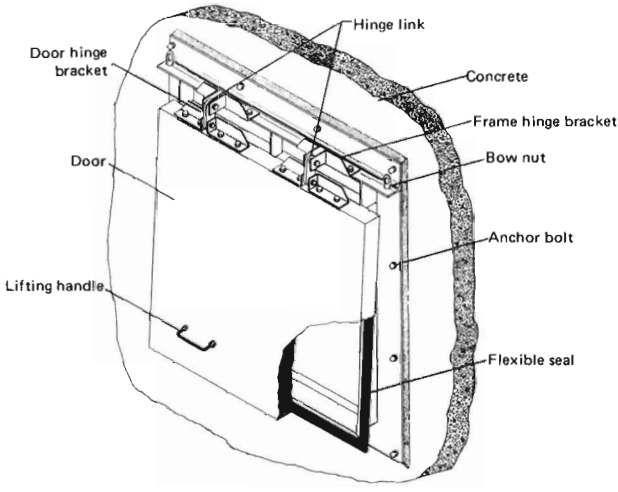


Figure 1. Typical standard swing check valve.

larger valves the disc or flap may be double hung. Flap shapes are normally (but not necessarily) circular.

Swing check valves present relatively high resistance to flow in the open position as well as creating turbulence, because the flap 'floats' in the fluid stream. They may also tend to chatter in systems having frequent flow reversals. Swing check valves are normally used in horizontal pipelines. They can also be used in sectional pipelines with upward flow. They are not suitable for use in systems with pulsating flows. However, weight added to the flap or disc

Standard series swing check valve.



Large flexible-flap valve.

(or spring-loading) can control the opening pressure as well as assisting closure under back pressure.

Commonly the body shape incorporates a 'dead' volume in which fluid can be trapped downstream of the flap once the valve is closed. If necessary, a drain can be incorporated at this point, e.g. when it is desirable to drain a system completely on shut-down.

The double-plate check valve shown in Figure 2 is particularly suitable for pumping and general industry applications such as water treatment, irrigation, general circuits and industrial processes.

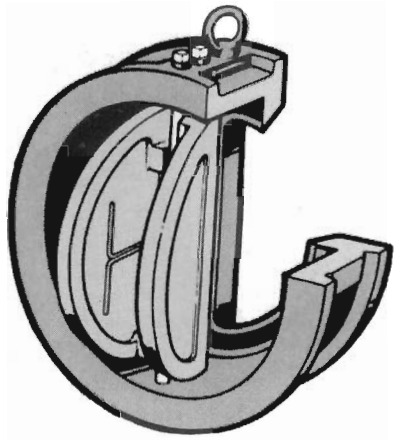


Figure 2. Double-plate swing check valve.

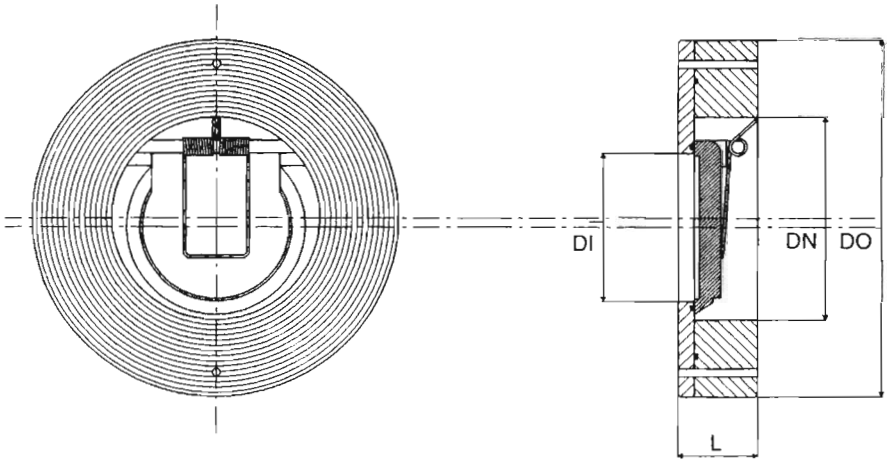


Figure 3. Sprung swing check valve.

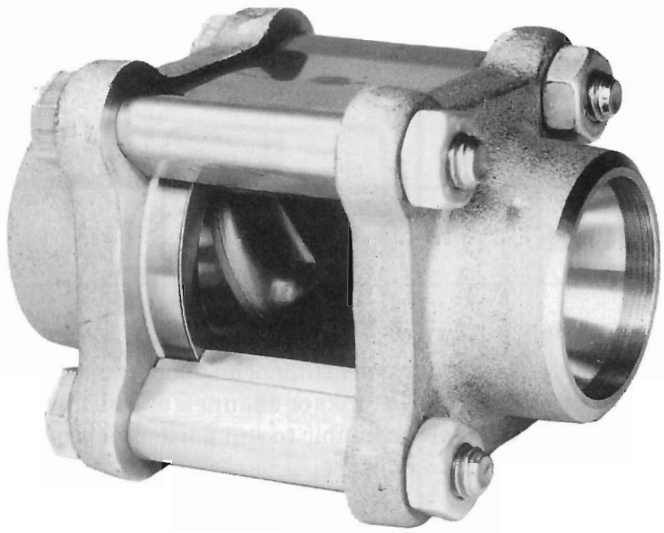


Figure 4. Three-piece construction swing check valve.

The valve is mounted between flanges and is suited to installations where space is limited. The swing check valve shown in Figure 3 has only one moving part and is of the sprung type. It has a tight shut-off and is capable of working in temperatures up to 600°C and pressures up to 100 bar. The spring mechanism is usually made from Iconel-X, titanium or Hastelloy.

Swing check (flap) valves are also produced in a three-piece construction similar to that used in ball valve design (Figure 4). The straight-through flow makes it particularly suitable for hydrocarbon and chemical process lines. For maintenance purposes, the valve body swings outward to allow access to the check and seats.

Materials

Body materials used for swing check valves include cast iron, bronze, cast steel, forged steel, stainless steel, high-duty alloys and also plastics. Valve discs may be in similar materials or composites.

Applications

Main application areas for swing check valves are the water industry, including pumping and water treatment, irrigation, and the petrochemical industry including hydrocarbons and industrial processes. Other applications can be found in air conditioning and general industry.

Penstocks

A penstock is a single-faced valve consisting of an open frame and a door. This form of valve is normally located in tanks or channels as a means of controlling flow into a pipe. Many types are available to suit particular requirements and operating conditions. The main ones are:

(i) Penstocks for operating against pressure, i.e. pressure forcing the door onto the frame.
(ii) Penstocks for operating against off-seating pressure, i.e. pressure forcing the door away from the frame.
(iii) Penstocks designed to accommodate both seating and off-seating pressures.

Seating pressure can be accommodated by the use of side wedges only. Off-seating pressure requires the use of bottom wedges or top and bottom wedges (see Figure 1). Penstocks subject to sealing pressure normally seal tighter than penstocks for off-sealing pressure duties. Both types can be made virtually drop-tight with correct installation, distortion of the gate frame at

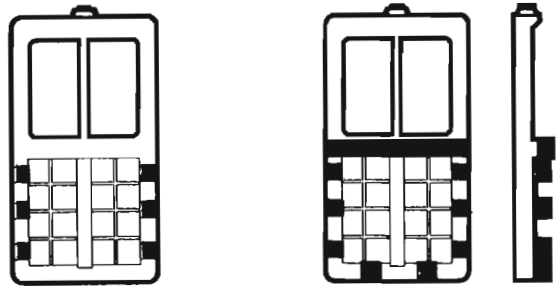


Figure 1. Penstocks showing the location of wedges.

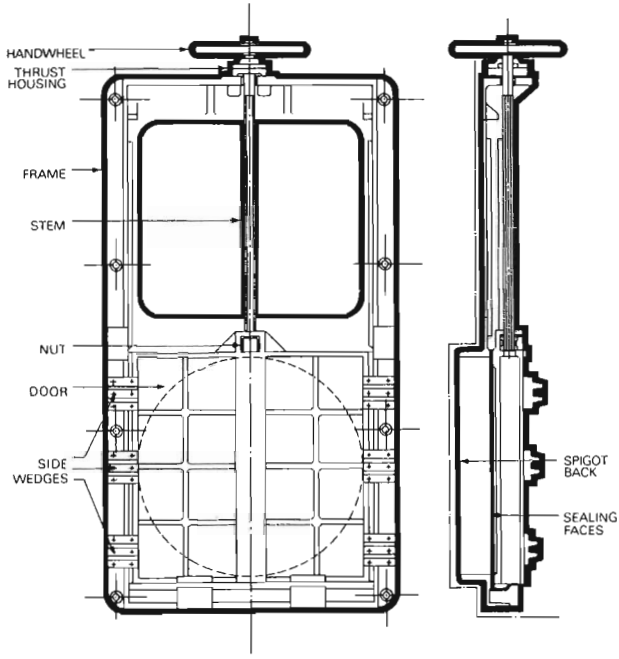
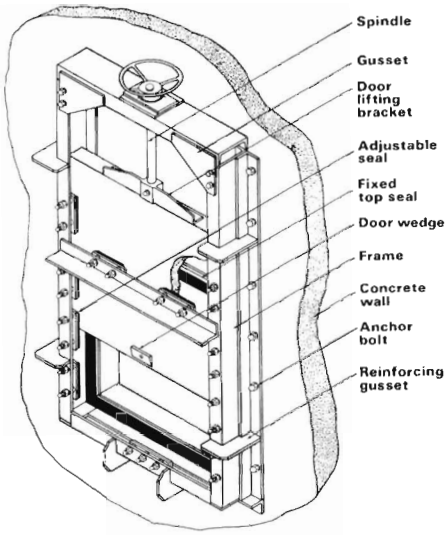


Figure 2. Typical penstock.

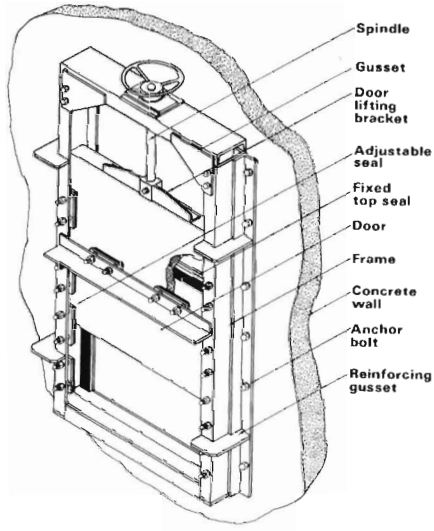
the time of installation being the determining factor as far as leakage is concerned.

Penstock frames may be circular or rectangular. In the latter case a preferred proportion of width to depth is 2:3 for vertical form, and 4:3 for horizontal form. Frames and gates are commonly made of cast iron, although plastic materials (usually reinforced steel) are also used for gates operating in aluminium, stainless steel or epoxy-coated frames for corrosive applications. Frames may be for channel or wall-mounted application (Figure 3). Sealing faces in suitable materials are embedded into both the frame and door surfaces.

Handwheel operation of the gate is normal, using a rising stem supported by a suitable headstock or bracket. The advantage of a rising stem is that the screw thread at the bottom of the stem is not usually immersed and is readily accessible for lubrication. A non-rising stem eliminates the need for a headstock and merely rotates through a nut in the penstock door (see Figure 2). The threaded portion at the bottom is then usually immersed in the product being handled. Different systems for raising and lowering the gate may be employed on modulating penstocks used for flow-control purposes (Figures 4 and 5).



Chased-Invert Type.



Flush-Invert Type.

Figure 3. Wall-mounted penstocks.

Discharge through penstocks

A penstock when opened represents a partial obstruction in an open channel over which liquid accelerates with a free liquid surface. Its performance is thus essentially similar to that of a weir where flow rate Q is proportional to width and velocity head. Working formulae are:

$$\begin{aligned} Q\,(\text{Imp gal/min}) &= 0.13 \times \text{area}\,(\text{ft}^2) \times \sqrt{2\,g} \times \text{head}\,(\text{ft}) \\ Q\,(\text{US gal/min}) &= 0.158 \times \text{area}\,(\text{ft}^2) \times \sqrt{2\,g} \times \text{head}\,(\text{ft}) \\ Q\,(\text{m}^3/\text{s}) &= 0.7 \times \text{area}\,(\text{m}^2) \times \sqrt{2\,g} \times \text{head}\,(\text{m}) \end{aligned}$$

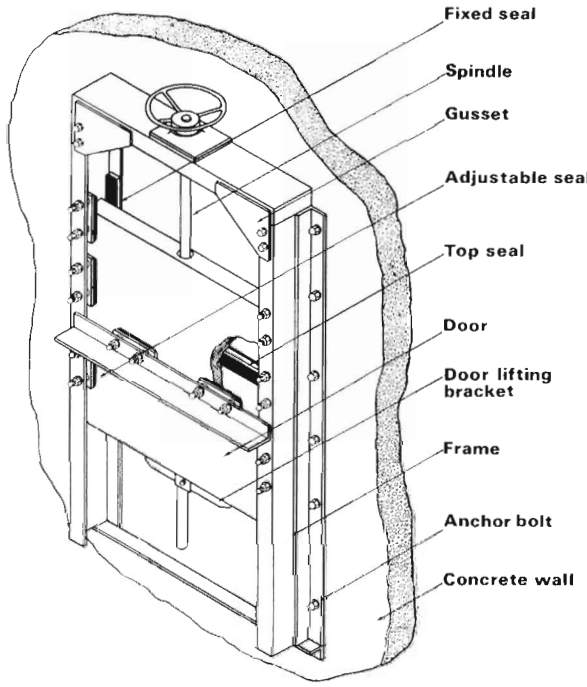


Figure 4. Weir penstock.

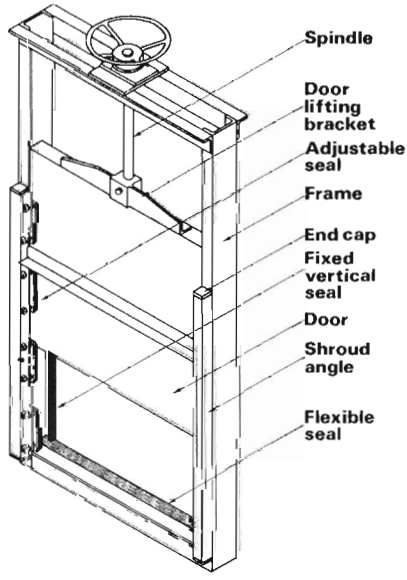


Figure 5. Channel penstock.

Miscellaneous Valves

Where processes or storage applications require continuous safety, the three-way changeover valve allows the user to cross over from one relief-valve system to another. The design permits two valves on a single riser. This arrangement protects the system with one active valve while the other valve is either in reserve or being serviced. Construction details are shown in Figure 1.

The valve works with many general and specialised applications and can incorporate an interlock system that allows either valve to be discharged into

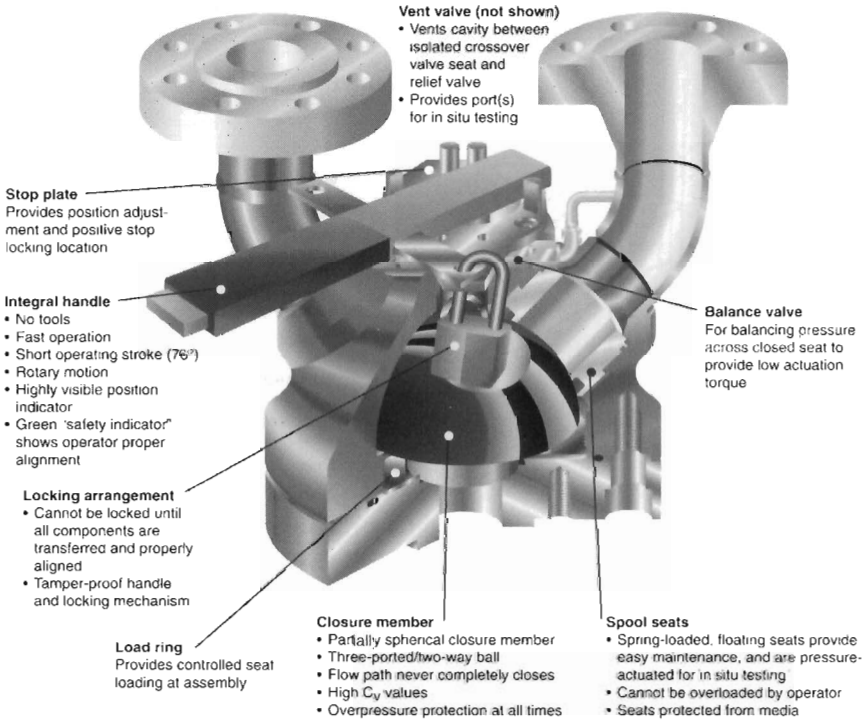


Figure 1. Three-way changeover valve.

Quick cross three-way changeover valve.

a single header. One valve mounts on the riser, the other on the outlets of the relief valves. The valves are operated simultaneously through a simple linkage. This type of valve can also be adapted for remote actuation, still maintaining the single movement rotary change-over action.

Typical areas where the valve is used include chemical plants, fertilizer plants, offshore platforms, refineries, pulp and paper mills, gas distribution systems, toxic service, environmental protection, chlorine storage tanks, refrigeration, dual filtration and process systems.

Pneumatic piston controlled on–off valve

Typically, this type of valve is best suited for controlling the flow of fluids, gases, steam and other substances apart from explosive substances (Figure 2).

The valve is equipped with a position indicator. Generally the material of construction is either AISI 316, bronze or brass. Although the valve can be fitted in almost any position, it must be fitted so that the direction of flow is opposite to the plunger-closing position, otherwise water hammer can result.

Tunnel diverter valve

This valve is designed for use in pressure or vacuum systems to divert or converge pellets: granules, fine powders or abrasive materials. Two types of seals are

Figure 2. Piston-controlled on–off valve.

used: O-ring seals for applications conveying pellets and granular materials, and air-assisted seals for conveying powdered or abrasive materials where three air inlets introduce compressed air into the diverter-valve housing.

An unusual design of check valve is shown in Figure 3. This features a lipped elastomeric membrane as the working element, offering virtually unrestricted flow in the open position with a capability of passing suspended solids up to the full bore diameter. The membrane itself is held open to a full circular form by the flow, the circumference of the membrane in this condition being D. Loss of head is thus minimal (e.g. directly comparable with that of a swing check valve).

With reverse flow, the membrane assumes a closed position with the lips in mating contact (Figure 4), i.e. the natural 'unloaded' form of the membrane. Closure is further assisted and maintained by the reverse flow impinging on the sides of the now wedge-shaped membrane. The length of seal in this case is $\pi.D/2$, or substantially half that of a conventional check valve (i.e. the potential leakage path is reduced by half).

The membrane itself is not subject to elastic deformation, merely flexure, and thus has a long life, particularly if the fluid does not contain abrasive solids in suspension. When servicing is required, replacement of the membrane

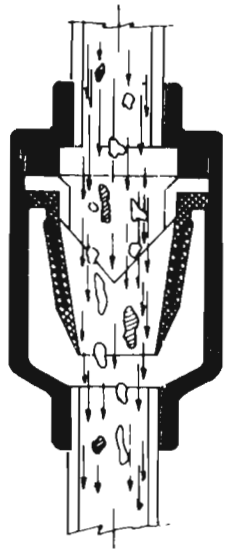


Figure 3. Membrane check valve.

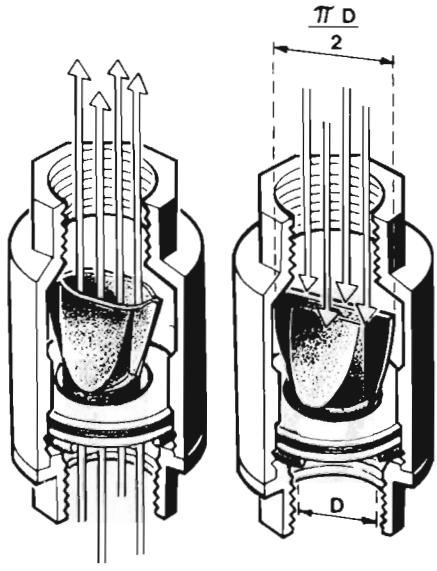


Figure 4.

is a simple operation. No other servicing is necessary. The membrane elastomer is selected according to the product to be handled.

Because of the elastic nature of the closure, this type of check valve cannot water hammer and is also noiseless in that it has no hinge or spring which can be excited into vibration in either the open or closed position.

Currently this valve is made in threaded form for water pipes up to 50 mm (2 in) diameter and flanged for water pipes from 50 to 400 mm (2 to 16 in) diameter. Valve sizes up to 125 mm (5 in) have a single passage. Larger valves have several passages, each with its individual membrane (Figure 5). This solution of dividing the total flow into partial flows with smaller flow rates which never open or close strictly eliminates water hammer in these larger valve sizes with higher flow rates.

Eccentric valves

The description 'eccentric valve' is applied to plug valves having an eccentric motion against a resilient facing, i.e. as the eccentric plug rotates 90° from open to closed, it moves into a raised eccentric seat. The complete action can be followed from Figure 6.

In the open position, the segmented plug is out of the flow path. Flow is straight-through, flow capacity is high. As the plug closes, it moves towards the seat without scraping the seat or body walls so there is no plug binding or wear. Flow is still straight-through.

In the closed position, the plug makes contact with the seat. When furnished with a resilient facing, the plug is pressed firmly into the seat for dead-tight shut-off. The eccentric plug and seat provide lasting shut-off because the plug continues to be pressed against the seat until firm contact is made.

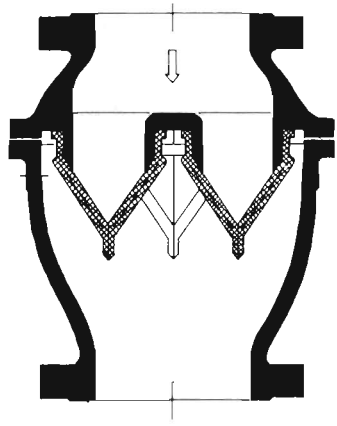


Figure 5.

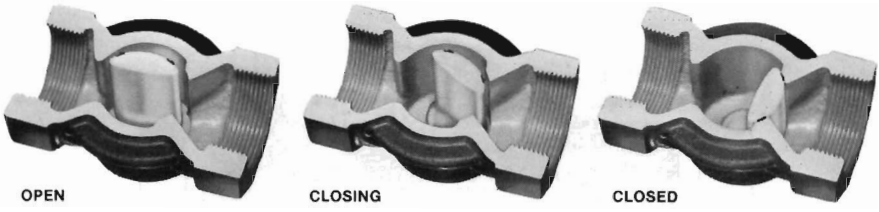


Figure 6. Eccentric valve: complete action.

Throttling characteristics of a valve of this type are generally excellent (Figure 7), and shut-off in the closed position is positive with air and gases as well as liquids.

The valve shown in Figures 8 and 9 has been specifically intended for applications such as tanker truck loading, portable tanks, intermediate bulk containers (IBCs) bulk transfer stations, and agricultural and aviation duties.

The unit is designed to avoid accidental spills and cannot be disconnected in the 'open' position. A handle prevents this and poppets automatically stop the flow from both directions when the unit is disconnected. Maximum working pressure is 150 lb/in^2. The valve must not be opened or closed when the pressure is in excess of 60 lb/in^2.

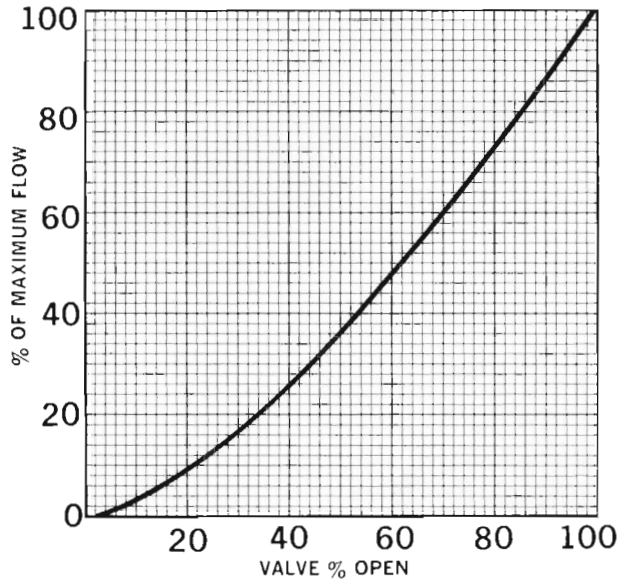


Figure 7. Throttling characteristics.

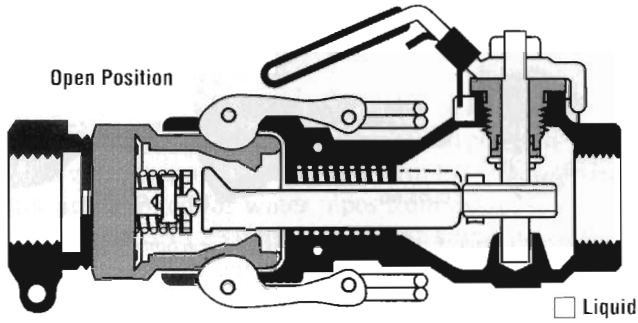


Figure 8. Dry disconnect valve: cutaway view.

Figure 9. Dry disconnect valve.

Polymer valves

Polymer valves are used to drain feed, changeover, sample, inject, distribute and control polyester (including PET), nylon, PVC, PP, PU, HDPE, LDPE and related polymers.

The different types of valves used in the polymer processes include:

- Feeding valves—disc valves are better suited than ram valves for feeding low viscosity feedstocks into reactors (Figure 10). Typical feeding valves are used to regulate the flow of polyester into esterification and polymerization reactors. For vacuum service, bellows are generally used. These should be of the external type due to the possibility of failure in a crystallising environment.
- Discharge valves—ram and disc-type bottom outlet valves are used to drain reactors or control access to the transfer lines between reactors and crystallisers (Figure 11).

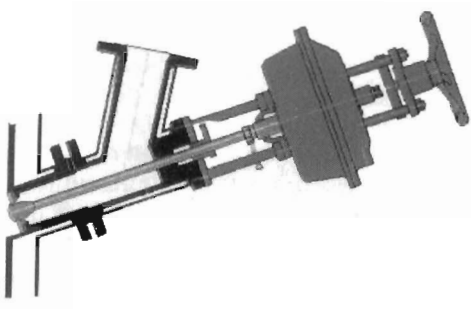


Figure 10. Feeding valve.

- Injection and stripping (deodourising) valve—in many processes, unwanted impurities or remnants, such as unpolymerized monomers in PVC and polyurethanes or solvents in paints and coating suspensions, are stripped from the batch at the end of the process by the injection of saturated steam. The ram tip of the valve is adapted to each vessel as well as the required flow conditions to optimise the spray pattern and prevent product reflux during the operating cycle and in the closed position.

Rather than emptying the reactor when an exothermic reaction goes out of control, the injection and stripping valve (Figure 12) injects a stopper. Another injection valve injects protective colloids. This type of valve is also used to inject steam to heat a reactor.

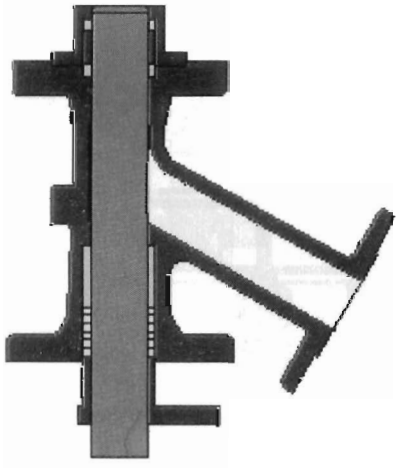


Figure 11. Discharge valve.

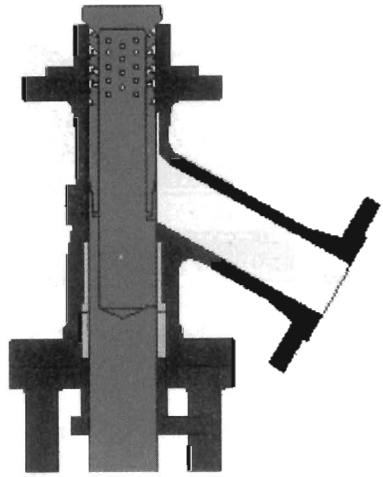


Figure 12. Injection and stripping (desodorising) valves.

- Spray rinse valves—typically used to rinse polymer reactors, especially in the production of PVC where the dome and bottom pad are the parts most in need of cleaning. Valves can be used with water or steam at up to 40 bar.
- Sampling valves—for drain and sampling and flush or purge.
- Polymer additives injection valve—these valves allow small amounts of additives and catalysts such as titanium dioxide to be injected into the line and distributed evenly through the polymer (Figure 13). Different types are available.

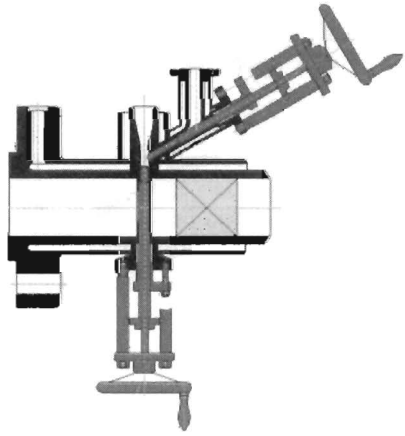


Figure 13. Polymer additives injection valve.

- Multiport diverter valves—these eliminate multiple in-line valves with associated distributor 'T' pieces and piping. Main lines can be divided up to six lines with the valves having up to seven inlets and outlets.
- Filter switching valves—usually two valves are involved for switching duplex filters in high-viscosity polymer plants. The inlet valve diverts the flow to one of the duplex filters and the outlet valve guides the flow back to the main line. Piston diverter valves and rotating disc valves are used for this process. Both types of valves can also incorporate particular features and modes of operation.
- In-line valves—these are used to control and shut off the flow of polymer through the piping system. Ball valves and globe valves are not suitable for this duty. Y-globe valves are used in both manual on/off and automatic control versions with polyester. As an alternative, gate valves are used in low pressure and vacuum applications.
- Dye head valves—these valves combine a bottom outlet piston or an end of line Y-globe valve with a stranding dye head, the one used in polyester and nylon polymerization plants.

SECTION 3

Pressure Valves and Services

Check Valves

Safety and Relief Valves

Self-Acting Reducing Valves

Air Relief Valves

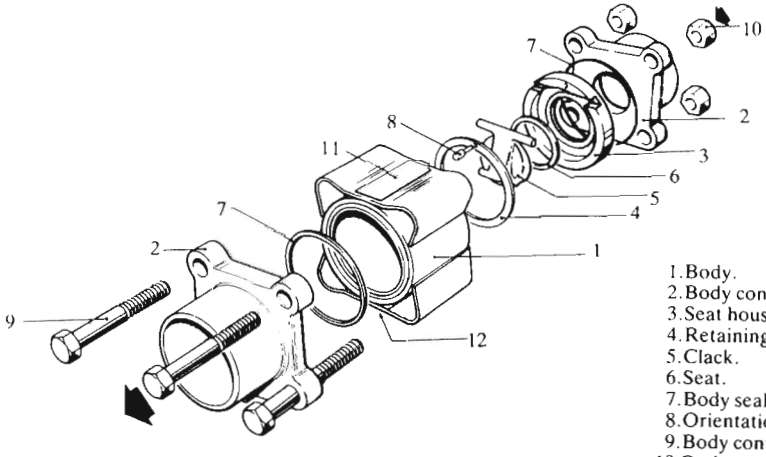
Foot Valves

Check Valves

In general terms, check valves are intended to prevent reverse flow in a line e.g. after a pump has stopped and to prevent water hammer. They are also known as non-return valves, reflux valves, flap valves, retention valves and foot valves in different services. The basic principle of the valve is to only allow flow in one direction only and with non-return valves, the check valve is self actuating when flow is reversed. Discs, wafers or membrane diaphragms are used in this type of valve.

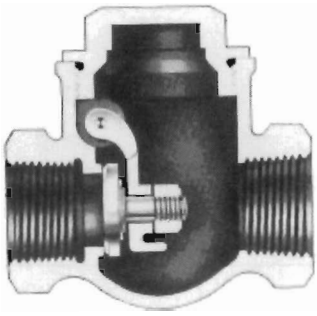
There are numerous types of closing systems in check valves but basically the check valve can be categorised as follows:

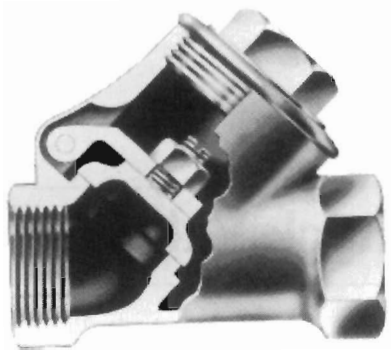
(i) Swing- or plate-type valves (swing/plate check valves)—Figure 1, where the check mechanism is a hinged plate or flap, or disc—see chapter on Flap Valves, Section 2. The butterfly check valve is a variant on this principle—see chapter on Butterfly Valves, Section 2.



Swing check valve, (exploded view).

1. Body.
2. Body connector
3. Seat housing.
4. Retaining plate.
5. Clack.
6. Seat.
7. Body seal.
8. Orientation pin.
9. Body connector bolt.
10. Body connector nut.
11. Optional clock spring.
12. Body label.
13. Identification label.





Swing check valves.

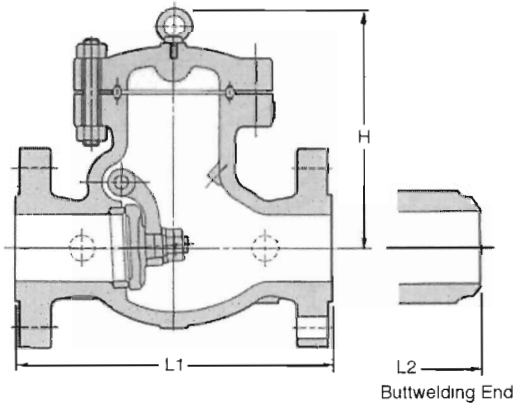


Figure 1. Bolted cover swing check valve.

(ii) Tilting disc check valves, similar to swing-type check valves but with a profiled disc.
(iii) Guided or lift-type valves where the check mechanism incorporates an element which lifts along an axis in line with the axis of the body seat. These may be further sub-divided into:

  (a) disc check valves.
  (b) piston check valves.
  (c) ball check valves.

(iv) Foot valves: specifically check valves fitted to the bottom of a suction pipe.
(v) Spring-loaded check valves.
(vi) Wafer check valves: includes swing-type, sprung disc twin plate.
(vii) Check and surge-suppressor valves: including multi-door check valves for larger pipelines, and electrically- and pneumatically-operated surge-suppressor valves.
(viii) Hydraulic and pneumatic check valves.

Tilting disc check valves

The basis of the tilting disc check valve is a 'lifting' section disc, pivoted in front of its centre of pressure and counterweighted and/or spring-loaded to assume a normal closed position. With flow in one direction the disc lifts and 'floats' in the stream, offering minimum resistance to flow. The balance of the disc is such that as flow decreases the disc will pivot towards its closed position, reaching this before flow has actually ceased, sealing before reverse flow commences. With reverse-flow, reverse-flow pressure and the counterweight system hold the disc closed (Figure 2). Operation is smooth and silent under all conditions.

Valves of this type normally have resilient sealing rings mounted on a metal face. Metal seals may be used for high-temperature applications.

Guided or lift-type disc valves

Lift-type disc valves are similar in configuration to globe valves except that the disc or plug is automatically operated, i.e. is capable of floating in its seat. The

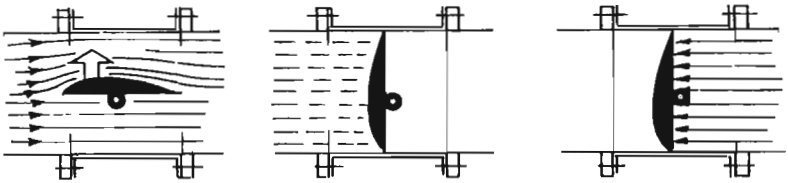


Figure 2. Tilting disc check valve.

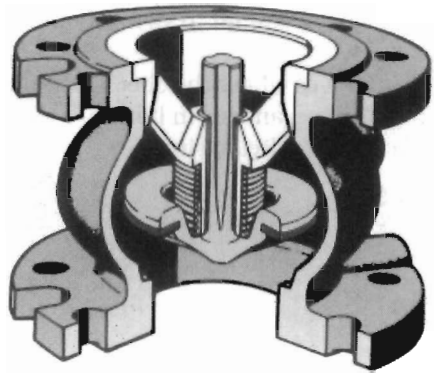


Figure 3. Standard guided non-return check valve.

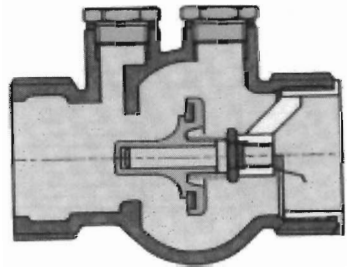
disc or plug is lifted by flow in one direction, permitting through flow. With reverse flow the disc or plug is held on its seat by reverse-flow pressure, giving shut-off. A typical standard check valve is shown in Figure 3.

Valves of this type are further categorised by geometric configuration, i.e. horizontal, angle (oblique) and vertical.

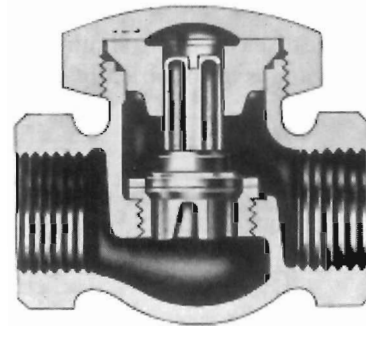
Piston check valves

The piston-type lift check valve incorporates a dashpot applied to the check mechanism (Figure 4), otherwise it is basically similar to a lift-type disc valve. The advantage of the dashpot is that it provides a damping effect during operation.

Lift-type piston check valves are commonly used in conjunction with globe and angle valves on piping systems subject to surge pressures or frequent changes in flow direction.



Check valve for high-duty pressure water systems.



Horizontal lift check valve.

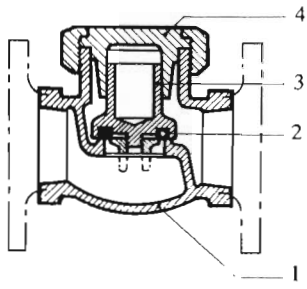


Figure 4. Piston check valve.

Ball check valves

The check element in a lift-type ball valve is a spherical ball, suitably restrained but capable of floating off and onto a seat. With forward flow the ball is forced away from the seat, opening the valve. With reverse flow the ball is forced onto the seat to produce a seal and shut-off. A particular advantage of ball check valves is that they can prove more suitable for use with viscous fluids than other types (Figure 5).

Ball check valves may be of all-metal construction, metal ball with resilient seat, mixed construction (metal or plastic ball), or all-plastic construction.

Foot valves

Foot valves, which often include a strainer, are fitted to the end of a suction pipe and prevent a pump emptying when it stops and therefore not needing priming when restarting. They should have a minimum resistance to flow, with the

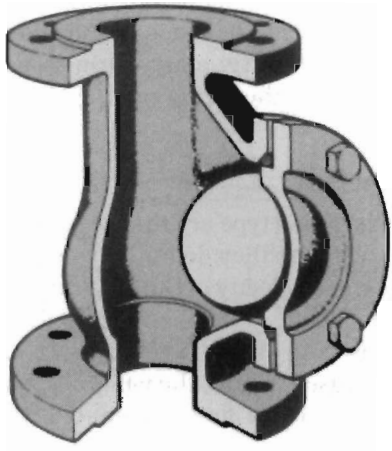


Figure 5. Ball check valve. The closing system is a ball lifted up by the fluid and guided to a lateral housing.

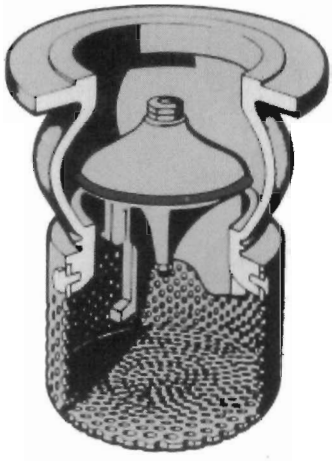


Figure 6. Foot valve for pumping installations with substantial flow.

Figure 7. Membrane foot valve for irrigation and drainage pumps.

actual valve element or flap as light as possible if the risk of cavitation is to be avoided. The valves may be of the single flap (Figures 6 and 7) or multiple flat-type, membrane, guided or ball-operating systems. See chapter on Foot Valves.

Spring-loaded check valves

Lift-type check valves may be spring-loaded for more positive shut-off action, particularly as regards more rapid-response cessation of flow, i.e. they can be adjusted to close before flow has fully ceased rather than having to rely on reverse-flow pressure. They can be of disc, plug or ball-type and can work in any position, i.e. horizontal, inclined, upward or downward flow (Figure 8).

Spring-loaded check valves can be made in the widest variety of materials with stainless steel or high-duty alloy springs as necessary. Opening characteristics are governed by the spring rate.

In-line spring assisted valves

The advantages of valves of this type are that they can be installed in the line in any orientation and typically they do not rely on gravity or reverse flow to close. Instead, as the forward velocity of the fluid slows, the spring assist starts to close the disc.

Due to the spring assist and short travel distance of the disc, by the time forward velocity has decreased to zero, the valve disk has reached the seat and the valve is closed. With reverse flow eliminated, the forces necessary to produce water hammer on both upstream and downstream sides of the valve are substantially reduced.

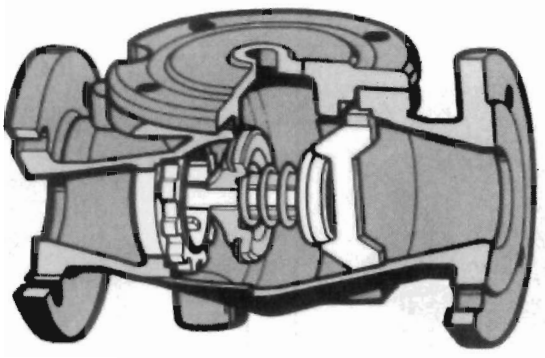


Figure 8. Spring-loaded check valve for protecting drinking water networks.

In-line check valves of this type are probably among the most popular types and are used in many industries including chemical, food and beverage, mining, oil and gas, pulp and paper, building services and general industry duties.

A basic in-line check valve is shown in Figure 9.

A list of typical applications for spring-assisted in-line check valves is shown in Table 1.

Water hammer

This is the generation and effect of high-pressure shock waves (transients) in relatively incompressible fluids. Water hammer is caused by the shock waves that are generated when a liquid is stopped abruptly in a pipe by an object such as a valve disc. Symptoms include noise, vibration and hammering pipe

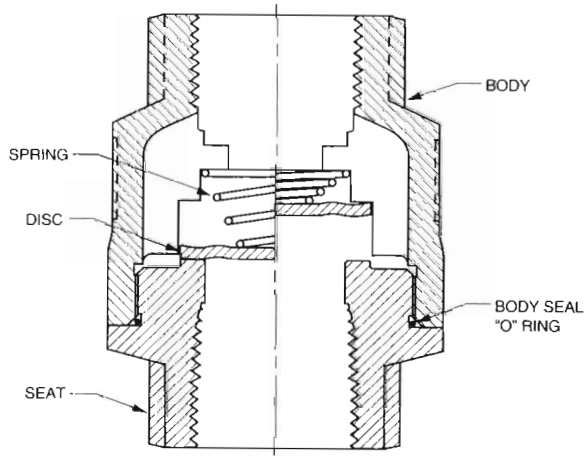
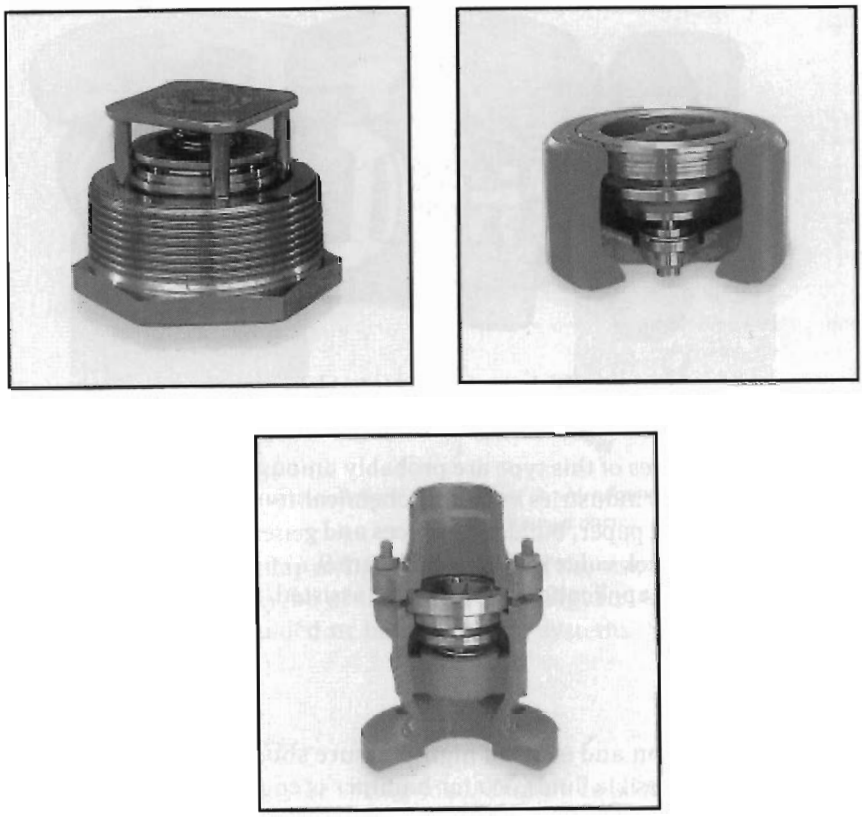


Figure 9. Spring-assisted in-line check valve.



In-line check valves.

sounds which can result in flange breakage, equipment damage, ruptured piping and damage to pipe supports. Whenever incompressible fluids exist in a piping system, the potential exists for water hammer. The risks of water hammer developing are particularly high when the velocity of the fluid is high, there is a large mass of fluid moving and/or when there are large elevation changes within the piping systems. The check valve shown in Figure 10 is specially designed for use on the discharge side of reciprocating air or gas compressors. It includes a pulse damping chamber to maintain the disc in the open position during the momentary reductions in flow associated with each cycle of a reciprocating compressor and to protect against premature seat wear.

Restrictor check valves are generally used for applications that require higher cracking pressures to open the check valve. They should not be considered a substitute for a pressure-relief valve.

A general check valve trouble shooting guide is given in Table 2.

The operation of in-line check valves is not normally affected by their proximity to elbows, 'Ts' control valves, etc. It is not good practice to install

Table 1. In-line check valves

Applications
Building maintenance
Compressor discharge
Condensate lines
Pump discharge
Steam lines
Water lines
Chemical processing
Boiler feed and discharge
Compressor discharge
Condensate lines
Cooling towers
Cryogenics
Evaporators
Metering pumps
Mineral dewatering
Nitrogen purge
Process lines
Pump discharge
Steam lines
Vacuum lines and breakers
Water treatment
Food, beverage and drug
Autoclaves
Boiler feed and discharge
Chemical lines
Compressor discharge
Condensate lines
Cookers
Evaporators
Metering pumps
Pump discharge
Refrigeration (hot gas defrost)
Steam lines
Vacuum lines and breakers
Mining
Boiler feed and discharge
Mine dewatering
Petroleum production and refining
Boiler feed and discharge
Compressor discharge
Condensate lines
Cooling towers
Crude and refined product lines
Evaporators
Generator inlet and discharge
Petroleum production and refining
Pump discharge
Steam lines
Vacuum lines and breakers
Water treatment
Power generation
Boiler feed and discharge
Compressor discharge
Cooling towers
Evaporators
Fly ash system
Pump discharge
Steam lines
Vacuum system
Water lines
Primary metals
Chemical lines
Compressor discharge
Condensate lines
Evaporators
Extrusion equipment
Hydraulic lines
Presses — water inlet and outlet
Pump discharge
Steam lines
Water lines
Water treatment
Pulp and paper
Boiler feed and discharge
Chemical lines
Condensate lines
Generator inlet and discharge
Metering pumps
Pump discharge
Steam lines
(digester and paper machines)
Water treatment
Textiles
Boiler feed and discharge
Chemical dye lines
Compressor discharge
Condensate lines
Metering pumps
Pump discharge
Steam lines

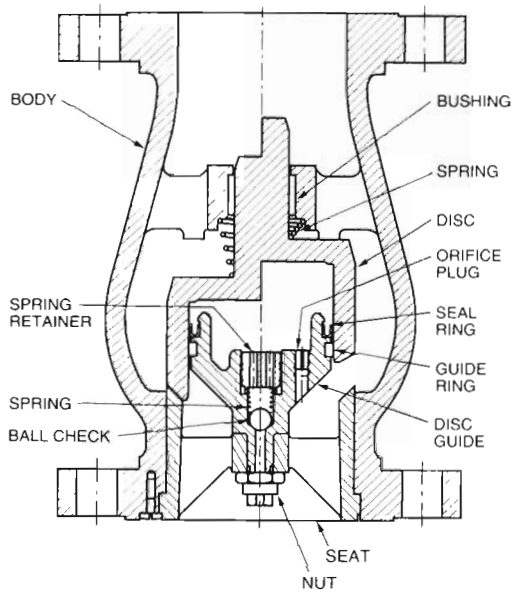


Figure 10. Check valve for reciprocating compressors.

in-line check valves directly to the outlet of such devices as it can result in decreased life due to turbulence caused by the fitting. Some manufacturers recommend that in-line check valves be installed a minimum of five pipe-diameters downstream of any fitting that would cause turbulence. The flow arrow on the body casing, if shown, must be pointed in the direction of the flow.

Wafer check valves

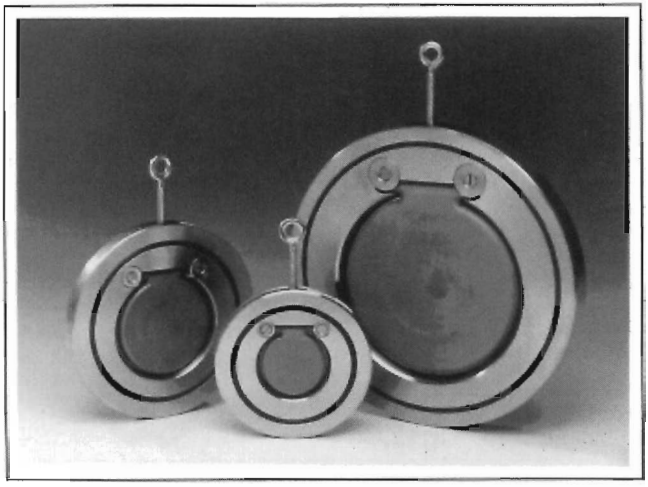
Typically wafer-style-design check valves are used as an effective solution for the prevention of reverse flow in pipes carrying most types of liquids, steam gases, and vapours. They are usually designed to fit between two pipeline flanges.

The valves are opened by the flow pressure of the fluid and closed by a spring when flow ceases and before reverse flow can occur (Figure 11).

Typical applications include:

- Steam boiler flooding protection
- Pipeline fitting protection
- Prevention of reverse flow
- Vacuum breaker

A typical wafer check valve with its pressure-loss diagram is shown in Figure 12.



Water-type check valve.

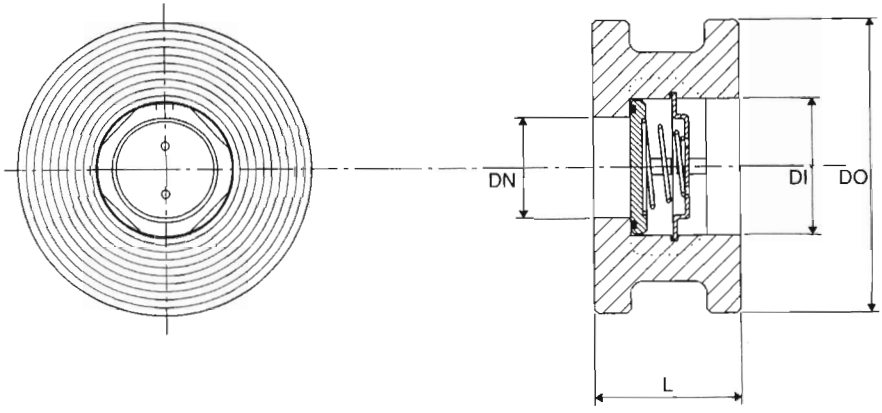
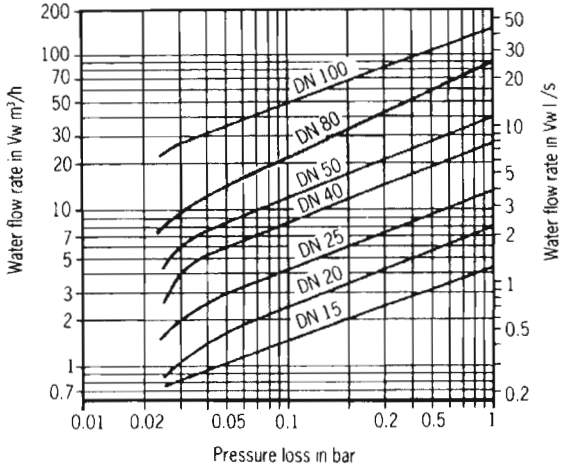


Figure 11. Spring disc wafer check valve.

Hydraulic and pneumatic check valves

Check valves employed in hydraulic and pneumatic applications are more comprehensively covered in the Hydraulic Handbook and the Pneumatic Handbook both published by Elsevier Science Limited. These valves are generally used where high pressures (up to 10,000 lb/in^2) in standard form where positive leak-tight sealing is required.

Pressure loss diagram



Pressure loss diagram with open valve at 20°C

The values indicated are applicable to spring loaded valves with horizontal flow. With vertical flow, insignificant deviations occur only within the range of partial opening.
The curves given in the chart are valid for water at 20°C. To determine the pressure drop for other fluids the equivalent water volume flowrate must be calculated and used in the graph.

$$Vw = \sqrt{\frac{Q}{1000}} \times V$$

Vw = Equivalent water volume flow in l/s or m³/h
Q = Density of fluid kg/m³
V = Volume of fluid l/s or m³/h

Figure 12. Typical wafer-type check valve and pressure loss diagram.

Table 2. Check valve trouble-shooting guide

Symptom	Cause	Solutions
Water hammer, loud noise, vibration, ruptured piping, equipment damage.	Slow-closing check valve.	In-line spring assisted check valve.
Steam wear (pointed stem), elongated seat guide, bushing wear.	Low flow, pulsating flow, improper sizing.	Custom sizing of the check valve intervals. PDC for reciprocating air or gas medium.
Excessive seat leakage (greater than MSS-SP61).	Dirt, trash, foreign substance in the valve.	Clean out the valve. Install strainers if it is a recurring problem. Install a soft seat if bubble tight shut-off is required.
Noise, clicking, tapping.	Low flow, pulsating flow, improper sizing.	Custom sizing of the check valve internals. PDC for reciprocating air or gas medium.
Reverse flow.	Slow-closing check valve.	In-line spring-assisted check valve.
Component breakage, valve failure.	Reciprocating compressor.	PDC for reciprocating air or gas medium.
Missing internals.	Valve not full open, pulsing flow, improper sizing.	Custom sizing of the check valve internals. PDC for reciprocating air or gas medium.

Various types of hydraulic and pneumatic check valves are shown in Figure 13. The distinguishing feature of these valves is their zero leakage achieved by a flexible seal seat (Figure 14).

The flexible seal seat design allows the poppet in the check valve to impact only slightly on the 'O' ring in the closed position. The metal-to-metal contact between the poppet and the end cap serves as a mechanical seat. Under reverse pressure, the 'O' ring flexes only as much as is needed to seal around the nose of the poppet and to expel any foreign particles. As a result the 'O' rings are protected from excessive wear.

Five flow holes drilled into the poppet core are positioned to provide a streamlined flow path through the valve. The combined area of these holes is greater than the area of either the inlet or outlet parts. The flow is directed through the centre of the spring.

Typically, hydraulic and pneumatic check valves incorporate ball-type, poppet, cartridge shuttle and split-flange designs and are used in a wide variety

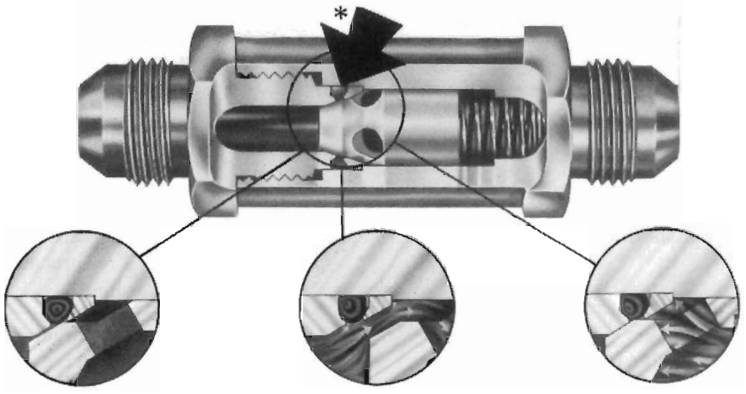


*Figure 13. Hydraulic and pneumatic check valve with flexible seal seat design. *Flexible seal seat.*

*Figure 14. Hydraulic and pneumatic check and relief valves. *Flexible seal seat.*

of industries including agriculture, aerospace, road equipment, robotics, industrial machinery, medical equipment instrumentation and controls, chemical processing and handling.

Check valves are commonly used in combination with flow control valves, the type and operating characteristics of which can influence the choice of check valve type.

Suitable combinations are:

Swing check valve—used with ball, plug, gate or diaphragm control valves.

Lift check valve—used with globe or angle valves.

Piston check valve—used with globe or angle valves.

Butterfly check valve—used with ball, plug, butterfly, diaphragm or pinch valves.

Spring-loaded check valves—used with globe or angle valves.

The exception is the foot valve, normally associated with a pump (i.e. there is no other valve positioned between the foot valve and the pump).

See also chapters on Swing check/Flap valves, Non-return valves, Water services.

Safety and Relief Valves

Valves that are vital for the protection of people and plant are termed Safety and Relief Valves. These valves operate automatically when a predetermined pressure level is exceeded by releasing an adjustable spring which holds a valve disc against a valve seat.

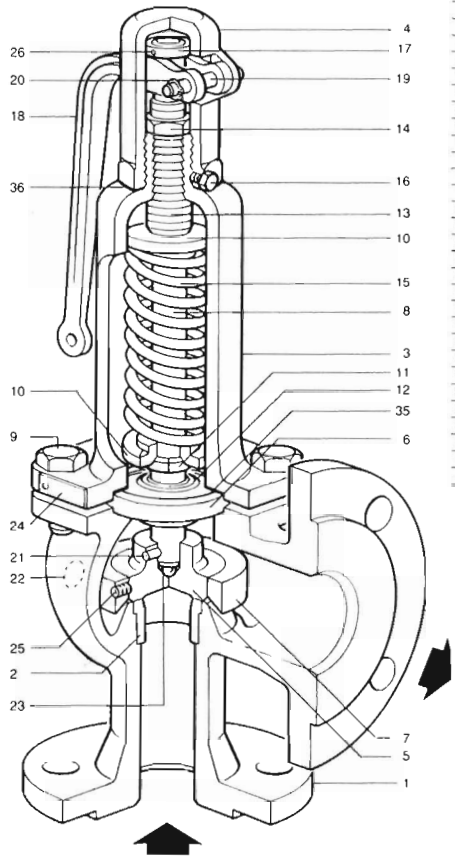
There are, however, distinctions between safety valves and relief valves that lead to the following definitions and terminology.

- Safety Valve—A valve which automatically discharges gases and vapours so as to prevent a pre-determined safe pressure being exceeded. It is characterised by a rapid full-opening action and used for steam, gases or vapour service (Figure 1).

Safety valves can be further categorised as follows:

(i) Low-Lift Safety Valve—A low-lift valve in which the disc lifts automatically such that the actual discharge area is determined by the position of the disc.
(ii) Full-Lift Safety Valve—A valve in which the disc lifts automatically such that the actual discharge area *is not* determined by the position of the disc.
(iii) Pilot-Operated Safety Valve—A safety valve, the operation of which is initiated and controlled by the fluid discharged from a pilot valve which is itself a direct loaded safety valve.

- Relief Valve—A valve which automatically discharges fluid, usually liquid when a pre-determined upstream pressure is exceeded (Figure 2). It may be provided with an enclosed spring housing suitable for closed discharge system application.
- Pressure Relief Valve—A safety device designed to protect a pressurised vessel or system during an overpressure event, by relieving excess pressure, and to reclose and prevent the further flow of fluid after normal conditions have been restored. It is characterised by a rapid opening pop action or by opening generally proportional to the increase in pressure over the opening pressure (Figure 3).



Materials of construction

Item	Component	Material - SV 57 / SV54
1	Body	GGG-40.13/GSC-25
2	Seat	1.4507
3	Bonnet	GGG-40.3/GS-C25
4	Cap	GGG-40.3
5	Disc	1.4507
6	Disc guide	GGG-40.3
7	Skirt	1.4031
8	Spindle	1.4034
9	Body Bolts	DIN-931 5.6 ZN/DIN-933 CK-35
10	Spring washers	CK 45
11	Retainer ring	1.4034
12	Guide sleeve	1.4031
13	Spring adjustment screw	1.4034
14	Lock nut	Carbon steel DIN 1651 9S Mn 36 Zp
15	Spring	Carbon Steel DIN 17225 50 crV4
16	Cap bolt	DIN-931 5.6 ZN
17	Collar	Carbon steel Zinc
18	Lever	GGG 40.3
19	Pin	Carbon steel Zinc
20	Circlip	DIN-471 Carbon steel
21	Pin	DIN-7343
22	Drain Hole	½" BSP
23	Spindle Ball	1.4034
24	Identification plate	Aluminium
25	Locking Screw	DIN-913 A2
26	Ring pin	DIN- 1481
27	Lever stem	1.4034
28	Cam	GGG-40.3
29	Packing	Graphite
30	Gland	1.4305
31	Nut	DIN-1471
32	O - Ring retainer	1.4031
33	O - Ring	According to service
34	Gland nut	C. steel
35	Gasket (relief only)	Asbestos free
36	Gasket (relief only)	Asbestos free

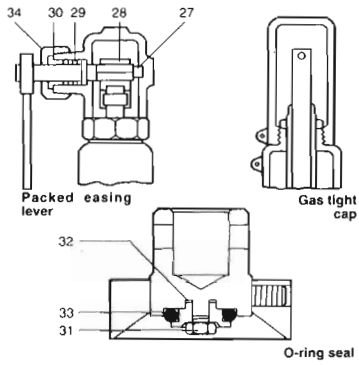
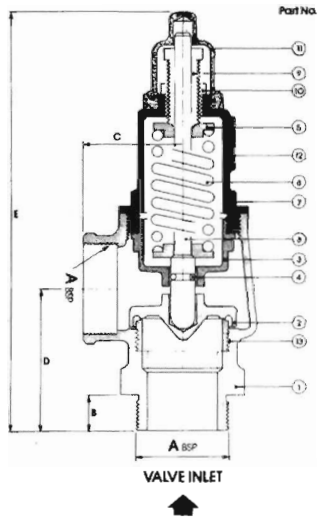


Figure 1. Safety valve suitable for steam, gas and liquid service.

- Pilot-Operated Pressure Relief Valve—A second type of pressure relief valve in which the major relieving device is combined with and is controlled by a self-actuated auxiliary pressure relief valve.
- Safety Relief Valve—A valve which will automatically discharge gases, vapours or liquids so as to prevent a pre-determined safe pressure being exceeded. It is characterised by a rapid full-opening action or by opening in proportion to the increase in pressure over the opening pressure, depending on the application, and may be used either for liquid or compressible fluid (Figure 4).



1	BODY
2	VALVE DISC
3	GUIDE
4	'O' RING
5	SPRING PLATE
6	SPRING
7	COVER
8	SPINDLE
9	ADJUSTING SCREW
10	LOCKNUT
11	DOME
12	NAMEPLATE
13	RENEWABLE SEAT

Figure 2. Liquid relief valve.

Figure 3. Pressure relief valve.

Figure 4. Full-lift safety relief valve.

A safety relief valve can be further categorised as:

(i) A Conventional Safety Relief Valve—A valve which has a spring housing vented to the discharge side of the valve. The operational characteristics (open and closing pressure and relieving capacity) are directly affected by changes of the back pressure on the valve.

(ii) A Balanced Safety Relief Valve—A valve which incorporates means of minimising the effect of back pressure on the operational characteristics (opening and closing pressure and relieving capacity).

Since all of these types of valves are safety devices, there are many codes and standards throughout the world written to control their design and application. Some of these codes and standards are shown in Table 1. Among the most widely used is the ASME Boiler and Pressure Vessel Code, commonly referred to as the ASME Code.

More specific information may be found by referring to this code, various published standards and by consulting literature published by safety and relief valve manufacturers.

Safety Valves

Typical operating parameters for safety valves are given in Table 2. Safety valve set pressure and temperature limits are governed by a number of factors and may not always coincide with manufacturers' published limits for the applicable materials and flange ratings. Particular limits may be based on spring limitations, specific material selection or other design considerations. With boiler applications, for example, set pressures and total capacity requirements for safety valves are usually established by the design agent or boiler manufacturer.

Safety valves are intended to open and close within a narrow pressure range; therefore, valve installations require careful and accurate design, both as to inlet and discharge piping. The higher the operating pressure and the greater the valve capacity, the more critical becomes the need for proper design of the installation.

Safety valves should always be mounted in a vertical position directly on nozzles having a well rounded approach that provides smooth, unobstructed flow from the vessel or line to the valve.

A safety valve should never be installed on a nozzle having an inside diameter smaller than the inlet connection to the valve, or on excessively long nozzles. The pressure drop occurring in the inlet piping should be calculated at actual flow of the valve. Where safety valves are installed to protect piping systems, as on the low pressure side of a reducing valve or on a turbine by-pass, the pipe or header must be of sufficient size to maintain flow under the safety valve while it is discharging. A typical design of a pop-type safety valve is shown in Figure 5.

Table 1. Codes and standards

Regulatory body	Codes and standards
Allami Energerhkai es Energiabiztonsagtechnikai Felugyelet (AEEF) (State Authority for Energy, Management and Safety) Budapest VIII Koztarsasag ter 7. Hungary	Safety Valves 22/1969/VI.12 (mod) 29/1960/VI.7 (orig)
American National Standards Institute 1430 Broadway New York, NY 10018, USA	B16.34 Steel Valves, Flanged and Buttwelded Ends B16.5 Steel Pipe Flanges and Flanged Fittings B31.1 Power Piping B31.3 Chemical Plant and Petroleum Refinery Piping B31.4 Liquid Petroleum Transportation Piping Systems B95.1 Terminology for Pressure Relief Devices ANSI/ASME PTC 25.3 Performance Test Code, Safety and Relief Valves
American Petroleum Institute 2101 L Street Northwest Washington, DC 20037, USA	API RP 510 Pressure Vessel Inspection Code API RP 520 Recommended Practice for the Design and Installation of Pressure Relieving Systems in Refineries: Part 1—Design; Part II—Installation API RP 521 Guide for Pressure Relief and Depressuring Systems API Standard 526 Flanged Steel Safety Relief Valves API Standard 527 Commercial Seat Tightness of Safety Relief Valves with Metal to Metal Seats API 2000 Venting Atmospheric and Low Pressure Storage Tanks API Guide for Inspection of Refinery Equipment Chapter XVI—Pressure Relieving Devices
The American Society of Mechanical Engineers United Engineering Center 345 East 47th Street New York, NY 10017, USA	Boiler and Pressure Vessel Code Section I—Power Boilers Section II—Materials Section IV—Heating Boilers Section VII—Care of Power Boilers Section VIII—Pressure Vessels Section IX—Welding and Brazing Qualifications

Table 1 (*continued*)

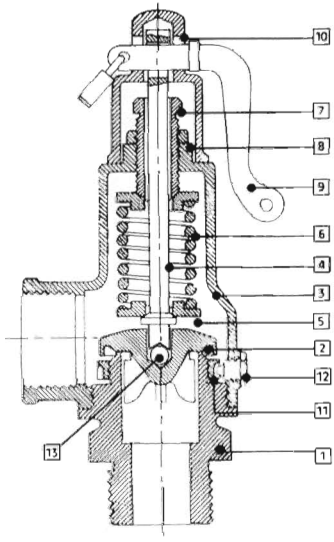
Regulatory body	Codes and standards
Association Francaise de Normalisation Tour Europe Cedex 7 F-92049 Paris La Defence, France	NFE 29-410 to 420
Australian Standards Association No. 1 The Crescent Homebush New South Wales 2140, Australia	AS1271 Safety Valves, Other Valves, Liquid Level Gages and Other Fittings for Boilers and Unfired Pressure Vessels 1990 Edition AS1210 Unfired Pressure Vessels (EAA Unfired Pressure Vessel Code) 1989 Edition AS1200 Pressure Equipment 1994 Edition
British Standards Institute 389 Chiswick High Road London W4 4AL, England	BS6759 Parts 1, 2 and 3 Safety Valves
Canadian Standards Association 178 Rexdale Boulevard Toronto, Ontario M9W 1R3, Canada	CSA Z299.2.85 (R1991)—Quality Assurance Program—Category 1 CSA Z299.3.85 (R1991)—Quality Assurance Program—Category 3 CSA Z299.4.85 (R1991)—Quality Assurance Program—Category 4
Chlorine Institute Inc. 2001 L Street, NW Washington, DC 20036, USA	Pamphlet Type 1-1/2″ JQ Pamphlet 41 Type 4″ JQ
CC NASTHOL Shenogina Street 123007 Moscow, Russia	GOST R Certification System
Deutsche Institut Fur Normung Burggrafenstrasse 6 D-10787 Berlin, Germany	DIN 50049 Materials Testing Certificates
Comite Europeen de Normalisation (European Committee de Standardisation) rue de Stassart 36 B-1050 Brussels, Belgium	CEN Standards for Safety Valves Pressure Equipment Directive
Heat Exchange Institute, Inc. 1300 Sumner Avenue Cleveland, OH 44115, USA	HEI Standards for Closed Feedwater Heaters
International Organisation for Standardisation Case Postale 56 CH-1211 Geneve 20, Switzerland	ISO-900 Quality System ISO-4126 Safety Valves—General Requirements

Table 1 (*continued*)

Regulatory body	Codes and standards
I.S.C.I.R. Central Bucuresti Frumoasa nr. 26, Romania	Romanian Pressure Vessel Standard
Japanese Industrial Standard Committee Japanese Standards Association 1-24, Akasaka 4-chome, Minato-ku Tokyo 107 Japan	JIS B8210 Spring Loaded Safety Valves for Steam Boilers and Pressure Vessels
Manufacturers' Standardization Society of the Valve and Fitting Industry 1815 North Fort Myer Drive Arlington, VA 22209, USA	SP-6 Finishes of Contact Faces of Connecting End Flanges SP-9 MSS Spot Facing Standard SP-55 Quality Standard for Steel Castings
Ministerie Van Sociale Zaken En Werkgelegenheid Directoraat Generaal Van De Arbeid Dienst Voor Het Stoomwezen 2517 KL Gravenhage Eisenhowerlaan 102, The Netherlands	Stoomwezen Specification A1301
National Association of Corrosion Engineers P.O. Box 1499 Houston, TX 77001, USA	NACE MR0175
National Board of Boiler and Pressure Vessel inspectors 1055 Crupper Avenue Columbus, OH 43229, USA	NB-25 National Board Inspectors Code NB-65 National Board Authorization to Repair ASME and National Board Stamped Safety Valves and Relief Valves
National Fire Protection Association Batterymarc-Park Quincy, MA 02269, USA	NFPA 30 Flammable and Combustible Liquids Code
Schweizerisher Verein fur Druckbehalteruberwachung (SDVB) Postfach 35 8030 Zurich, Switzerland	Specifications 602—Safety Valves for Boilers and Pressure Vessels
Den Norske Trykkbeholderkomite (TBK) Norsk Verkstedsindustris Standardiseringssentral Oscarsgate 20, Oslo, Norway	TBK General Rules for Pressure Vessels
Verband der Technischen Uberwachungs-Vereine e. V (TUV) Kurfurstenstraße 56 4300 Essen 1, Germany	TRD 421 AD-Merkblatt A2

Table 2. Safety valve operating parameters

Parameter	Definition
Set pressure (also known as crack pressure)	(i) *Liquid services:* inlet pressure at which valve starts to discharge under service conditions. (ii) *Gas or steam services:* inlet pressure at which the valve pops under service conditions.
Differential set pressure	Difference between set pressure and back pressure (where present).
Overpressure	Pressure increase over the set pressure of the valve or relief device.
Blowdown	Difference between the set pressure and resetting pressure expressed either as a specific pressure or percentage of the set pressure.
Back pressure	Any pressure on the discharge side of a pressure-relief valve.
Accumulation	Pressure increase over maximum allowable working pressure of a vessel or system during discharge through the pressure relief valve.
Operating pressure	Normal allowable working pressure of the system or vessel.



No	PART	MATERIAL
1	SEAT	GUNMETAL
2	VALVE DISC	GUNMETAL
3	BODY	GUNMETAL
4	SPINDLE	H.T.BRASS
5	SPRING END PLATE	BRASS
6	SPRING	STEEL-ZINC PLATED
7	ADJUSTING SCREW	BRASS
8	LOCK NUT	BRASS
9	LEVER	BRONZE
10	DOME	GUNMETAL
11	BLOWDOWN RING	GUNMETAL
12	SETTING SCREW	H.T.BRASS
13	BALL	STAINLESS STEEL

Figure 5. Typical pop-type safety valve.

The discharge piping from safety valves should be equal in size to, or larger than, the nominal valve outlet and should be as simple and direct as possible. Good practices must be observed with discharge manifold lines. All discharge piping in the discharge system must be vented to a safe disposal area to prevent personnel injury when the valve discharges.

The valve shown in Figure 6a is typically used for steam generators and steam systems. It is a high capacity reaction-type valve designed specifically for saturated steam service on boiler drums having design pressures above 103 bar (1500 lb/in^2).

A typical valve operating cycle (Figure 6b) is as follows:

As pressure in, say, a boiler increases to the safety valve set point the valve will pop open. After the valve opens steam passes through a series of annular flow passages (A) and (B) which control the pressure developed in chambers (C) and (D). The excess steam is exhausted through guide ring openings (E) to the valve body bowl (F).

As pressure in the boiler decays, the dynamic forces on the lower face of the disc holder assembly are reduced and the safety valve disc begins to close. Assisted by pressure in chambers (C) and (D), the valve at this point closes sharply and tightly.

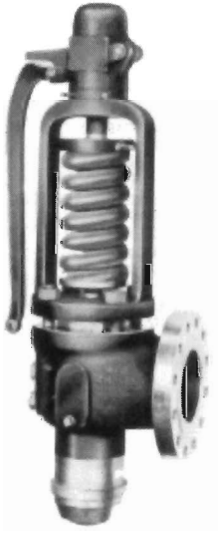


Figure 6A. Safety valve for saturated steam applications.

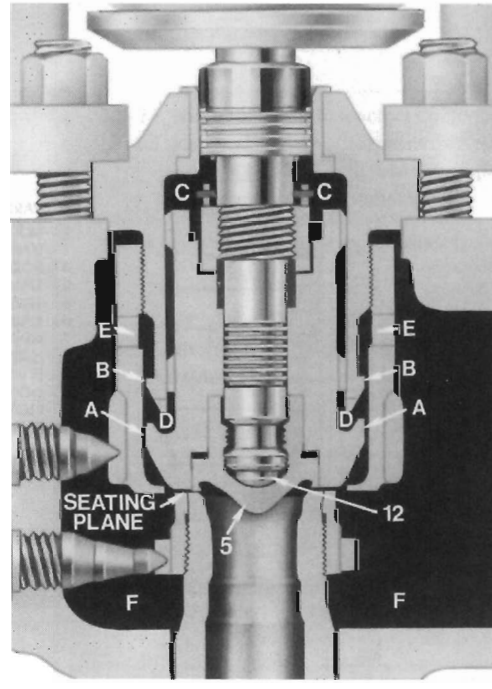


Figure 6B. Safety valve operating principle.

Figure 7 shows a safety valve frequently used in process applications. The valve has a closed bonnet that contains the process fluid within the safety valve preventing any release to atmosphere.

In Figure 8, the safety valve incorporates a balanced bellows to provide satisfactory safety valve performance when the developed back pressure becomes excessive. Balanced bellows ensure that safety valve characteristics such as lift and relieving capacity, opening and closing pressure and stability are not unduly influenced by static pressure in the discharge manifold.

Balanced safety valves must be installed when the percentage build-up back pressure in the exhaust system is allowed to exceed the percentage overpressure applicable to the safety valve. Valves that vent to the atmosphere, either directly or through short vent stacks, are not subjected to elevated back pressure conditions. Valves installed in a closed system, i.e. on corrosive, toxic or valuable recoverable fluids, or when a long vent pipe is used, may develop high back pressure. Back pressure which may occur in the downstream system while the safety valve is closed is called superimposed back pressure. Back pressure which may occur after the valve is open and flowing is called dynamic or built-up back pressure.

Figure 9 shows a double-spring high-lift safety valve that combines a top guided design to provide an unobstructed seat bore with a floating disc.

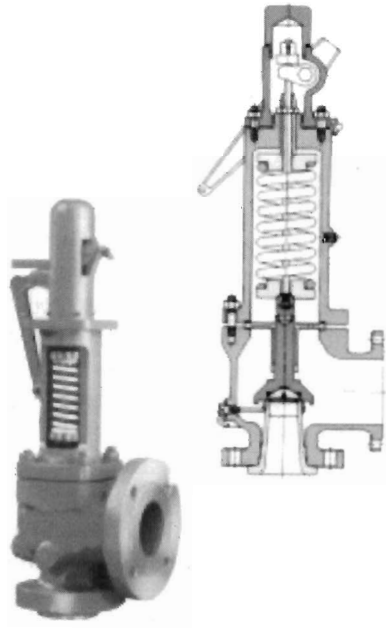


Figure 7. Basic safety valve for process applications (closed bonnet type).

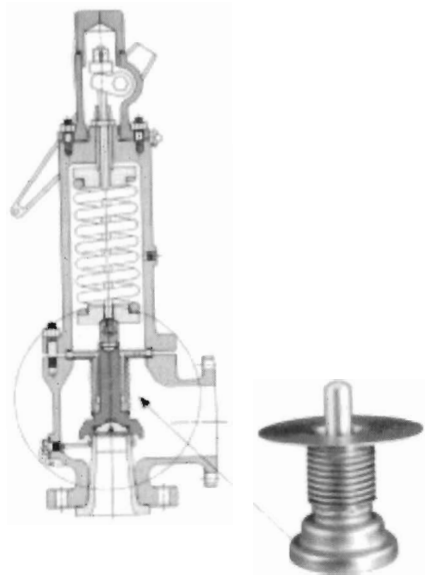


Figure 8. Safety valve for process applications (balanced bellows type).

Relief Valve

A basic difference between the design of spring-loaded safety valves and relief valves is that, in safety valves, the poppet or disc overhangs the seat to promote faster lift whereas, in a relief valve, the area exposed to overpressure is the same whether the valve is open or closed. As a consequence, a safety valve pops open while a relief valve lifts gradually with increasing pressure until it reaches its fully open position.

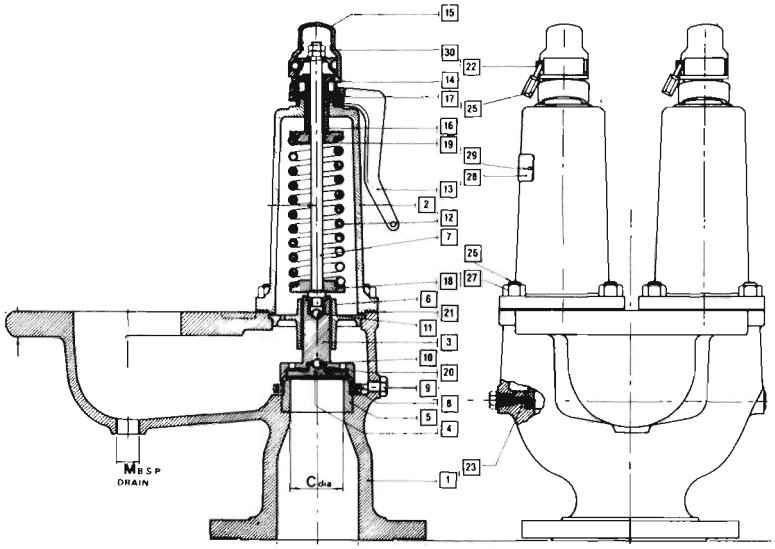
The relief valve shown in Figure 10 is a standard type suitable for relieving excess pressures of water oil, air, gases or steam where high discharge rates are not required. Duties include the protection of pipelines against overpressure and protection against thermal expansion. It is filtered in the upright position. A spring-loaded side-discharge version is shown in Figure 11.

Other spring relief valves have cartridge-type assemblies for easy cleaning. They are usually suitable for use with positive displacement pumps of the rotary or reciprocating type. They can also be used as combined relief and by-pass valves.

The relief valve (Figure 12) is manufactured from plastic —PVC, PVDF and CPVC with solid Teflon®* shaft, intended as a chemical-resistant relief valve for corrosive and pure liquids. The relieving pressures can be adjusted by screwing the adjusting bolt up or down to decrease or increase the pressure setting.

This type of valve is *not* a pop safety-type valve.

*Dupont registered trade mark.



1	Body	11	Spindle Ball	21	Body Gasget
2	Cover	12	Spring Steel	22	Locking Pin
3	Valve Disc Holder	13	Easing Lever	23	Seat Securring Pin
4	Valve Disc	14	Dome	25	Padlock
5	Seat Ring	14a	Screwed Dome	26	Body Stud
6	Guide	15	Dome Cap	27	Body Stud Nut
7	Spindle	16	Adjusting Screw	28	Nameplate
8	Blow Down Ring	17	Locknut	29	Nameplate Screw
9	Setting Screw	18/19	Spring Plate	30	Locknut
10	Valve Disc Ball	20	Disc Retaining Clip		

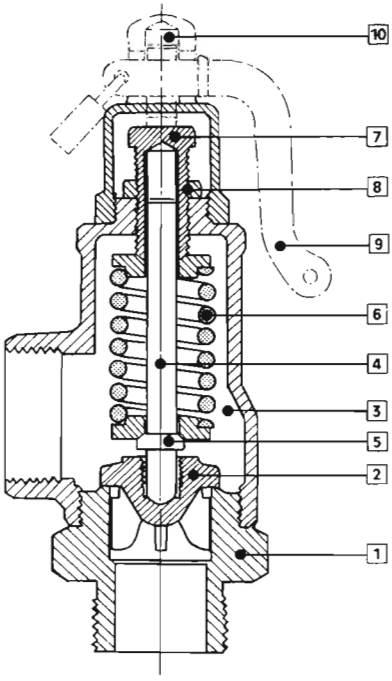
Figure 9. Double-spring high-lift safety valve.

Emergency relief valves of the type shown in Figure 13 are designed to meet the stringent conditions of container, rail, road and static tanks for emergency venting under total fire engulfment conditions. Usually manufactured from 316 stainless steel, these types of valves can incorporate a manually operated vacuum vent button.

The type of relief valves shown in Figure 14 is ideally suited for air, acetylene, ammonia, freon 12 and 22, hydrogen, carbon dioxide, oxygen, aromatic fuels, synthetic oils, tetrachloride and toluene, at operating pressures up to 2400 lb/in^2. It can be mounted in horizontal and vertical positions.

In closed operation, the spring load is carried by a metal-to-metal seat. An O-ring provides a tight seal and the sealing efficiency increases as the pressure increases up to cracking pressure. At cracking pressure the ports in the poppet open fully and eliminate the rapid increase in pressure. Flow is throttled between the poppet shoulder and seat and a regularly increasing flow area is

Figure 10. Standard spring-operated relief valve.



1	Seat	Gunmetal
2	Valve Disc	Gunmetal
3	Body	Gunmetal
4	Spindle	H.T. Brass
5	Spring End Plate	Brass
6	Spring Sheradized	
7	Adjusting Screw	Brass
8	Lock Nut	Brass
9	Lever	Bronze
10	Lever Dome	Plastic
10a	Leak Proof Dome	Gunmetal

Figure 11. Spring-loaded side-discharge relief valve.

provided with increasing flow rates. When fully open, the inline construction and full flow ports permit maximum flow with minimum increase in system pressure (see Figure 15).

High pressure variants operate at pressures up to 10,500 lb/in^2.

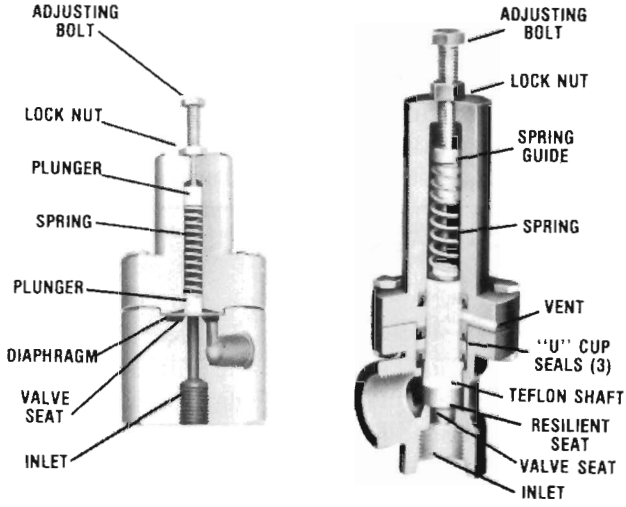


Figure 12. Chemical-resistant relief valves.

Figure 13. Emerging relief valves.

Pressure Relief Valves

The basic spring-loaded pressure relief valve (Figure 16) has been developed to provide overpressure protection.

- Overpressure may be defined as a pressure increase over the set pressure of a pressure relief valve, usually expressed as a percentage of set pressure.
- Set pressure is the pressure measured at the valve inlet at which a pressure relief valve should commence to lift under service conditions.
- Popping pressure is the value of increasing static pressure at which the disc moves in the opening direction at a faster rate as compared with corresponding movement at higher or lower pressures.

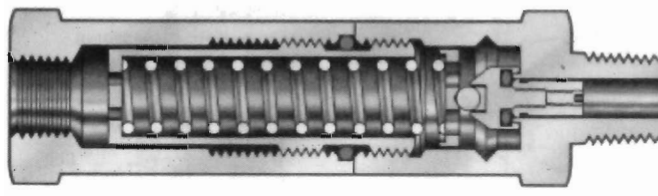


Figure 14. High-pressure relief valve.

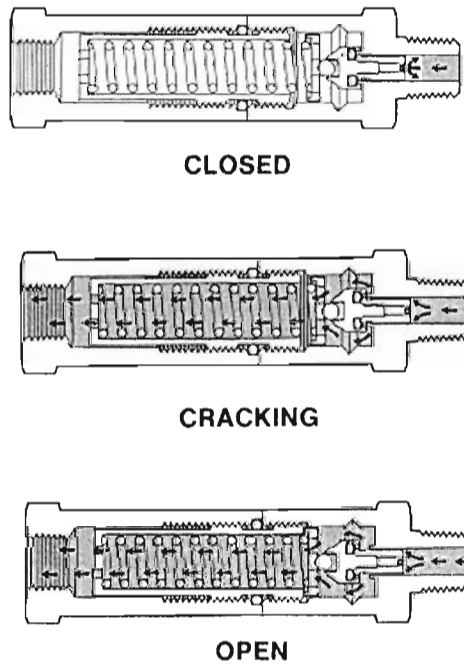


Figure 15. High-pressure relief valve method of operation.

The valve shown in Figure 16 consists of a valve inlet or nozzle mounted on the pressurised system, a disc held against the nozzle to prevent flow under normal system operating conditions, a spring to hold the disc closed, and a body or bonnet to contain the operating elements. The spring load is adjustable to vary the pressure at which the valve will open.

The sole source of power for the pressure relief valve is the process fluid.

The pressure relief valve must open at a pre-determined set pressure and close when the system pressure has returned to a single safe level. Pressure relief valves must be designed with materials compatible with many process fluids from simple air and water to the most corrosive media. This type of valve is required to remain on systems for long periods of time and must have the ability to maintain tight shut-off. Most manufacturers recommend that system operating pressures not exceed 95% of set pressure to achieve and maintain proper seat tightness integrity.

Examples of spring-loaded pressure relief valves are given in Figure 17.

A rupture disk device (Figure 18) is a non-reclosing pressure relief device actuated by inlet static pressure and designed to function by the bursting of a pressure containing disk. A rupture disk is the pressure containing and pressure sensitive element of a rupture disk device. These products provide full opening with instantaneous pressure relief in the event of system upset. Application of rupture disk devices to liquid service should be carefully evaluated, especially if used in combination with a safety or safety relief valve.

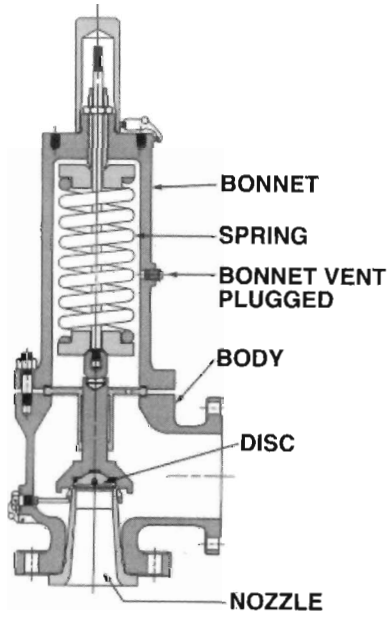
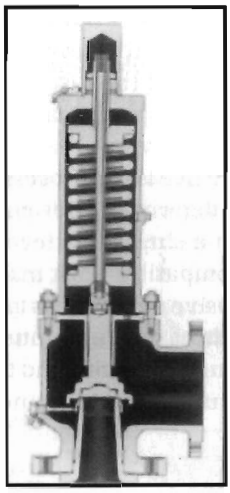
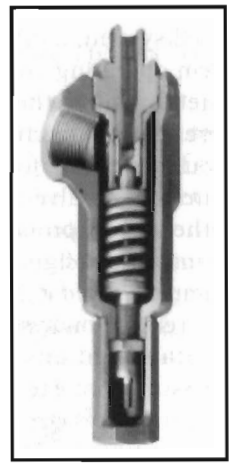


Figure 16. Standard spring-loaded pressure relief valve.





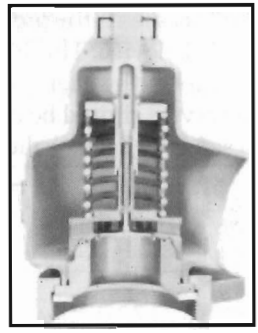
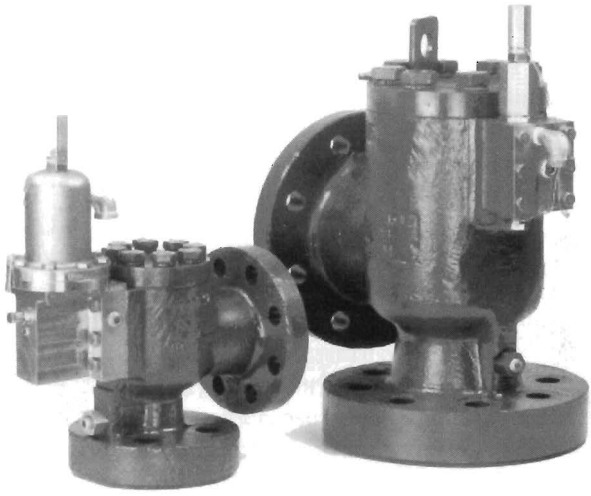


Figure 17. Pressure relief valves: top left—standard valve; top right—screwed valve with single trim; lower—sanitary valve for foodstuffs and pharmaceuticals.

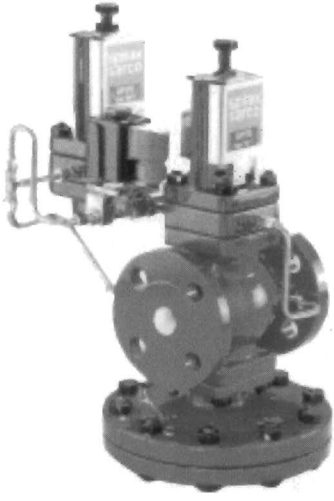
Pilot-Operated Pressure Relief Valve

This type of valve consists of a main valve with a piston- or diaphragm-operated disc and a pilot. Under normal conditions the pilot allows system pressure into the piston chamber. Since the piston area is greater than the disc seat seal area, the disc is held closed. When the set pressure is reached, the pilot actuates to shut off system fluid to the piston chamber and simultaneously vents the piston chamber. This causes the disc to open (Figure 19).

Another version of a pilot-operated pressure reducing valve is shown in Figure 20. Other constructions have integral porting, eliminating the need for tubing to activate the valve and relieve the system pressure, as all pressurisation is performed through porting machined into the main valve and the mating pilot valves.



High-pressure pilot-operated safety relief valve.



Two pilots combined on the main body of a pressure-reducing valve.

Pilot-operated relief valves have several advantages. As the system pressure increases, the force holding the disc in the closed position increases. This allows the system operating pressure to be increased to values within 5% of set pressure without danger of increased leakage in the main valve. Valves can be set fully open at the set pressure and closed with a very short blowdown. A reducing valve will modulate from its maximum capacity down to zero load when it will shut. However, if the valve is to work under low load conditions for much of its life, there may be a good case for fitting two smaller valves in parallel.

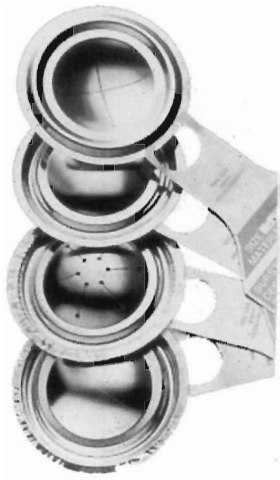


Figure 18. Rupture disk device.

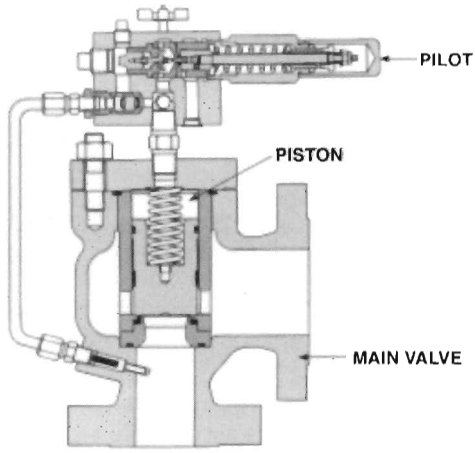


Figure 19. Snap-acting pilot-operated pressure relief valve.

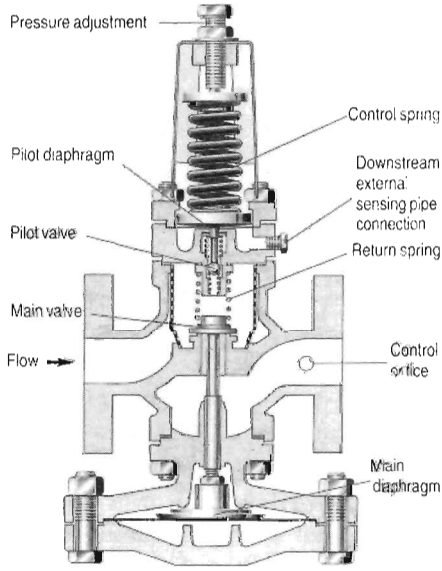


Figure 20. Standard pilot-operated pressure-reducing valve for steam, air and industrial gases.

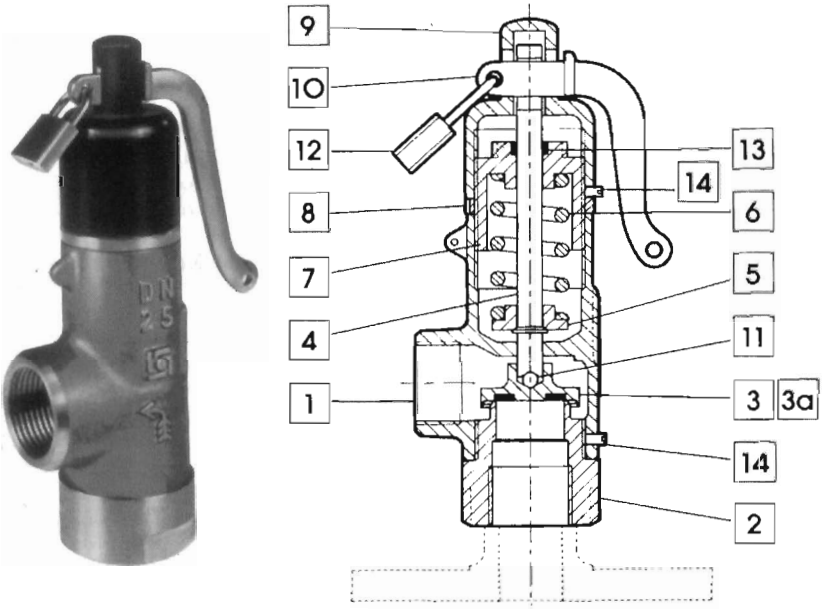
Modulating pilot valve designs limit fluid loss and system shock. However, this type of valve is generally only recommended for clean service and is found in a broad range of applications and industries including steam, air and industrial gases, petroleum-refining offshore applications, chemical processing, pulp and paper mills and general manufacturing. There are numerous styles and designs available from many manufacturers.

Safety Relief Valve

The purpose of a safety relief valve is to discharge a given amount of vapour, gas or liquid, whilst preventing the pressure increase exceeding a pre-determined level. The safety relief valve should close with the smallest drop in pressure consistent with tight closure, and it should remain pressure-tight up to the time of the next response to an overpressure situation. A standard safety relief valve is shown in Figure 21.

The valve must be reliable so that the action is always a repeat of the previous action. A safety relief valve should be used on any closed vessel or system in which the pressure can be other than atmospheric and where, under any circumstances, the design pressure of the system can be exceeded.

In most instances the discharge pipework is direct to atmosphere, but when the medium is toxic, inflammable or otherwise objectionable, complex-type discharge pipework systems are used and, frequently, more than one valve discharges into the system, resulting in a variable back pressure at the safety relief valve.



1	Body	Gunmetal	7	Adjusting Screw	Brass
2	Seat	Gunmetal	8	Locking Ring	Brass
3	Resilient Disc	Brass-EPDM/Viton	9	Dome	Plastic
3a	Disc	Brass	10	Lever	Brass
4	Spindle	Brass	11	Ball	Stainless Steel
5	Spring Cap	Brass	12	Padlock	Brass
6	Spring	Chrome Vanadium or Stainless Steel	13	Bush	P.T.F.E
			14	Pinning Screw	Steel

Figure 21. Typical certified safety relief valve.

When such a discharge system is adopted, the safety relief valve must be designed in such a way that the effects of the variable back pressure on the set pressure are minimised. This requires the use of a balanced bellows valve.

The safety relief valve should be as maintenance-free as possible.

Sizing Safety and Relief Valves

Proper sizing and selection of safety and relief valves is critical. The first step in applying overpressure protection to a vessel or system is to determine the type of fluid, set pressure, back pressure, allowable overpressure and required relieving capacity; the next step is to establish inlet temperature, compressibility factor, gas constant or isentropic coefficient, molecular weight, specific weight, specific gravity and viscosity.

Sizing equations are available from manufactures and regulatory bodies, e.g. British Standards BS 6759, American Standards to ASME Code Section VIII and European Standards A.D. Merkblatt A2. All capacities can be calculated in accordance with the internationally accepted sizing equations using the certified coefficients of discharge. Typical sizing equations in accordance with specific standards are, for example:

In accordance with **BS 6759: 1984** [Modified for the effects of set pressure below 3.0 bar, back pressure and superheated steam]

For steam:

$$A = \frac{E}{0.525\,P.Kdr.Fp.Fb.F_{SH}} \quad \text{or} \quad E = 0.525\,P.A.Kdr.Fp.Fb.F_{SH}$$

For compressed air:

$$A = \frac{Q_1}{0.193\,P.Kdr.Fp.Fb.\sqrt{\frac{288}{T}}} \quad \text{or} \quad Q_1 = 0.193\,P.A.Kdr.Fp.Fb.\sqrt{\frac{288}{T}}$$

For gases:

$$A = \frac{Q_2}{P.C.Kdr.Fp.Fb.\sqrt{\frac{M}{ZT}}} \quad \text{or} \quad Q_2 = P.A.C.Kdr.Fp.Fb.\sqrt{\frac{M}{ZT}}$$

For liquids:

$$A = \frac{Q_2}{1.61\,Kdr.Fv.Fw.\sqrt{\rho\Delta P}} \quad \text{or} \quad Q_2 = 1.61\,A.Kdr.Fv.Fw.\sqrt{\rho\Delta P}$$

For hot water:

$$A = \frac{Q_3}{0.329\,Kdr.P.Hws.} \quad \text{or} \quad Q_3 = 0.329\,A.Kdr.P.Hws.\sqrt{\rho\Delta P}$$

Key to equations

A	=	Office area	mm^2
E	=	Required capacity of steam	kg/hr
Q_1	=	Required capacity of compressed air	l/s
Q_2	=	Required capacity of gas/liquid	kg/hr
Q_3	=	Required capacity of hotwater	kW
P	=	Absolute inlet pressure (set pressure + overpressure +1.013)	bar abs
ΔP	=	Relieving pressure – Back pressure (set pressure + overpressure – back pressure)	bar gauge
T	=	Inlet temperature	°K (°C + 273)
ρ	=	Liquid density	kg/m^3
M	=	Molecular weight	kg/kmol
Z	=	Compressibility factor	

$$Z = \frac{10^5 \text{ P.V.M.}}{\text{R.T.}}$$

where

R	=	Universal gas constant—8314 N.m./kmol.k
V	=	Specific volume of gas at STP conditions
C	=	Gas constant Use the following formula

$$C = 3.9458\sqrt{K\left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}}$$

K	=	Isentropic exponent at the relieving inlet conditions. If the value of K is not available at these conditions the value at 1.0135 bar abs and 15°C should be used

Capacity correction factors

Fp	=	Capacity correction factor for the effects of low set pressure
Fb	=	Capacity correction factor for the effects of back pressure (balanced bellows valves only)
Fv	=	Capacity correction factor for the effects of viscosity (liquids only)
Fw	=	Capacity correction factor for the effects of back pressure (liquids only; balanced bellows valves only)
Fsh	=	Capacity correction factor for the effects of superheat
Fdr	=	De-rated coefficient of discharge. Select Kdr appropriate to the fluid
Hws	=	Hotwater correction for vented system (0.5 if vented/1 if pressurised)

In accordance with **A.S.M.E. Code Section VIII and API RP 520**

[Modified for the effects of set pressure below 3.0 bar, back pressure and superheated steam]

Note:- When sizing valves in accordance with ASME Code Section VII, the certified capacity may only be calculated at 10% overpressure or 3 psig, whichever is the greater and without the use of correction factors Fp, Fb, Fv, Fw and Fsh. Set pressures below 15.0 psig may not be ASME stamped.

For steam:

$$A_1 = \frac{W}{51.5\,Pg.Kdr.Fp.Fb.F_{SH}} \quad \text{or} \quad W = 51.5\,Pg.A_1.Kdr.Fp.Fb.F_{SH}$$

For air/gases:

$$A_1 = \frac{Q.\sqrt{G.Tg.Z}}{1.175\,Pg.Cg.Kdr.Fp.Fb} \quad \text{or} \quad \frac{Q = 1.175\,Pg.Cg.A_1.Kdr.Fp.Fb}{\sqrt{G.Tg.Z}}$$

For liquids:

$$A_1 = \frac{V_L\sqrt{G}}{38\sqrt{\Delta P_L}\,Kdr.Fv.Fw} \quad \text{or} \quad V_L = \frac{38A_1\sqrt{P_L}Kdr.Fv.Fw}{\sqrt{G}}$$

Key to equations

A_1	=	Office area	in^2
Q	=	Required capacity of air/gases	SCFM
W	=	Required capacity of steam	lb/hr
V_L	=	Required capacity of liquid	usgpm
Pg	=	Absolute inlet pressure (set pressure + overpressure + 14.7)	psia
ΔP_L	=	Relieving pressure – Back pressure (set pressure + overpressure – back pressure)	psig
Tg	=	Inlet temperature	°R (°F + 460)
G	=	Specific gravity	
Z	=	Compressibility factor for the gas or vapour at P or T conditions (if not given use Z = 1)	
Cg	=	Imperial gas constant. Use the following formula	

$$Cg = \sqrt{K\left(\frac{2}{K+1}\right)^{\frac{K+1}{K-1}}}$$

K = Isentropic exponent at the relieving inlet conditions. If the value of K is not available at these conditions the value at 14.7 psi abs and 59°F should be used

Capacity correction factors

Fp	=	Capacity correction factor for the effects of low set pressure
Fb	=	Capacity correction factor for the effects of back pressure (balanced bellows valves only)
Fv	=	Capacity correction factor for the effects of viscosity (liquids only)
Fw	=	Capacity correction factor for the effects of back pressure (liquids only; balanced bellows valves only)
Fsh	=	Capacity correction factor for the effects of superheat
Kdr	=	De-rated coefficient of discharge. Select Kdr appropriate to the fluid

In accordance with **A.D. MERKBLATT A2**

[Modified for the effects of set pressure below 3.0 bar, back pressure and superheated steam]

For steam:

$$Ao = \frac{Qm.\chi}{Kdr.P.Fb.Fp} \quad \text{or} \quad Qm = \frac{Ao.Kdr.P.Fb.Fp}{\chi}$$

For air/gases:

$$Ao = \frac{0.1791\,Qm}{\psi Kdr.P.\sqrt{\frac{M}{ZT}}\,Fp.Fb} \quad \text{or} \quad Qm = \frac{Ao.\psi Kdr.P.\sqrt{\frac{M}{ZT}}\,Fp.Fb}{0.1791}$$

For liquids:

$$Ao = \frac{0.6211\,Qm}{Kdr.\sqrt{\rho\Delta P}\,Fv.Fw} \quad \text{or} \quad Qm = \frac{Ao.Kdr.\sqrt{\rho\Delta P}\,Fv.Fw}{0.6211}$$

Key to equations

Ao	=	Office area	mm^2
Qm	=	Required capacity of steam, air, gases or liquids	kg/hr
P	=	Absolute set pressure (set pressure + 1.013)	bar abs
ΔP	=	Relieving pressure – Back pressure (set pressure – back pressure)	bar gauge
T	=	Inlet temperature	°K (°C + 273)
ρ	=	Liquid density	kg/m^3
M	=	Molecular weight	kg/kmol
K	=	Isentropic exponent at the relieving inlet conditions. If the value of K is not available at these conditions the value at 1.0135 bar abs and 15°C should be used	
ψ	=	A.D. Merkblatt outflow function for air and gases	
χ	=	A.D. Merkblatt pressure medium coefficient for steam $= \frac{0.6211\sqrt{PV}}{\psi}$	

V = Specific volume in m^3/kg for supercritical pressure relief

Capacity correction factors

Fp	=	Capacity correction factor for the effects of low set pressure
Fb	=	Capacity correction factor for the effects of back pressure (balanced bellows valves only)
Fv	=	Capacity correction factor for the effects of viscosity (liquids only)
Fw	=	Capacity correction factor for the effects of back pressure (liquids only; balanced bellows valves only)
Kdr	=	De-rated coefficient of discharge. Select Kdr appropriate to the fluid

Manufacturers' engineering support information and technical data are essential if the correct valve is to be selected for the job. Some manufacturers supply full details on a computer program. Generally the program is easy to use with many features including: quick and accurate calculations, user-selected units, selection of valve size and style, valve data storage, printed reports, specification sheets and dimensional drawings.

There is no substitute for qualified engineering analysis, and the application of safety and relief valves of any type or make should be assigned only to fully trained personnel and be in strict compliance with rules provided by the governing codes and standards. Selection of safety and relief valves should not be based on arbitrarily assumed conditions or incomplete information. Valve selection and sizing is the responsibility of the system engineer and the user of the equipment to be protected.

Testing Safety Valves

Safety valves should be tested regularly to ensure that they have retained their capability of operating at design lift-off pressure. Two basic methods of testing are:

On-line testing by deliberate overpressure of the system to determine the actual pressure at which the valve lifts off its seat.

Off-line testing by removal of the valve from its line or position and determination of active lift-off by hydraulic test.

It is also possible to apply a hydraulic test for on-line testing using a portable hydraulic test pack.

Self-Acting Reducing Valves

Self-acting reducing valves generally fall into two main categories: (i) direct-acting valves and (ii) relay- or pilot-operated types.

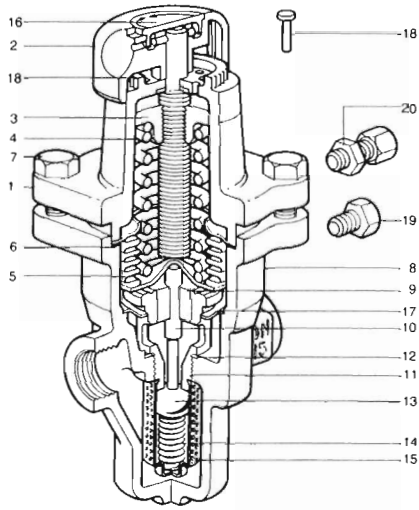
An example of a direct-acting pressure reducing valve for steam, compressed air and other gases is shown in Figure 1. The valve is designed for point-of-use installations. On start-up, the upstream pressure, aided by a return spring, holds the valve head against the seat in the closed position. Downstream pressure is set by rotating a handwheel in a clockwise direction which compresses the control spring and extends the bellows. This downward movement is transmitted via a push rod which causes the main valve to open. Liquid then passes through the open valve into the downstream pipework and also surrounds the bellows. As downstream pressure increases, it acts through the bellows to counteract the spring force and closes the main valve when the set pressure is reached. The main valve modulates to give constant downstream pressure.

Materials used for the bellows include phosphor bronze and stainless steel with nitrile main valve. Other diaphragms used include rubber, synthetic rubbers, stainless steel and phosphor bronze materials.

The direct-acting reducing valve shown in Figure 2 is designed for use with liquids and incorporates a balanced piston design providing accurate control of pressure under stable load conditions. The valve is installed in a horizontal pipeline. Typical applications include laundry equipment and reducing pressure at the point of use on Injection Moulding machines.

Pressure reduction in water systems aids both the efficient design of the piping network and protects consumers from excessive noise from high velocity within buildings, high-pressure discharge at taps and other outlets, and climbing overnight pressures when the distribution network is lightly loaded. The ability to control water-entry pressures ensures a balanced distribution network and also limits the maximum supply volume and so reduces water waste.

Cost-effective steam distribution depends on keeping pipe sizes to the minimum and having the highest acceptable distribution pressure between the boilerhouse and the areas of steam usage, then dropping pressure at the working area to the levels for the highest heat transfer, efficiency and safety.



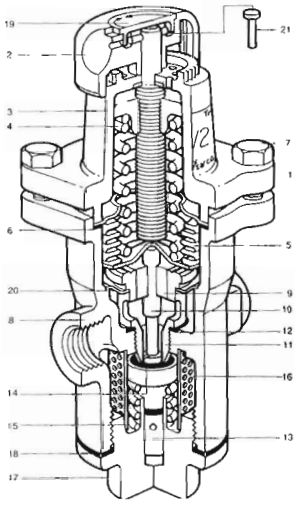
No.	Part	Material	
1	Spring Housing	Aluminium — Epoxy coated LM 24	
2	Adjustment Hand Wheel	Mineral Reinforced Nylon	
3	Top Spring Plate	Cast Iron	DIN 1691 GG 20
4	Pressure Adjustment Spring	Silicon Chrome Spring Steel	BS 2803 685 A55 Range 2
5	Bellows Assembly Option	Stainless Steel Phosphor Bronze/Brass	316Ti/316L
6	Bellows Assembly Gasket	Stainless Steel Reinforced Exfoliated Graphite	
7	Spring Housing Bolts	Steel — Zinc plated BS 3692 Gr 8.8 M8 x 25mm	
8	Body Screwed Flanged	SG Iron SG Iron	DIN 1693 GGG 40.3 DIN 1693 GGG 40.3
9	Guide Bush	Graphite filled PTFE	
10	Pushrod	Stainless Steel	ASTM A276 316L
11	Valve Seat	Stainless Steel	BS 970 431 S29
12	Valve Seat Gasket	Stainless Steel	BS 1449 316 S11
13	Valve	Stainless Steel	AISI 420
14	Valve Return Spring	Stainless Steel	BS 20056 316 S42
15	Strainer Screen	Stainless Steel	BS 1449 316 SH
16	Spring Range Identification Disc	Polypropylene	
17	Bulkhead Plate	Stainless Steel	316 L
18	Tamperproof Pin	Mild Steel - Copper Plated	
19	Blanking Plug	Stainless Steel	BS970 431 S29
20	Compression Fitting	Brass	

Figure 1. Direct-acting pressure reducing valve.

A relay- or pilot-operated reducing valve for steam services is shown in Figure 3. It comprises:

(a) The valve body, which contains the main valve and seat piston assembly.
(b) The control head, which houses the pilot valve assembly with its associated diaphragm and main adjusting spring.

This type of valve works by balancing the downstream pressure against a control spring. This modulates a small valve plug over a seat (the pilot). The flow through this seat is directed in turn to the main valve diaphragm (phosphor bronze or stainless steel), where it modulates the main valve.



Materials

No.	Part	Material
1	Spring housing	Aluminium - Epoxy coated LM 24
2	Adjustment Hand Wheel	Plastic — Polypropylene
3	Top Spring Plate	Cast Iron DIN 1691 GG 20
4	Pressure Adjustment Spring	Silicon Chrome BS 2803 685 A55 Spring Steel Range 2
5	Bellows Assembly	Phosphor bronze/brass BS2872 CZ122 (Stainless Steel optional 316Ti/ 316L)
6	Bellows Assembly Gasket	Reinforced Exfoliated Graphite
7	Spring Housing Bolts	Steel — Zinc plated BS 3692 Gr 8.8 M8 x 25mm
8	Body	Gunmetal BS1400 LG2
9	Guide Bush	Graphite filled PTFE
10	Pushrod	Stainless Steel ASTM A276 316L
11	Valve Seat	Stainless Steel BS 970 431 S29
12	Valve Seat Gasket	Stainless Steel BS 1449 316 S11
13	Piston	Stainless Steel BS970 431 S29
14	Valve Head	Nitrile Rubber
15	Piston Return Spring	Stainless Steel BS2056 Gr302 S26
16	Strainer Screen	Stainless Steel BS 1449 304 S16
17	Cap	Brass BS 2872 CZ 122
18	Cap Gasket	Reinforced Expholiated Graphite
19	Spring Range ID Plate	Polypropylene
20	Bulkhead Plate	Stainless Steel 316 L
21	Tamperproof Pin	Mild Steel - Copper Plated

Figure 2. Direct-acting pressure reducing valve for liquids.

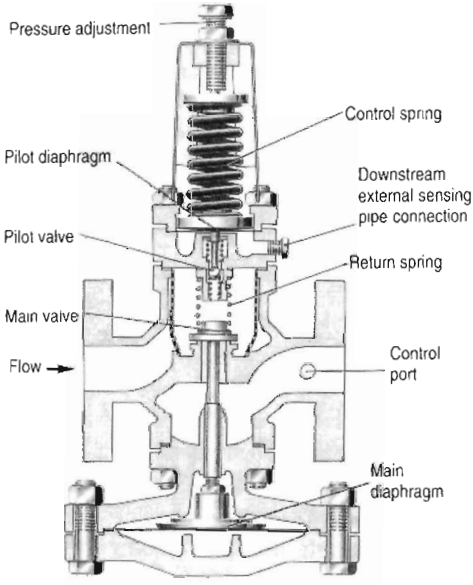


Figure 3. Pilot-operated pressure reducing valve.

Under stable load conditions, the pressure under the pilot diaphragm balances the force set on the adjustment spring. This settles the pilot valve, allowing a constant flow across the main diaphragm. This ensures that the main valve is also settled to give a stable downstream pressure. When the downstream pressure rises, the pilot valve closes and pressure is released from the main valve diaphragm through the control orifice, to close the main valve.

Any variations in load or pressure will immediately be sensed on the pilot diaphragm which will act to adjust the position of the main valve, ensuring a constant downstream pressure. In order to achieve the most stable operating conditions an external pressure sensing pipe is used. This becomes more important as the valve is used near its maximum capacity or under critical flow conditions.

A solenoid will provide for remote on/off control and a fully adjustable set point is possible using an air-driven pilot. The set point can then be adjusted via a compressed air regulator situated away from the valve. For example, the valve may be high up in a pipeline but adjustment can be made from an air regulator at ground level.

The characteristics of both pilot-operated and direct-operated reducing valves are shown in Figure 4. Both curves are shown for 25 mm (1 in) valves reducing from 10 to 3.5 bar (150 to 509 lbf/in^2).

It should be noted that in the case of the direct-acting valves (including those with balance pistons) the outlet pressure falls as the flow through the valve increases. Thus if the valve is set at a no-flow setting of 3.5 bar (50 lbf/in^2), the outlet pressure falls by about 0.35 to 3.15 bar (5 to 45 lbf/in^2) when

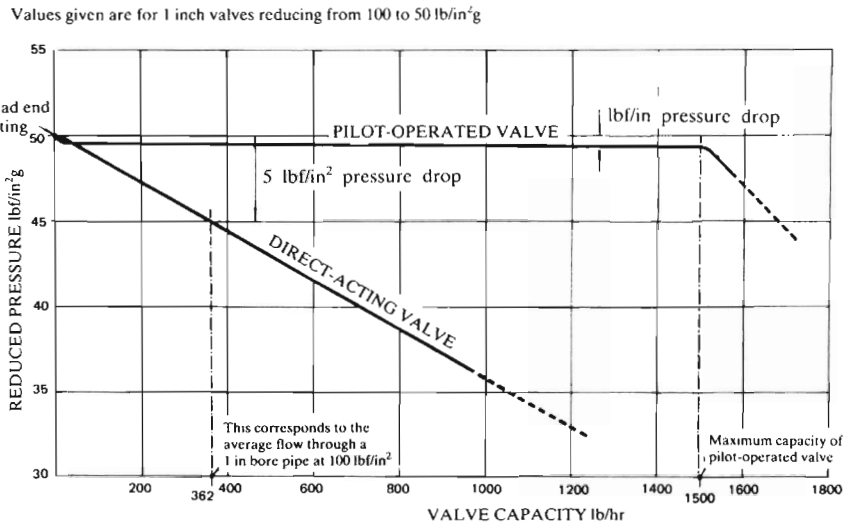


Figure 4. Self-acting reducing valves.

passing an average flow for this type of valve. The direct-acting valve is usually made equal in size to the inlet pipe.

In the case of the pilot-operated valve it will be seen that apart from an initial pressure drop of 0.035 bar (2 lbf/in^2) from the dead-end setting of 3.5 bar (50 lbf/in^2) the outlet pressure remains constant until maximum-rated capacity is reached.

It should also be noted that, in the examples shown, the 25 mm (1 in) pilot-operated valve is capable of passing a flow of more than four times that of the direct-acting valve, and with only 0.035 bar (2 lbf/in^2) pressure drop as compared with a drop of 0.35 bar (5 lbf/in^2).

Applications of reducing valves

Reducing valves are used for reducing one pressure to another, control being via throttling of the fluid through the valve and its seat. Reducing valves should never be deliberately oversized as if the valve is too big then the lift of the valve will be small and wire drawing or erosion of the valve and seat can result. Additionally, small variations in valve opening cause large changes in flow which at small flow demands can lead to pulsating pressure being generated in the downstream flow.

The following notes designate the main fields of application of self-acting reducing valves.

Air or gases

This application includes all compressed air systems for use with power tools, pneumatic control systems, etc., and control valves for the storage and distribution of industrial gases, etc.

Both direct-acting and pilot-operated reducing valves may be used for these duties and are selected according to the accuracy of control required and whether or not the valves are intended to give a dead tight shut-off under no-flow conditions.

Water

Reducing valves are extensively used in industrial and domestic water distribution, fire protection systems and the limitation of water pressures in high buildings, etc. Direct-acting valves with piston valves are generally used for these duties. As a general rule, reducing valves are used mainly as pressure limiting devices in water-distribution systems.

Because of high peak demands at times of heavy industrial usage, water authorities usually have great difficulty in maintaining pressures in the systems, although high pressures are usually available at the source of distribution, such as at reservoirs or main pumping stations. Very large pressure drops are

experienced in the system during high demands and as a result there is a tendency for the pressure to be below normal at the point of usage.

However, when the total demand in the system drops, much higher pressures are experienced in the distribution system and these are frequently in excess of the normal pressure ratings for the equipment being used. This can give rise to burst mains or excessively high discharge rates from domestic fittings, such as water closets, wash basins, etc. or storage tanks.

It is therefore common practice to fit a reducing valve in the line which, under high flow conditions, normally operates in the wide open position and presents only a nominal resistance to flow (such as would be experienced with an ordinary globe stop valve). However, at periods of low demand and high pressure, the reducing valve becomes effective and reduces the pressure in the downstream mains to an acceptable limit. It is important in such applications that the outlet pressure is not affected by inlet pressure variations and for this reason the direct-acting valves with piston balance are admirably suited to this application.

Other liquids

In this field, reducing valves are used for such applications as: controlling ram pressures on hydraulic presses; bearing lubrication systems in rolling mills and heavy industrial equipment; and for pressure control in fuel-oil systems. Again valves are normally used for these applications. In many applications the flow is relatively constant and the outlet pressure from the reducing valve therefore remains constant.

In fuel-oil systems the flow variations are normally of the order of 50 to 100%, in which case the outlet pressure variation would probably be of the order of 0.14 to 0.21 bar (2 to 3 lbf/in^2), depending on the size of valve used. The variation would be in the order of 0.35 bar (5 lbf/in^2) between full and no-flow conditions.

Steam

This particular category covers by far the majority of reducing valve applications and in general there are two broad sections.

Power

Reducing valves are only occasionally used on power installations involving steam, i.e. direct steam supply, steam engines and turbines, etc. In these cases the general principles of application still apply, although special problems do sometimes arise in the case of reciprocating machinery which may give rise to pulsations in the pipework system, and these can be amplified by the reducing valve itself. This is normally overcome by providing adequate pipe volume both upstream and downstream of the reducing valve to act as a 'steam accumulator'.

Process

With saturated steam, temperatures and pressures are strictly related and, because of this, it is frequently found convenient to control temperature by controlling the steam pressure. Applications in the process field includes space heating, kitchen equipment, sterilizing equipment, curing processes in the rubber and plastics industries, etc., industrial cooking equipment, etc. In fact, anywhere steam is used as a heat-transfer medium, reducing valves will invariably be installed.

In general, only low pressure steam, usually below 3.5 bar (50 lbf/in^2), is used for process purposes. At such low pressures the latent heat content of the steam is relatively high and is easily transferred from the steam to the product being processed.

Size of pipes and fittings

The inlet and outlet pipes should be sized to suit the maximum steam demands of the system, e.g. see Table 1. Pipe sizes should always be determined in terms of pressure drop and not by such rules as arbitrary steam velocities.

Correct sizing of pipework and fittings associated with all valves is extremely important in order to obtain the best possible operation. Specifically:

(i) Strainers should always be equal in size to the inlet pipe.

(ii) When globe valves are used as inlet and outlet stop valves, these should also be equal in size to the respective pipe, into which they are fitted.

(iii) When parallel slide valves are used as stop valves, these can be fitted equal in size to the reducing valve for reduced pressures between 30 and 70% of the inlet pressure. They should be equal in size to the respective pipe when the pressure difference between the inlet and outlet is 2 bar (30 lbf/in^2) or less. When they are connected directly to the reducing valve the length of distance pieces between value and fitting should not exceed three pipe diameters.

(iv) In order to provide a streamlined flow at the approach to the reducing valve, a straight length of pipe equal to 10 pipe diameters should be provided between the fitting and the reducing valve (this does not apply to parallel slide valves). Typical reducing valve layouts are shown in Figures 5 and 6.

Reducing valves in parallel

As already mentioned, two reducing valves in parallel should be considered when the minimum flow through the system is less than 10% of the maximum capacity of a single reducing valve, or when the valves are expected to work for long periods on 'no-flow' or 'dead-end' conditions, or working in partially completed plant systems. A typical layout is shown in Figure 7.

Table 1. Steam pipe capacities (lb/hr dry saturated)

Pressure	Pipe size in inches												
lbf/in² *bar*	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4	5	6	8	10
5	12	32	63	106	163	320	536	813	1560	2550	3820	6180	100.000
0.35	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*	*0.3*	*0.3*	*0.3*
10	15	40	79	113	206	404	676	1055	1962	3220	4810	8000	12.950
0.09	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.5*	*0.4*	*0.4*
20	18	54	107	182	300	586	980	1400	2680	4390	6550	11.300	15.650
1.38	*0.6*	*0.7*	*0.7*	*0.7*	*0.8*	*0.8*	*0.8*	*0.7*	*0.7*	*0.7*	*0.7*	*0.6*	*0.5*
30	24	69	137	245	377	740	1240	1880	2600	5900	8810	14.700	22.300
2.07	*0.8*	*0.9*	*0.9*	*0.9*	*1.0*	*1.0*	*1.0*	*0.9*	*0.9*	*0.9*	*0.9*	*0.8*	*0.7*
50	35	98	203	357	582	1140	1910	2640	4880	8000	12.000	21.450	33.400
3.45	*1.2*	*1.3*	*1.4*	*1.5*	*1.6*	*1.6*	*1.6*	*1.4*	*1.3*	*1.3*	*1.3*	*1.2*	*1.1*
75	47	136	284	495	780	1493	2500	3800	7100	11.600	16.900	30.600	48.400
5.17	*1.6*	*1.8*	*2.0*	*2.1*	*2.2*	*2.1*	*2.1*	*2.1*	*2.0*	*2.0*	*1.9*	*1.8*	*1.7*
90	53	157	332	581	896	1755	2940	4460	8280	13,570	19.450	35.400	54.500
6.21	*1.8*	*2.1*	*2.4*	*2.5*	*2.5*	*2.5*	*2.5*	*2.5*	*2.4*	*2.4*	*2.2*	*2.1*	*1.9*
100	59	173	362	615	984	1928	3220	4840	9040	14.820	21.800	38.900	61.500
6.90	*2.0*	*2.3*	*2.6*	*2.6*	*2.8*	*2.8*	*2.8*	*2.7*	*2.6*	*2.6*	*2.5*	*2.3*	*2.2*
120	68	204	431	755	1182	2320	3900	5710	10.920	17,910	26.000	46.900	73.000
8.27	*2.3*	*2.8*	*3.2*	*3.4*	*3.5*	*3.5*	*3.5*	*3.3*	*3.3*	*3.3*	*3.1*	*2.9*	*2.7*
150	83	252	539	945	1420	2900	4770	7100	13.600	22.300	32.500	59.100	93.000
10.34	*2.8*	*3.5*	*4.1*	*4.4*	*4.5*	*4.4*	*4.2*	*4.2*	*4.2*	*4.2*	*4.0*	*3.8*	*3.6*
180	96	296	642	1131	1748	3440	5890	8750	16.680	27.300	40.000	71.500	112.000
12.41	*3.3*	*4.2*	*5.0*	*5.3*	*5.4*	*5.5*	*5.7*	*5.5*	*5.4*	*5.4*	*5.2*	*4.8*	*4.5*
200	107	324	708	1238	1942	3880	6530	9750	18,880	31,000	44,300	80,000	126,000
13.79	*3.7*	*4.6*	*5.6*	*5.9*	*6.1*	*6.3*	*6.4*	*6.4*	*6.3*	*6.3*	*5.8*	*5.5*	*5.2*
220	116	354	770	1350	2120	4200	7150	10.850	20.800	34.000	49.000	90.000	141.000
15.17	*4.0*	*5.0*	*6.0*	*6.4*	*6.6*	*6.8*	*7.0*	*7.0*	*7.0*	*7.0*	*6.5*	*6.3*	*5.9*
250	133	408	871	1525	2385	4760	8100	12.360	23.800	39,000	57.000	105.000	168.000
17.24	*4.5*	*5.7*	*6.7*	*7.1*	*7.3*	*7.6*	*7.8*	*8.0*	*8.0*	*8.0*	*7.6*	*7.8*	*7.0*
300	157	496	1025	1798	2800	5160	9550	14,760	28,400	46.500	68,900	125.900	202.000
20.69	*5.3*	*7.2*	*7.8*	*8.3*	*8.5*	*8.9*	*9.2*	*9.6*	*9.6*	*9.6*	*9.4*	*9.1*	*8.9*

Note: Figures in *italic* show pressure drops (lbf/in²) for equivalent lengths equal to 360 pipe diameters.

When using this table, allowance should be made for the effects of bends and fittings in the pipeline.

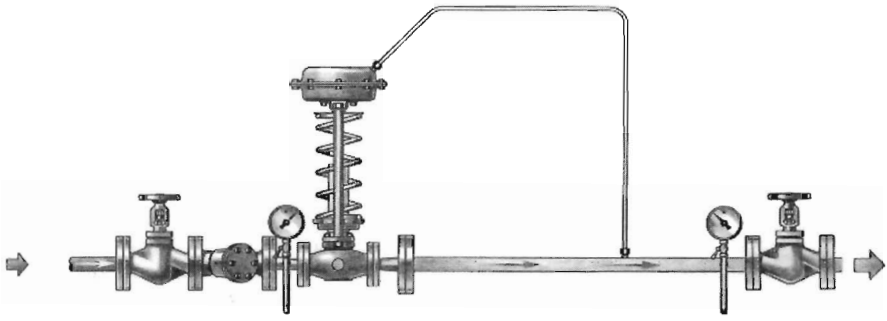


Figure 5. Control of water distribution.

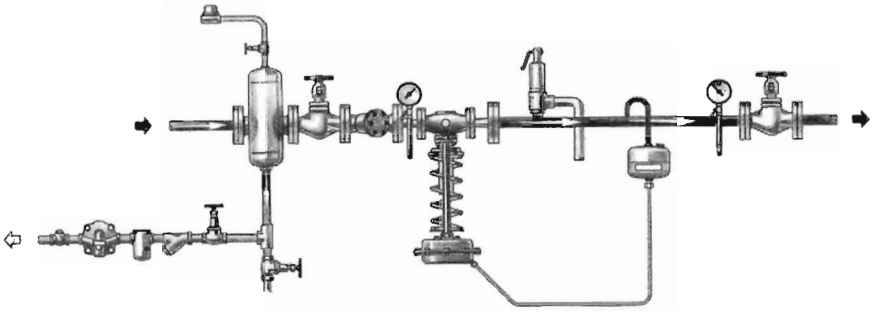


Figure 6. Control of steam distribution.

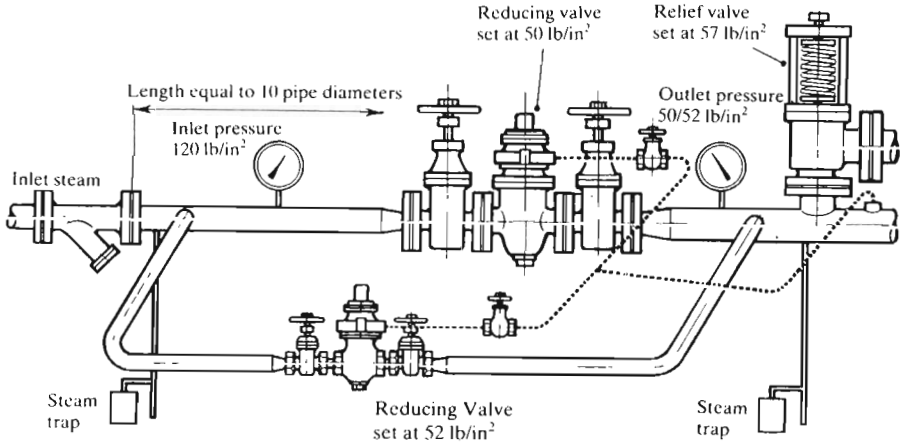


Figure 7. Parallel arrangement of reducing valves.

In order that the valves can deal effectively with minimum capacity variations of less than 10%, two unequally sized reducing valves having a maximum capacity equal to the required capacity should be connected in parallel with the outlet pressure of the smaller valve set 0.14 to 0.21 bar (2 to 3 lbf/in^2) higher than that of the large valve. In this way the larger valve would shut at low demands leaving the smaller valve to handle the low flows. As the demand increases the larger valve will open automatically as the reduced pressure falls, and share the load with the small valve. By this method capacity ratios of up to 100:1 can be obtained.

Superheated steam

Superheated steam is less dense than saturated steam and, therefore, for the same pressure drop the reducing valve will have slightly smaller capacity. The reduction in capacity is dependent on the amount of superheat. Capacity figures quoted in manufacturers' catalogues are normally for dry saturated steam. When steam is superheated above 28°C (50°F) before it enters the reducing valve, dry steam capacities should be multiplied by the following factors:

56 to 83°C (100 to 150°F) of superheat—0.89
83 to 111°C (150 to 200°F) of superheat—0.86
111 to 167°C (200 to 300°F) of superheat—0.82

Steam traps

Whenever possible, pilot-operated reducing valves should be sited at some point in the pipeline where they cannot become flooded with condensate during periods of low flow or prolonged shutdown. If this is not possible then steam traps (and, if possible, dirt pockets) should be fitted to both the inlet and outlet pipework to remove any condensate which may accumulate in the vicinity of the reducing valve.

Condensate can be trapped between the piston and pilot valve when the steam flow is resumed and this prevents the main valve from closing as the reduced pressure may continue to rise above the setting and eventually cause the relief valve to blow.

The thermodynamic steam trap shown in Figure 8 is suitable for use in condensate removal from high pressure steam mains and for turbine casing drainage.

On start up, incoming pressure raises the disc and cooled condensate plus air is immediately discharged (A). Hot condensate flowing through the trap releases flash steam. High velocity creates a low pressure area under the disc and draws it towards the seat (B). At the same time there is a pressure build-up of flash steam in the chamber above the disc, which forces it down against the

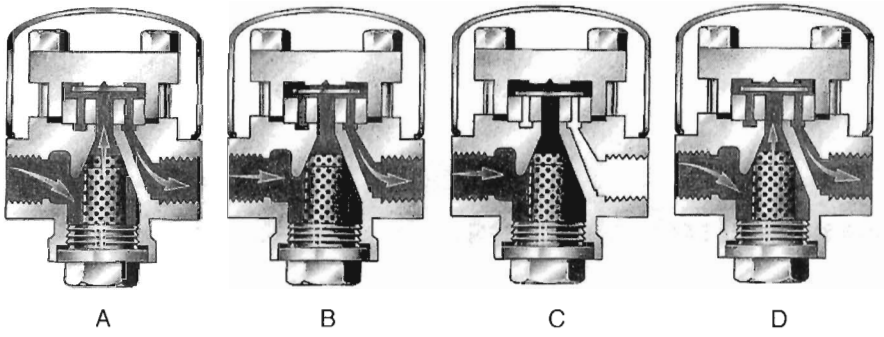


Figure 8. Thermodynamic steam trap—operating sequence.

pressure of the incoming condensate until it seats on the inner ring and closes the inlet. The disc also seats on the outer ring and traps pressure in the chamber (C). Pressure in the chamber is decreased by condensation of the flash steam and the disc is raised by the incoming pressure. The cycle is then repeated (D).

Fitting of balance pipes

It is strongly recommended that a balance pipe should be fitted when the reduced pressure is 10% or less of the inlet pressure. The purpose of this pipe is to improve the performance of the reducing valve when working under difficult downstream conditions. It will also help to counteract any pressure drops in downstream pipework caused by undersized pipe fittings, etc., providing they are not excessive.

A stop valve should be fitted in the balance pipe to allow complete isolation of the reducing valve from the steam flow (particularly when a bypass line is fitted).

The balance pipe should be arranged to fall to allow it to drain into the downstream pipe. The tapping into the downstream pipe should be made at a point where smooth flow occurs preferably downstream of the relief valve. The downstream pressure gauge should be fitted as near to this point as possible.

Air Relief Valves

Air or gas trapped in a pipeline carrying a liquid can cause problems, e.g. reduce the effective flow, aggravate the effects of surge, and cause pump cavitation. Possible causes of air/gas entrainment are:

(i) The pipeline was fully charged with air/gas when empty.
(ii) Air is entrained at pump suction.
(iii) Air is drawn in through faulty joints or glands.
(iv) Air/gas is trapped in pockets during pipeline filling.
(v) Air/gas in solution is released due to changes in pressure and temperature.

The problem of dealing with air/gas entrainment is not usually a demanding one. Entrained air/gas will tend to collect at high points in the system. It can then be removed by introducing air release valves at these points. These may be simple, manually-operated valves (bleed valves), or fully automatic. In the latter case the valve should perform the following functions:

(a) release of air/gas accumulating in pipeline during normal pressurised operation, to prevent restriction to fluid flow
(b) retention of the fluid in the pipeline without loss under all operating conditions
(c) release of air/gas during pipeline filling at a volume rate sufficient to prevent back pressure restricting the filling rate
(d) admission of air to the pipeline during emptying at a rate sufficient to prevent excessive vacuum pressure in the pipe.

Single orifice valves (Figure 1) are capable of performing functions (a) and (b). They are normally used where only relatively small volumes of air/gas are to be released, or where it is desirable to provide additional ventilation at operating pressures. Dual-orifice valves are capable of performing all four functions. They can normally provide complete protection against air/gas entrainment under all system-operating conditions.

The type of fluid product being handled also affects the design requirements of the air release valve (especially automatic valves). With sewage or industrial

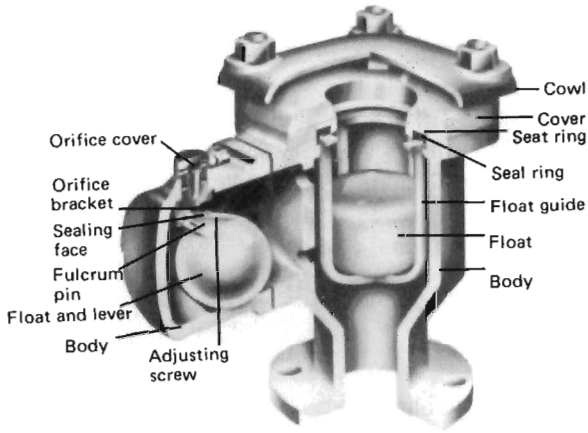


Figure 1. Single-orifice air relief valve.

effluent, for example, the solids content may block the release passage(s) periodically, causing unreliable operation. This can be overcome by using large-volume auxiliary float chambers to contain the fluid under all operating conditions so that it can never come into contact with the air valve elements.

An example of a dual-orifice air valve suitable for water systems is shown in Figure 2.

The valve combines small and large orifices. The small-orifice valve comprises a composite float and lever assembly sealing off a small-orifice vent. When the

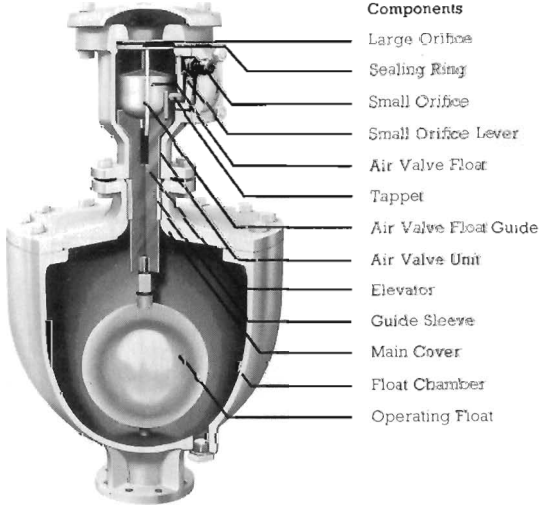
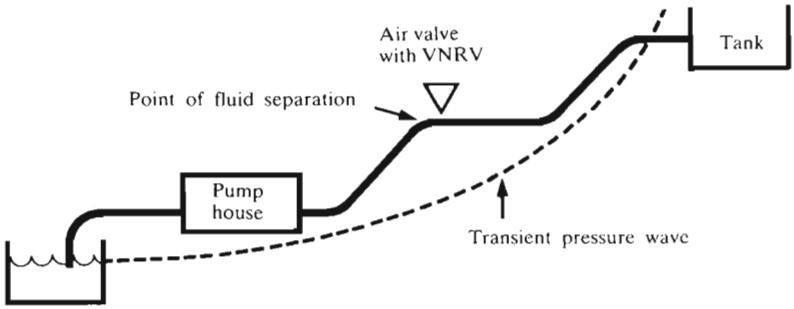


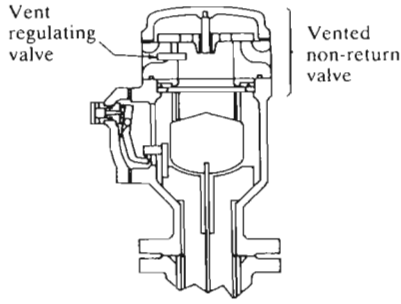
Figure 2. Dual-orifice air relief valve.

Underpressure air release valve.

Dual-orifice air valve.



Example of patented air relief valve with vented non-return valve for performing additional function of surge suppression.



Air relief valve.

float chamber is filling with water, the orifice is closed initially by the float working through a lever ratio of 5:1.

When the chamber is filled with water under pressure, the orifice is held closed by the combined upthrust of the float and the differential pressure over the orifice area. On air accumulated in the system entering the chamber under working pressure, the water level in the chamber is depressed until it reaches a point when the weight of the float is sufficient to uncover the orifice and exhaust air. Air is expelled until the water level rises again and causes the float to close the orifice.

The large-orifice valve consists of a float sealing off a large-orifice vent to the atmosphere. The float is held at a predetermined height in its casing by a ribbed cage which also guides the float onto the seat. During the pipeline filling or emptying, the 'aerokinetic' feature holds the float off the seat and keeps it completely stable under all air outflow or inflow conditions. The valve cannot close prematurely during outflow. It closes only when water enters the casing and raises the float onto the seat.

An example of the working of dual-orifice air relief valves designed for handling sewage and similar effluent is shown in Figure 3. When the pipeline

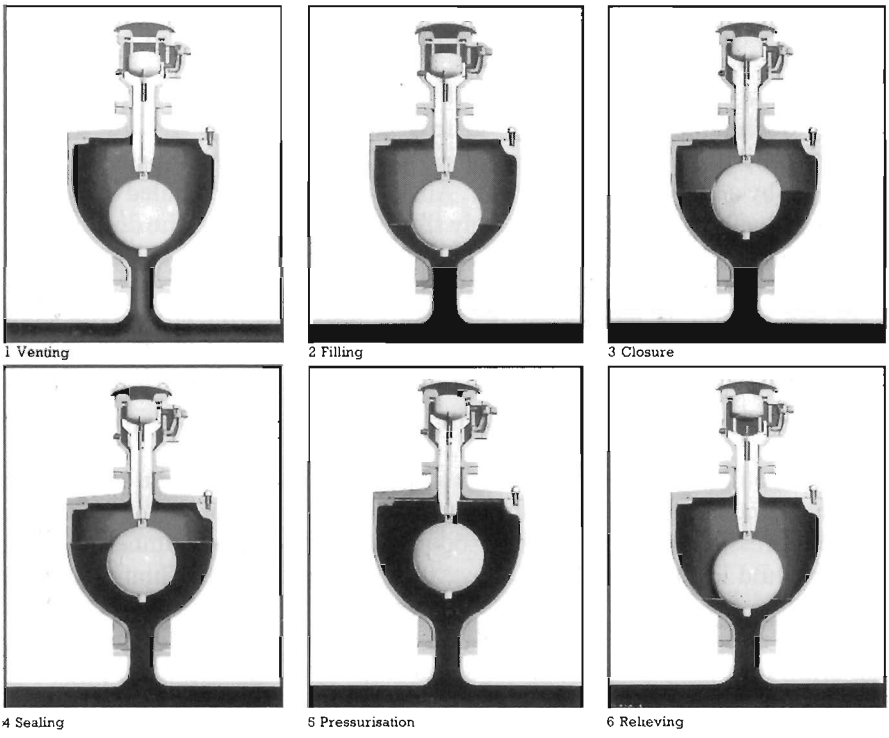
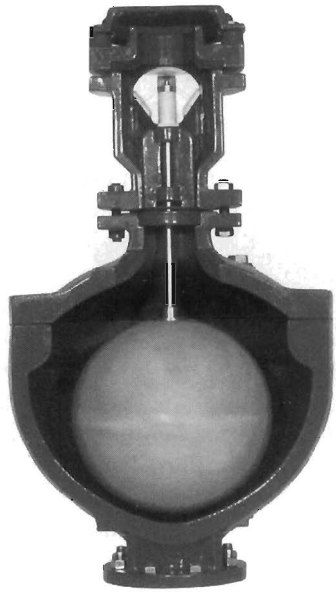


Figure 3. Operational sequence of a dual-orifice air relief valve.



Double-acting sewage air valve.

is empty, the spherical operating float is suspended from the elevator within the main chamber and the cylindrical float element of the air valve is supported by the guide cage. The operating lever of the small-orifice valve is held open by a tappet on the elevator. Air/gas having been inhaled or expelled from the pipelines is able to flow freely through both orifices, the design of the valve being such that the air flow creates a positive down force to hold the cylindrical float element stable within the guide cage.

As the air/gas is exhausted from the pipeline, liquid enters the main chamber and the operating float then rises with the liquid. The elevator, raised by the float, releases the small-orifice valve and engages the base of the cylindrical element, which rises until seated on the rubber face of the large orifice.

At this point air/gas outflow ceases and further inflow of liquid to the main chamber under pipeline pressure compresses the air/gas until maximum working pressure is reached. The proportions of the main chamber are such that the fluid level will not rise above the bottom face of the main chamber cover.

When the pipeline is emptied and pressure falls, the valve main chamber will drain into the pipeline and the operating float, following the liquid level, releases the cylindrical float to allow the large orifice to open. As the pipeline pressure falls to atmospheric, it opens the small-orifice valve. The pipeline is then able to ventilate freely and sub-atmospheric pressure conditions are avoided.

During normal operating conditions, air/gas will be released from the liquid and will collect under pressure in the main chamber, depressing the liquid level. The operating float falls with the liquid but system pressure will hold the cylindrical valve element on the large-orifice seat. As the operating float approaches the limit of its travel, the tappet on the elevator opens the small-orifice valve, releasing the accumulated air/gas under pressure. This in turn allows the liquid level to rise again and the small-orifice valve to close, thus completing a cycle.

Positioning of air relief valves

In systems handling water, air relief valves would normally be placed at all high points, i.e. where a rising section changes to a falling section. In systems handling sewage or industrial effluent, rather more extensive treatment is necessary, as illustrated in Figure 4.

Where the fluid is pumped through the pipeline it is desirable that a dual-orifice valve (valve A) be located just downstream of the pump-delivery valves.

Dual-orifice-type valves are also required at all peak points which are defined relative to the hydraulic gradient and not necessarily to the horizontal. In practice a peak may be considered as any pipe section which slopes up towards the hydraulic gradient or runs parallel to it. In the latter case the

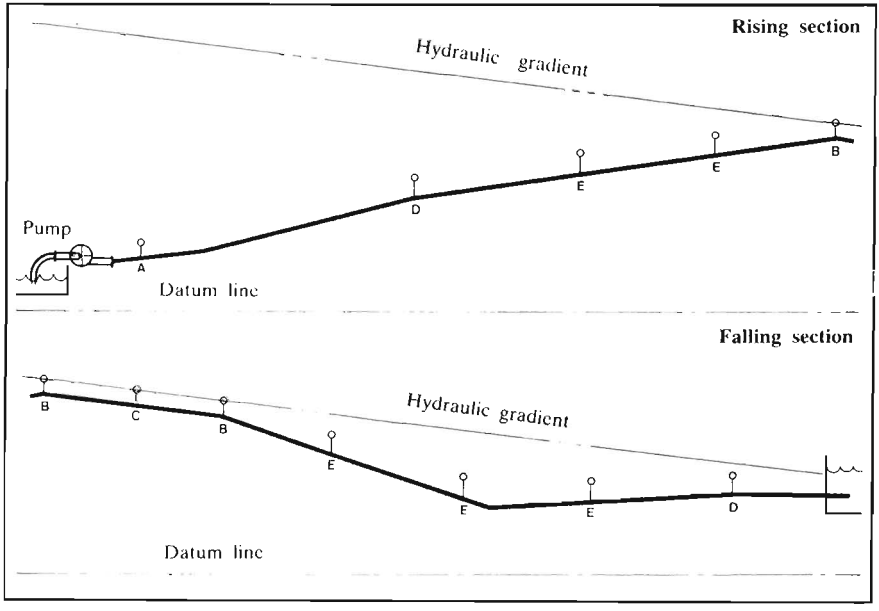


Figure 4. Typical sewage air valve location points.

minimum requirement is a dual air valve at each end of the section (valve B); any additional valves may be of a single-orifice type.

Positions where an increase in down slope occurs will require ventilation by a small orifice valve which should also be installed at points of decrease in up slopes (valve D).

Pipeline sections of uniform profile also require ventilation and dual-orifice units should be installed at about 800 m (2500 ft) intervals on these sections (valves E).

Foot Valves

A foot valve is basically a check valve fitted to the end of a suction pipe leading to a pump. Its purpose is to keep fluid trapped in the suction pipe when the pump stops, thus maintaining a suitable prime for the pump. When the pump restarts, the suction created opens the valve, giving full flow to the pump inlet. (Foot valves are unnecessary on self-priming pumps.)

Foot valves may be of a simple flap-type, or more usually lift-check or ball-check valves. They are commonly combined with an integral strainer. Some examples follow.

Poppet lift foot valve

In the example shown in Figure 1, the poppet assembly consists of a plastic tripod which can be displaced along a bore above the seat valve. The travel of the poppet is controlled by a stop on the end of the poppet legs acting as supports for the return spring shouldered onto a washer. This spring ensures that the valve will work in any position. The main characteristics of this design are low head losses with good sealing provided by a nitrile rubber O-ring.

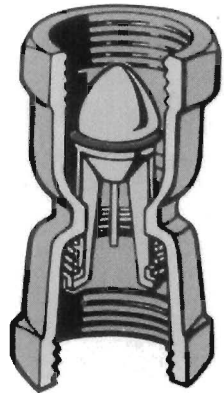


Figure 1. Foot valve with plastic tripod.

Figure 2 shows a design with the tripod in cast iron and with a cast-iron poppet head with streamlined tripod hub. Sealing is provided by a flat gasket shouldered by the poppet head and placed on a collar-type seat. This is a simple and robust design suitable for general applications.

Poppet-type foot valve with strainer.

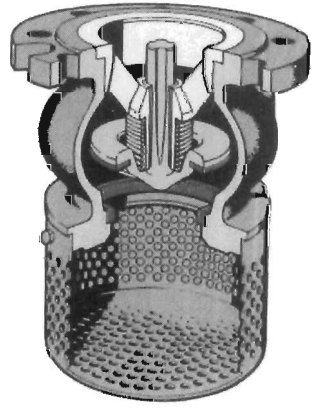


Figure 2. Foot valve with tripod and poppet head in cast iron.

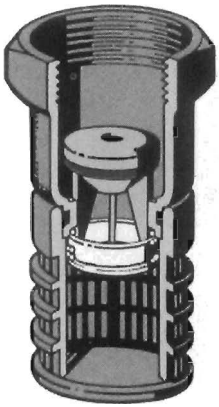


Figure 3. Foot valve with all metal poppet and profiled head.

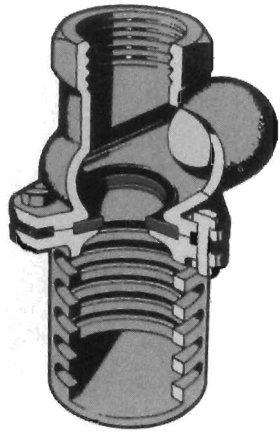


Figure 4. Ball foot valve.

Figure 3 shows a further design where the all-metal poppet with profiled head is guided by three legs and restrained by a downstream stop. Sealing is by a flat seal on a flat bearing surface. Valve travel is limited by the stop. A spring can be added to ensure that the valve will operate in any position.

Ball foot valve

An example of this type is shown in Figure 4. This is a simple ball valve guided by an inclined cylindrical chamber and seating on an O-ring. Note that the ball is displaced laterally along its chamber with inward flow, but it runs down

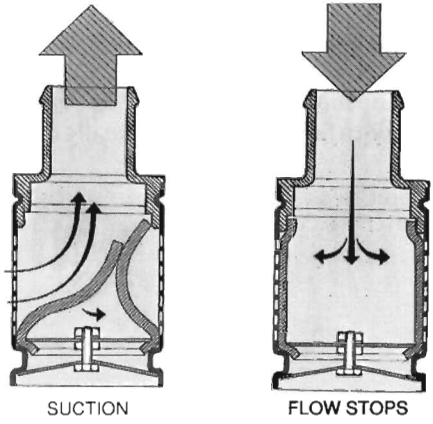


Figure 5. Membrane foot valve.

Figure 6. A selection of membrane foot valves.

the chamber onto its seat when the flow rate decreases. It is particularly suitable for use with contaminated waters or more viscous fluids.

All examples illustrated are of the type with integral strainer.

Membrane foot valves

Membrane foot valves consist of a cylindrical rubber membrane fitted inside a steel strainer. When there is a suction developed at the strainer, the membrane is displaced to allow fluid to flow through the valve. When back-flow conditions exist, the cylindrical membrane closes the apertures in the valve strainer, thus closing the valve, (see Figure 5).

A selection of membrane foot valves is shown in Figure 6. The lever fitted to one valve enables the valve to be drained by physically displacing the membrane when the lever is lifted.

See also the chapter on Check Valves.

SECTION 4

Control and Automation

Valve Actuators

Control Valves

Float Control Valves

Temperature Control Valves

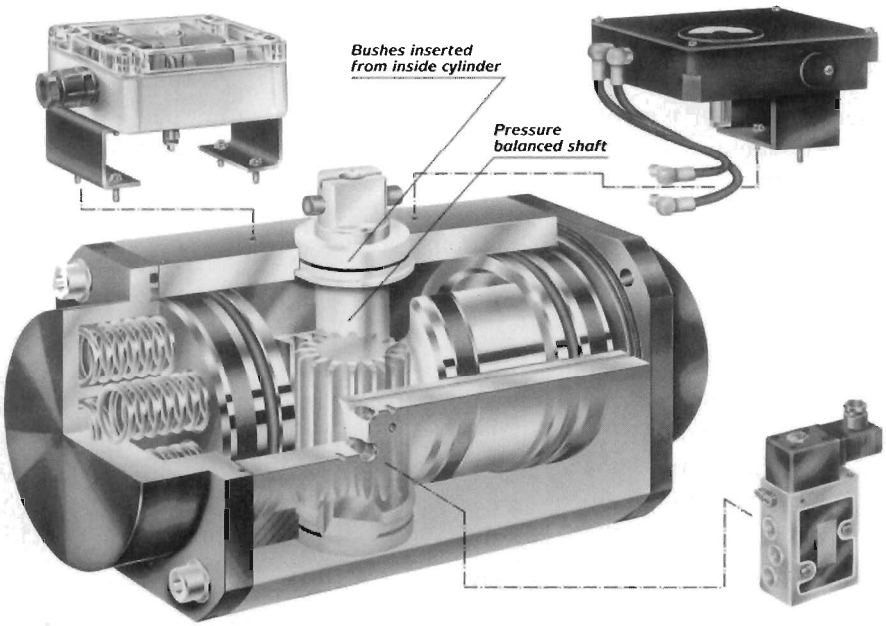
Regulators

Valve Actuators

Numerous types of devices exist for the remote operation of valves. These range from simple gearboxes to highly sophisticated motorised valves with automatic control, programmable logic controllers, microcomputers and field communications networks.

In basic terms, an actuator can be described as 'A device supplying force and motion to the closure member (ball, disc, plug, etc.) of a valve'.

There is a distinction between the actual requirements but, in general, the vast majority of applications are concerned with the opening and closing of



Standard-type pneumatic valve actuator.

valves. Certain systems may call for continuous modulating control which can set limits on the usefulness of both mechanical and energy systems.

In 1992, the world's first non-intrusive 'intelligent' enclosed actuator, that could be commissioned and interrogated without removing electrical covers, was launched.

All actuator settings and diagnostics are made through a sealed indication window using an infra-red setting tool, avoiding the use of penetrating shafts. Solid-state torque and limit measurement is used throughout, eliminating the use of springs, switches or levers.

The separation of the setting tool from the actuator provides a most effective method of security of the settings.

Multi-turn actuators—on–off duty

The general design principle of a multi-turn actuator is to turn a multiple of 360° at its output drive. The resulting rounds-by-stroke relationship can be from 2 to more than 1450. Within this range, position-indicating devices, such as limit switches, and electronic position transducers can be adjusted. Initially, multi-turn actuators fitted to valves transform the cycle movement of the output drive to linear movement according to the demands of the valve. Multi-turn actuators for on–off duty (short-time operation 10–15 min) mostly operate valves with only a few number of opening and closing periods a month.

Part-turn actuators—on–off duty

There is another type of multi-turn actuator for operating ball or butterfly valves or dampers, for example, with a movement of less than 360° for opening and closing.

Normally, the internal gear of the part-turn actuator is designed for a turn of 90°, although 120° and 180° are commonplace.

Thrust actuators—on–off duty

Thrust actuators may be fitted to valves requiring linear movement. They transform the torque of a multi-turn actuator into an axial thrust force by means of an attached thrust unit. Linear actuators are mainly used with globe valves or similar and, when indirectly mounted, may be used to operate butterfly valves, flap valves or dampers.

Multi-turn actuators—modulating duty

The requirements of modulating service (operation of control valves) on actuators are different from the 'normal' on–off duty.

Part-turn actuators—modulating duty

Typically, a part-turn actuator for operating a control valve consists of a combination of a multi-turn actuator with a worm gear, the connection between the two being achieved via the output drive.

It is probably more appropriate to deal with the overall subject of actuators under three main headings:

(i) main types of valve actuators
(ii) choice of energy systems
(iii) electric/electronic controls

Main types of valve actuators

The main types of actuators used are:

(a) manual operators
(b) cylinder actuators (pneumatic or hydraulic)
(c) vane actuators
(d) electric solenoid
(e) diaphragm actuators
(f) electric motor actuators

All have their particular virtues and uses.

Manual operators

Apart from the obvious job of providing a means whereby a person can open or close a valve, the requirements of a manual valve actuator may encompass any or all of the following:

Convert motion from linear to rotary

Valves of the gate, globe, diaphragm and pinch type utilise linear motion of the obturating members to achieve a seal. Handwheel operation implies rotary motion, and conversion is generally by nut-and-screw, which may be part of the valve or of a separate manual actuator.

Withstand thrust

When the threaded nut forms part of the manual actuator, it will have to withstand the operating thrust developed and incorporate suitable thrust bearings.

Lock the valve in position between operations

For valves operated by linear screw thread, position locking is achieved by use of an irreversible, (i.e. low-efficiency) thread. Butterfly valves must also be restrained against self-operation as a result of dynamic flow, and again this is customarily ensured by using irreversible, low-efficiency, gearing such as worm and wheel between valve stem and handwheel.

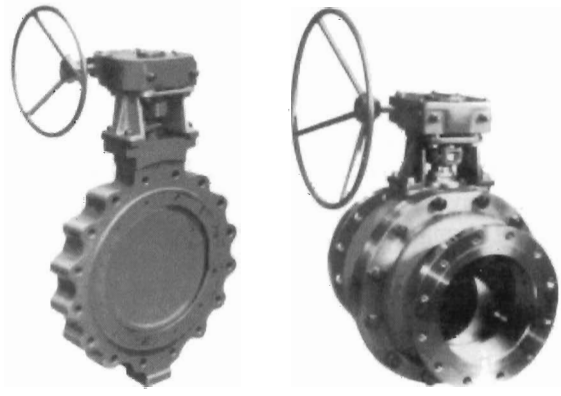
In each case the efficiency must be low enough so that the valve does not move from an intermediate position if pressure is applied to the stationary valve, and it will also stay in position if manually-operated with flow present. There have been many occasions when valve slamming has occurred under high-flow conditions with a gear ratio which was thought to be irreversible, but proved not to be when the handwheel was started under heavy-flow conditions and the valve took over.

This dynamic effect is less of a problem with plug and ball valves which have a higher ratio of static friction to dynamic torque and, in any case, are not suited in standard form to flow regulation.

Whatever manual means is adopted for the operation of valves, the main constraint is always the human muscle power available. It is difficult for a person to exert more than about 75 W (1/10 hp) continuously for any length of time by hand.

Size and type of valve, line pressure and other factors will determine the power required. For larger valves, this will nearly always mean the introduction of an intermediate gearbox with a handwheel capable of operating the valve comfortably with a human's strength—i.e. with a rim pull below 27 kg (60 lb).

The average male can exert up to three times this force momentarily, by pulling his weight on a handwheel, so that the extra force required to seat or unseat a valve is not a problem if the gearing is adequate. However, the



Manual gear actuators.

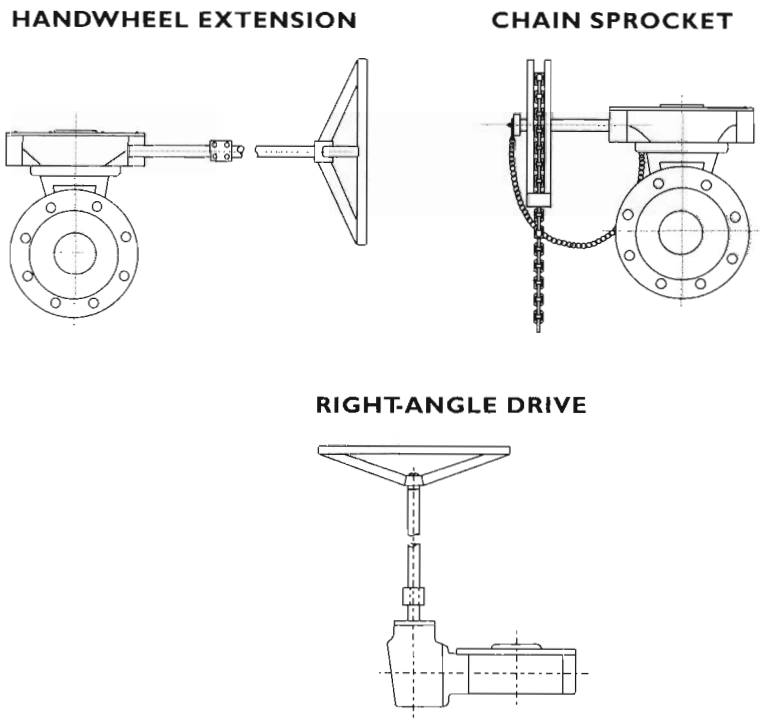
fundamental principle of gearing to reduce input torque inevitably means that the number of turns required of the handwheel increases. For large valves and pressures, the number of turns is such that manual operating time may be measured in hours rather than minutes.

There is no way, therefore, that emergency manual operation can be quick. The alternative philosophy is to accept that large valves are difficult to operate and require at least two people, or a team in an emergency, operating a larger handwheel with far fewer turns. There is no ready solution to this dilemma other than power operation.

Another reason for utilising reduction gearing is to reduce the torque to be transmitted via shafts and couplings to a remote operating point, e.g. spur gearing of a gate valve to a pedestal, say, on a floor above.

A side handwheel is generally more convenient than one with a vertical shaft. Bevel gear actuators are therefore widely used to reduce the operating torque of gate valves and bring their handwheel to a particular side for access.

The use of worm gearboxes and equivalent nut-and-screw scotch yoke actuators for quarter-turn valves automatically turns the drive through a right-angle, which may therefore be oriented in the right direction. Additional



Manual operators.

gearing for torque reduction is then usually provided by spur gears, although a further change of direction via a bevel gear may sometimes be needed.

Hypocycloidal gear-train manual actuators have been especially developed for the operation of centred-disc butterfly valves mainly used in the heating, ventilation and air conditioning industry (HVAC).

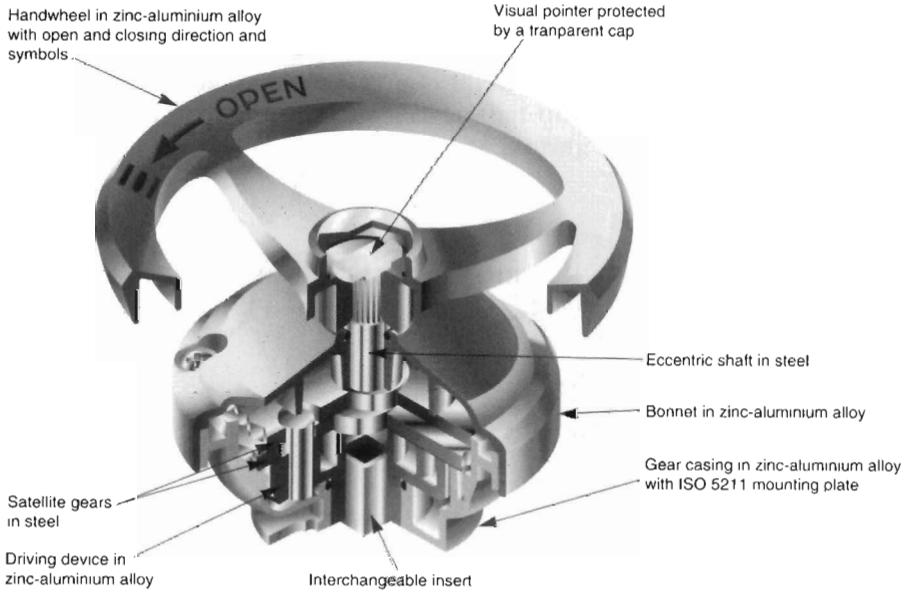
Other manual actuators with worm wheel and screw kinematics are used with $^1/_4$-turn valves including centred or double-eccentric disc butterfly valves, ball valves, etc. They are designed to deliver a constant output torque.

Signalling

A problem with manually-operated valves—especially in plants with centralised control—is the absence, usually, of any standard means of signalling the valve status, or of confirming that a required operation has been carried out. If this is necessary, special provision has to be made. Often this is done by attaching some form of external limit-switching mechanism, using switchboxes that meet environmental and safety requirements (see the section on Limit switches below).

Handwheel drives for powered actuators

All the aforementioned points apply to auxiliary manual drives for power actuators. However, the fact that the drive is auxiliary only and not the main



Hypocycloidal gear-train kinematics.

means of operation may make design compromises in the interests of economy more acceptable than they would be if manual operation were the regular and only means.

Cylinder actuators

This type has an actuator using a piston moving inside a cylinder by pneumatic or hydraulic pressure. It can be single-acting, i.e. equipped with a return spring, or double-acting, using air or oil pressure for movement in both directions.

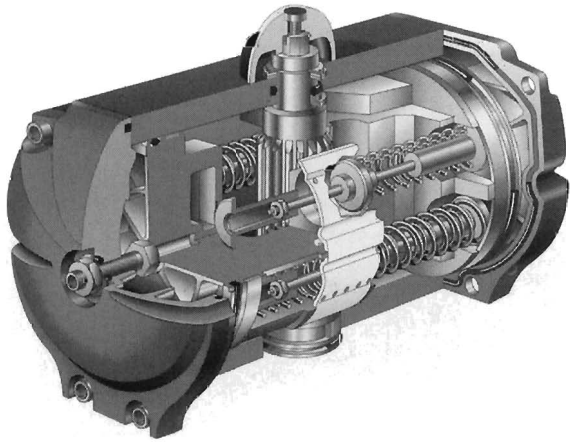
The piston and cylinder can be practically any length or diameter and readily converts pneumatic or hydraulic pressure into linear force. This can be further converted to part-turn operation by rack-and-pinion or linkage, i.e. scotch yoke.

Pneumatic actuators for industrial valves are predominantly applied in continuous processes. While one actuator may pass through hundreds of cycles, 24 hours a day, another may open and close just once a month. Pneumatic actuators can be applied to ball valves, plug valves and butterfly valves.

Vane actuators

A vane actuator is a pneumatically or hydraulically operated actuator used with rotary valves. Typically, the actuator has a paddle-like vane in a sector-shaped pressure casing giving a 90° rotary motion to the vane shaft connected to the valve stem.

Vane actuators can be double-acting, i.e. operated in both directions by air or gas pressure, or single-acting with a return spring.



Pneumatic spring-return actuator.

Electric solenoid

The electric solenoid tends to be limited to very small powers, i.e. to pilot duty rather than actuation duties for other than the smallest valves.

Diaphragm actuators

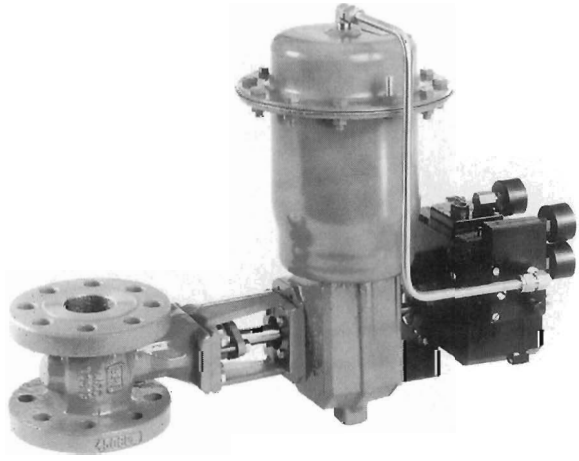
This can be described as a pneumatically operated actuator where the air chamber is sealed by a flexible diaphragm, with most of its flat area supported by a plate at the end of an actuator stem. Variable air pressure flexes the diaphragm and positions the stem with the assistance of a return spring. Spring-diaphragm actuators are designed for both proportional and on–off control of rotary valves. They may be operated by air, gas, water, oil or other supply media compatible with the diaphragm and its case.

Other types of spring-diaphragm pneumatic linear actuators are designed for operation with linear control valves. The action can be direct-acting, where the stem extends with increased air pressure, or reverse-acting, where the stem retracts with increased air pressure.

Electric-motor actuators

Stringent demands are made of electric actuators for industrial valves. Extreme temperature fluctuations and aggressive media that affect the actuator's resistance to chemicals are just two of them.

Microcomputers are being increasingly used to achieve more accurate and finer controls and adjustments. They are installed not only in large facilities but also in individual equipment. The trend will intensify with price reductions



Spring-diaphragm actuator.

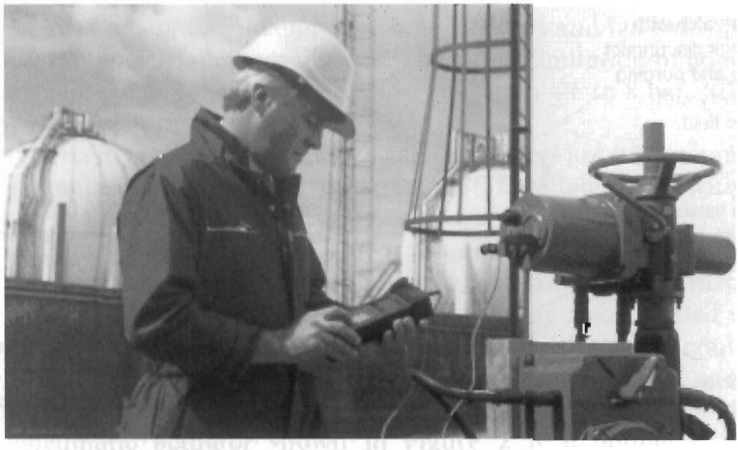
in microcomputers and with the desire to trace system hazards quickly. These factors have caused an acute need for automatic controls for entire piping systems.

Generally, electric-motor actuators are designed for use on ball valves, gate valves, butterfly valves, plug valves and any mechanical equipment calling for 90° rotational control, including dampers and ventilation grids, etc.

The development of the smart valve accessible by a digital communications link means that commands can initiate a stroke check of the valve, recording pressure versus valve travel as the valve is stroked. With an additional sensor for stem and shaft position, the data can then be used to evaluate the condition of the actuator and accessories under various parameters based on an investigation of the valve's stored history. Digital communications to the valve can measure input signal, pneumatic pressure and valve travel, comparing the data with stored expected value's and recommending corrective action. The electric motor will become a serious challenge to pneumatic power when its inertia matches that of a piston or a diaphragm and when gears have zero backlash. It must also rid itself of thermal overloads, limit switches, cams, heaters and thermostats, duty-cycle limitations and explosion-proof housings.

The trend, though, is definitely towards electronics and micro-electronics and for the future there is the possibility of an actuator that emulates a biological muscle—a fast, powerful mechanism that uses stored chemical energy and is controlled by weak electrical pulses. This device might consist of polymer strands that contract on signal and take their energy from a chemical bath that is recharged electrically, as needed by a continuously connected power source.

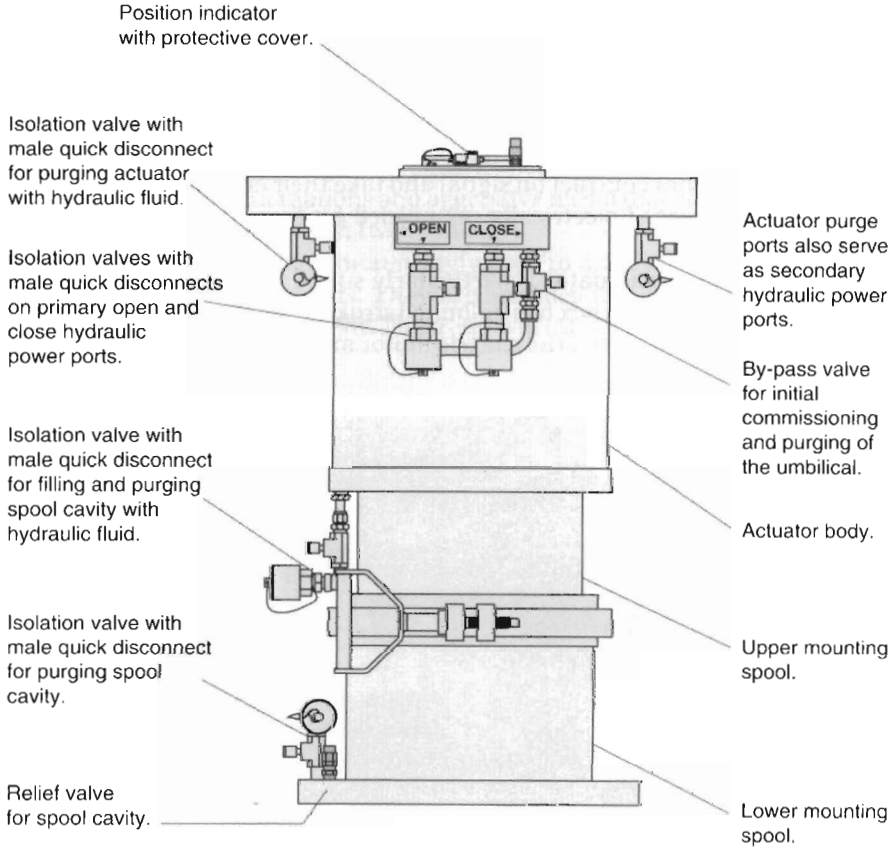
The electric-motor actuator is particularly suited where the stroke is long, because a motor with gearbox has unlimited stroke. However, there are different mechanical virtues between the electric motor and the piston and cylinder. As



Intelligent communication and control.

mentioned earlier, the piston can be kept continuously pressurised, whereas the electric motor cannot; a piston can maintain its position, but the drive of a motor must be mechanically self-locking in order to maintain its position when switched off. The motor does, however, have the virtue of kinetic energy—the ability to take a 'running jump'. Kinetic energy, however, places mechanical constraints on the use of motor actuators as the energy must be controlled and not misapplied.

In certain circumstances, electric-motor actuators are not very efficient. For example, when driving through a worm gear and nut-and-screw, e.g. on a gate valve, up to 90% of the motive power is trying to wear itself out and only 10% is useful. This is acceptable for intermittent valve operation, but it is one of the reasons why geared motor actuators are not well suited to continuous modulating or positioning control via stem nuts or self-locking gears. Multi-turn electric modulating actuators with linear output drives may be a better solution.



Rotary-vane subsea actuator.

Choice of energy system

Clearly the selection of the energy system for a particular valve-operating duty is not something that can be made in isolation. Overall design considerations, safety requirements, availability of supplies and total installed initial cost and subsequent maintenance costs all need to be considered.

No single type of control valve actuator is best for all applications. Demands for power, speed, stiffness and precision vary and cost considerations are always present. For some applications, there is no actuator that performs adequately.

Sometimes practical valve or environmental needs dictate the use of a specific type of actuator, in which case the energy source is predetermined. Sometimes the non-availability of an energy source—or the prohibitive cost of providing it—will rule out certain actuator options. What follows, therefore, is only a brief resumé of the basic systems available, and the practical and economic pros and cons of each for various duties. This must, of course, be related to the foregoing section on actuator types and their performance capabilities.

Advice is readily available from most actuator manufacturers on the choice, sizing, adaption, installation and commissioning of valve-control systems. For the unwary or inexperienced specifier, there may be some risk of bias in such advice from manufacturers of particular types of actuator. This is rare among leading suppliers whose own reputation must stand or fall on the soundness of advice in terms of performance and reliability.

Pneumatic systems

If the operation is to be within the confines of a plant where compressed air is available, the cheapest method of valve actuation is a pneumatic piston and cylinder. Pneumatic operation over a distance is, however, limited entirely by the high cost of making adequate compressed air available over long distances, ease of storage of compressed air facilities and fail-safe operation under electric-power failure conditions. The major limitation of pneumatics is available force due to practical pressure limitation—6 to 8 bar (80 to 100 lbf/in^2) being the normal maximum.

Ninety percent of modulating control valve actuators are still pneumatic.

There are many variations of pneumatic actuator available today with output torques up to 12,000 Nm (9000 ft.lbs).

The actuator shown in Figure 1 is of the double-acting rack-and-pinion type and is particularly suitable for the automation of a quarter-turn valves (butterfly snd ball valves). This type of actuator may also be fitted with an electronic integrated instrumentation unit to ensure the direct control and supervisory functions encountered in all modern processes and, more particularly, in communication by fieldbus.

The pneumatic actuator shown in Figure 2 is a double-acting type incorporating scotch yoke drive.

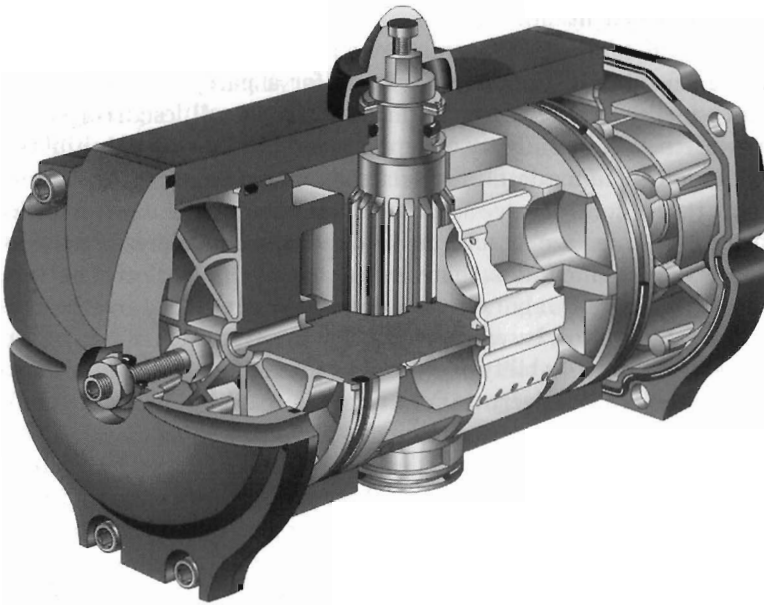


Figure 1. Double-acting rack-and-pinion pneumatic actuator.

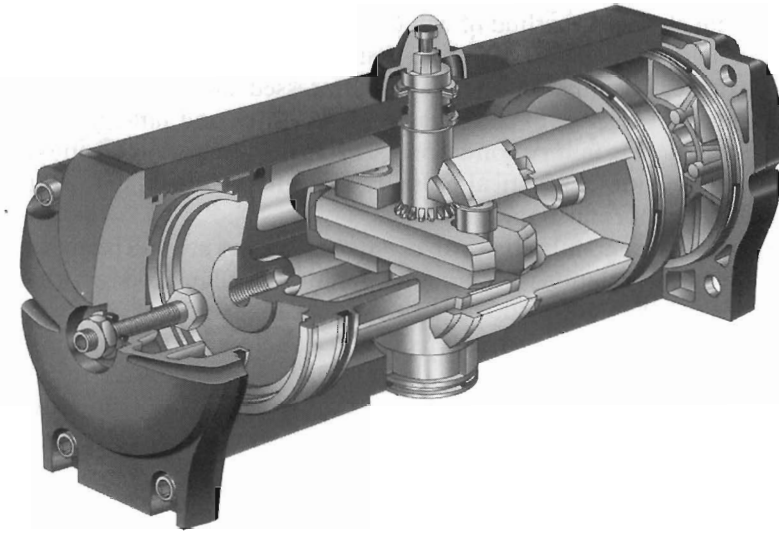


Figure 2. Double-acting pneumatic actuator with scotch yoke drive.

This actuator develops a variable torque and is well suited for the operation of larger size quarter-turn valves (butterfly and ball valves) when a significant torque is needed near the closed position or near the open position. A typical standard type of double-acting and spring-return piston-type actuator is shown in Figure 3.

This style of pneumatic actuator also employs a self-contained spring cartridge to protect against failure in either the open or closed position. Actuators of this type offer an extremely long cycle life and are well suited to operate almost any rotary valve in both modulating control and on–off service. Most actuators of this type are located in fully-closed housings, sealed against humidity and dust, and should not need regular maintenance. Another versatile unit is the positioner–actuator which consists of a double or single actuator, a pneumatic or I/P positioner and conventional or inductive limit switches. This is mainly used with small, segmented ball valves.

Normal operation of pneumatic actuators is generally accomplished by pressurising the appropriate supply ports by means of an air-control valve. Most solenoid and control valves perform better on lubricated air which may be added with an air line lubricator. Clean, dry air extends the life of pneumatic actuators and, if this is not available, an in-line filter should be used. Before hook-up, air lines should be purged to remove scale and other particles which could damage the control valve, positioner and actuator seals.

Figure 3. Standard-type double-acting and spring-return pneumatic actuator.

Vane systems

Rotary-vane valve actuators are used for quarter-turn valves in critical applications, especially on natural gas pipelines where the actuators are typically powered by natural gas using gas over oil tanks. Other applications include:

- quarter-turn valve control on crude-oil products pipelines with the actuators powered hydraulically or by nitrogen-storage vessels
- high-vibration applications including slurry-pipeline valves, pumping station valves and compressor-station valves
- offshore platform applications
- cryogenic or extremely low-temperature applications
- subsea-valve control
- high-speed applications with stroking times as fast as 250 ms

A typical rotary-vane actuator is shown in Figure 4.

The general principle of operation of this type of actuator is that opposite chambers in the actuator are corrected by pressure-equalising passages in the upper and lower heads. In this manner, the actuator produces a balanced torque as hydraulic force simultaneously pushes both of the rotor valves away from the stationary shoes.

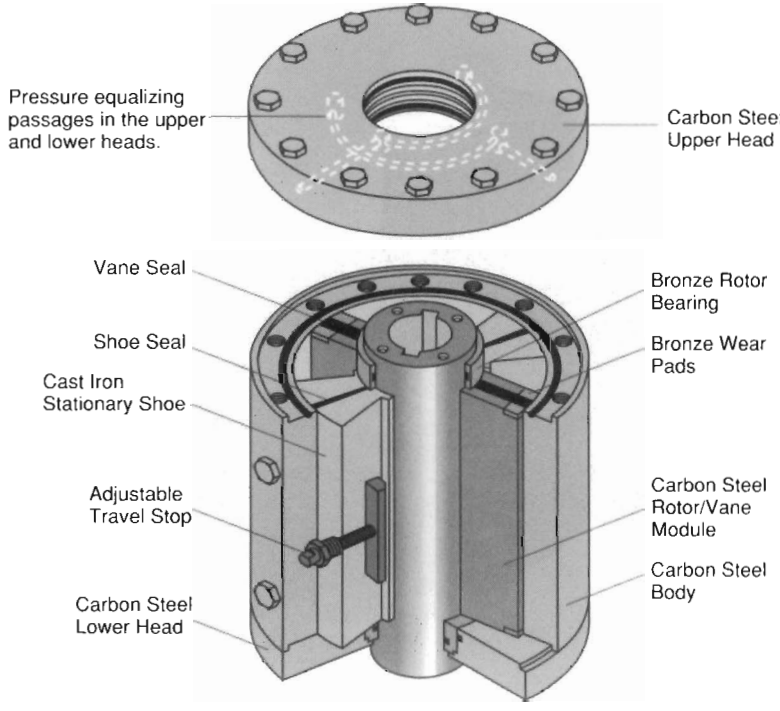
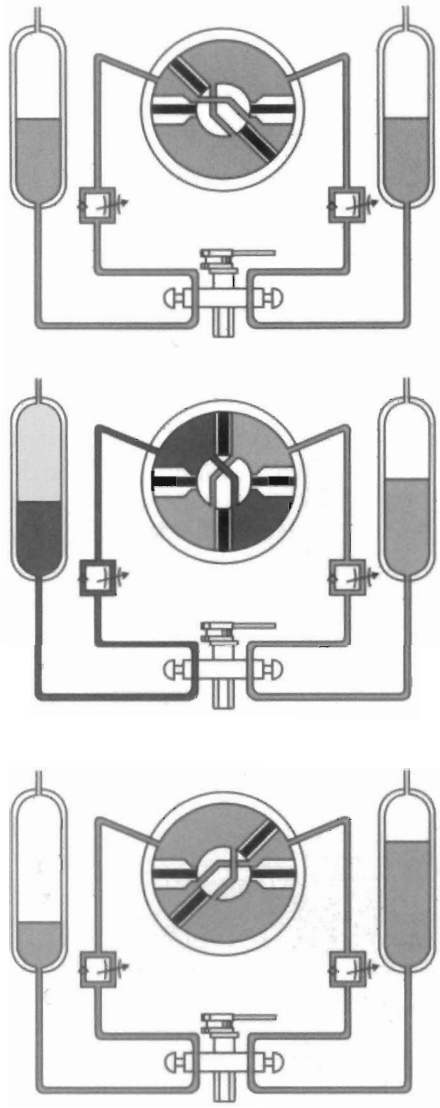


Figure 4. Rotary-vane actuator: schematic.

Torque output of the rotary-valve actuator remains constant throughout the full rotation of the valve. Constant torque output is an especially important feature in high-flow applications, plug-valve applications and for valves which have rotating seats. Constant torque output insures that the specified safety factor will not diminish at various positions during the valve stroke.

The rotary-vane actuator has often been described as the complete actuator for high-pressure duties. Regulators, pressure-reducing valves or relief valves



SEQUENCE 1

The actuator may be powered by a hydraulic power unit, stored gas pressure or by natural gas pressure from a pipeline. In this illustration, the actuator is fitted with gas hydraulic tanks and is powered by gas pressure. In the first sequence, the actuator is in the open position. There is no pressure in the actuator or tanks.

SEQUENCE 2

The actuator control system is used to admit high pressure gas into the closing gas hydraulic tank. The pressurized gas in the tank forces hydraulic fluid into the actuators closing port. Pressure equalizing passages allow both closing quadrants to be pressurized simultaneously providing balanced torque as the vanes push away from the stationary shoes. The actuator is rotating clockwise.

SEQUENCE 3

When the actuator reaches the fully closed position, the control system will allow all remaining pressure in the tank to vent to atmosphere, thus neutralizing the pressure in the tank and actuator.

High Pressure Gas
Pressurized Hydraulic Fluid
Non-Pressurized Hydraulic Fluid

Figure 5. Rotary-valve actuator: operating sequence.

are generally not required in the power supply circuit. The operating sequence of a typical rotary-valve actuator is described in Figure 5.

Hydraulic systems

Hydraulic systems are the natural choice if an exceptional duty requires a large amount of stored power (Figure 6). The forces available, and the speed

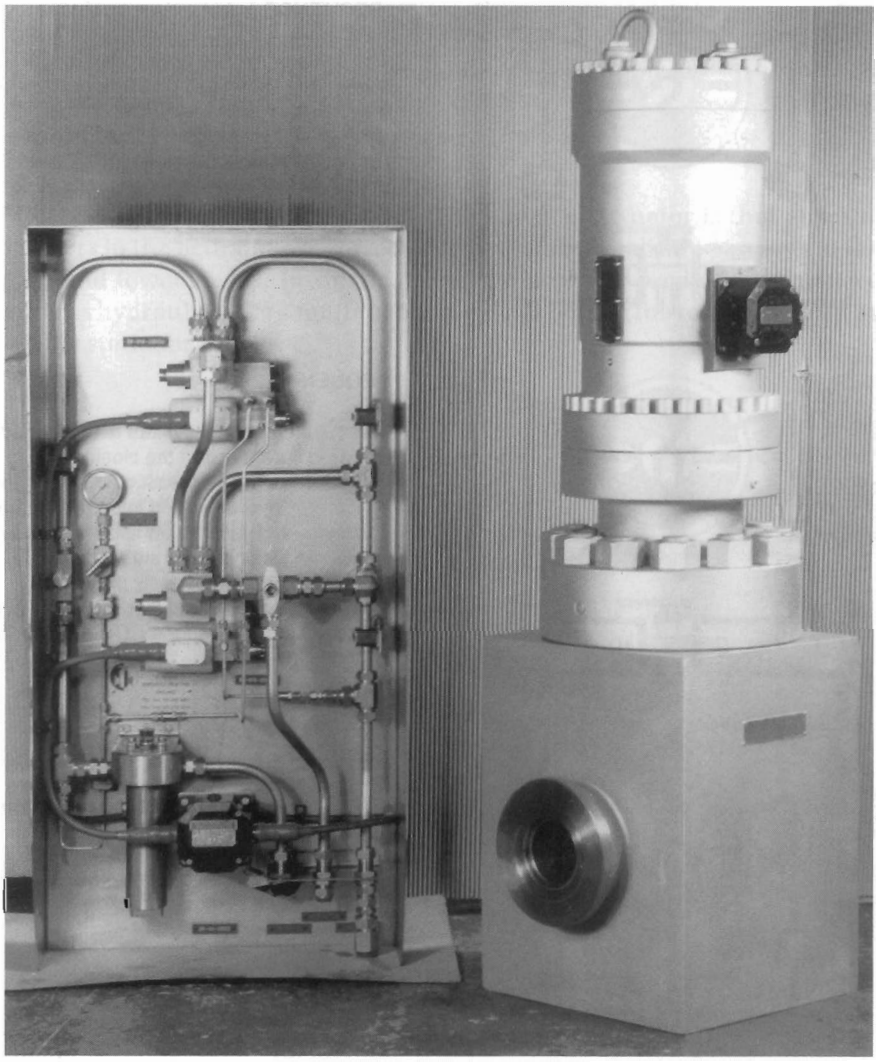


Figure 6. 15,000 lb/in² conduit-gate valve with hydraulic spring-return actuator and emergency shut-down control panel.

and control of the hydraulic actuator are virtually unlimited, i.e. the only method of operating a large valve in seconds is to pump up a hydraulic accumulator first. Unless these particular virtues are needed, the system is uneconomical and, for this reason, is not commonplace.

Furthermore, the hydraulic system is very expensive for operation over long distances. A pneumatically-operated valve is vented to atmosphere but, with the hydraulic system, the hydraulic fluid has to be returned through a line of greater suction to avoid pressure drop. For some special situations, such as tanker-cargo valves, however, hydraulics provide the only acceptable means of centralised control. Hydraulic systems are still used for fail-safe and standby duties.

Combined pneumatic/hydraulic systems (air–oil cylinder)

There are some specialised applications where the combination of pneumatics and hydraulics can meet particular operational, fail-safe and other needs. Usually, the principle involved is to use a plant's existing compressed-air supply to drive a hydraulic pump which, in turn, is used as the regular valve-actuator energy source, but which also tops up an accumulator for standby emergency use. Such systems can be devised to cater for virtually any supply-failure conditions. A typical application is for self-powered actuators in gas pipelines from which the live gas can pressurise a hydraulic accumulator system for emergency isolating valves. Live gas is also used to operate the actuator directly, as previously described.

Hydraulic actuators with output torque valves to 2000 Nm.

Electric systems

There are two main factors to be considered here: an electric motor as the power source, and electricity for the control system. Undoubtedly, full electric operation and control offers the greatest flexibility, and best suitability, to centralised automatic control. Remote indication by electrical position feedback and provision for stand-by manual operation are inherent if the system is totally electric.

Electric control

Much of the development in industry today is in the direction of centralised control, which in turn involves remote electrical control of valves, so a close look at electric valve actuators and their control systems is justified.

Electric valve actuation continues to evolve with astonishing speed. Among the leaders in the field, this evolution has resulted in very advanced, sophisticated designs suitable for instant adaptation to practically any kind of valve, in any environment, in any part of the world.

The weakness of electrical equipment is that electricity and water do not mix. However, electric actuators are required to operate in a wide variety of environments: high temperatures, steamy atmospheres, adverse weather conditions, mud, sand, flooding and so on. Thus the primary problem for the designer is not the mechanical duty—that is negligible—but to keep the environment out.

For example, a plant operating 5 days a week, 50 weeks a year, with a motorised valve of 1 minute stroke time, opening in the morning and closing in the evening, would demand a total actuator working life of only 7 days in 20 years. Thus, proper environmental sealing to enable an actuator to do nothing with complete reliability is paramount. A minimum requirement is that it should be watertight and flood-proof.

As a further safeguard to exclude the environment, the terminal area—which has to be exposed for wiring on site—should be separately sealed from the rest of the equipment, to prevent the ingress of dirt or water during installation, the most vulnerable period in an actuator's life.

Single-phase, watertight electric actuators are a simple and cost effective way of controlling small quarter-turn valves and dampers. They are suitable for use in many areas where an IP68 (NEMA 6) enclosure is required.

The example shown in Figure 7 is suitable for simple open–close duties where on–off control is required. This is achieved without the need for reversing contactors. The structural components of a typical standard electric valve actuator for use with cast-iron and stainless-steel ball valves and butterfly valves, including also motor-operated control valves and rotary control valves, are shown in Figure 8.

One example of how solid-state technology is being applied to electric motor controlled actuators is shown in Figure 9.

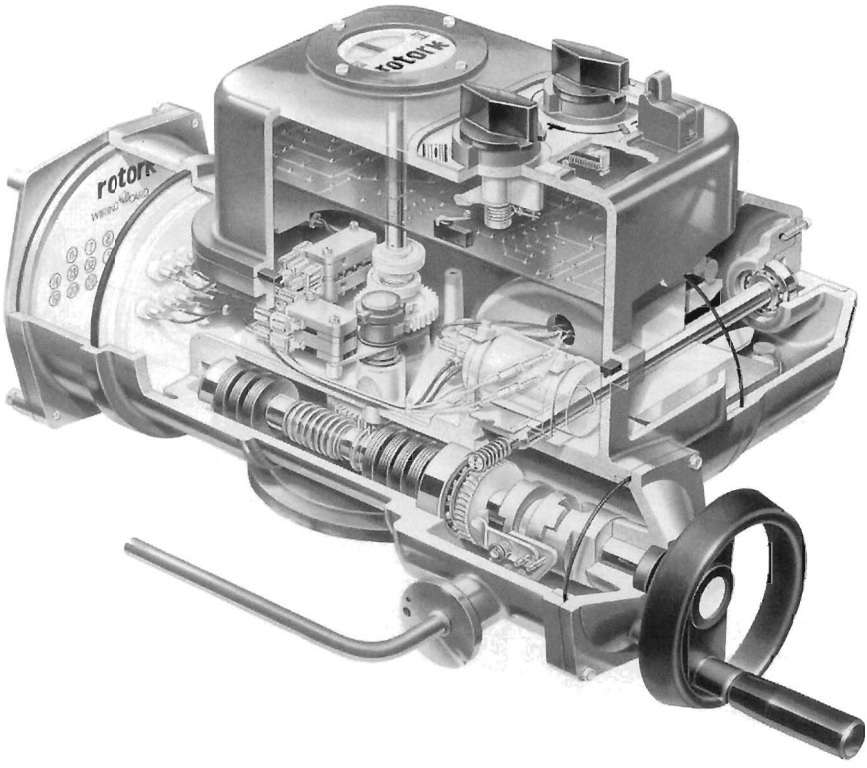


Figure 7. Single-phase electric actuator.

The actuator consists of a motor controlled by an integral solid-state control assembly driving through two stages of worm and wheel gearing to a quarter-turn output assembly giving clockwise-to-close output.

The solid-state assembly consists of two elements, the transformer rectifier providing DC power via thyristors to the motor and the CMOS gate array which controls and monitors the actuator functions and interfaces with remote controls. The logic circuits are protected from high-voltage transients which may appear at the actuator terminal by opto isolators. A schematic (Figure 10) shows the circuitry.

Electrically operated/electronically controlled

Intelligent, non-intrusive, three-phase electric valve actuators incorporate the latest electronic techniques and combine them with tried and tested motor and gearing technology (Figure 11).

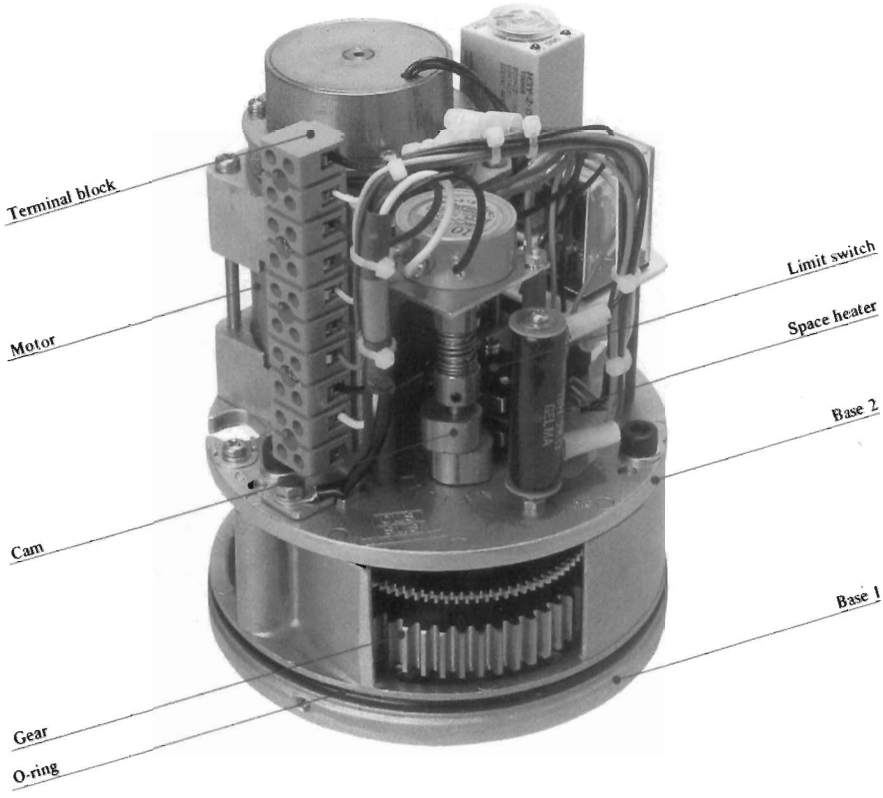


Figure 8. Electric valve actuator: structural components.

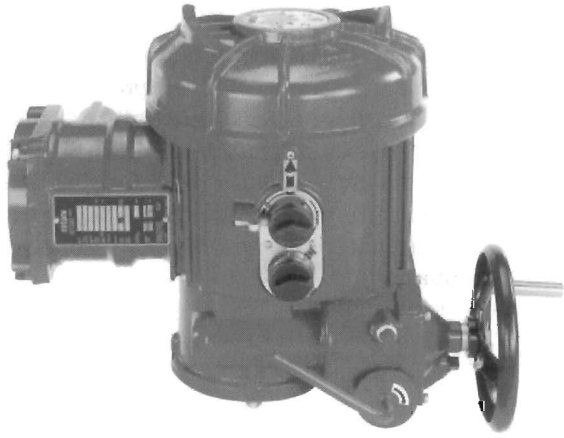


Figure 9. Electric quarter-turn actuator for fully-modulating duty.

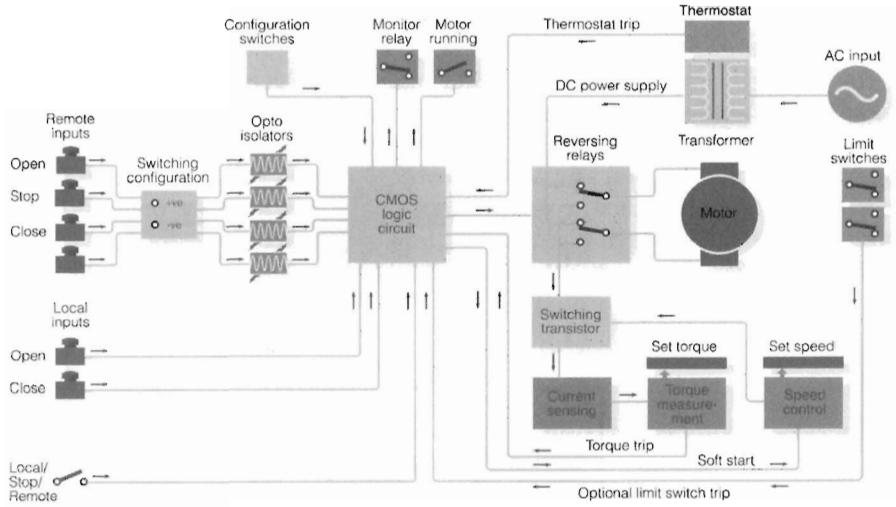


Figure 10. Circuitry of electric actuator shown in Figure 9.

Essentially, the non-intrusive actuator makes it unnecessary to remove electrical covers during motorised valve commissioning by providing local controls that do not penetrate the electrical enclosure.

The actuator consists of a self-contained unit for intermittent valve operation and comprises a three-phase motor, reduction gearing, reversing contactor starter with local controls and monitoring facilities, all based in a double-sealed, watertight enclosure to IP68 NEMA 4 and 6.

All torque and turn settings and configuration of the indication contacts are effected using a non-intrusive, handheld infra-red setting tool.

Infra-red setting

The infra-red programming and setting device is a handheld setting tool that allows the valve actuator to be configured, interrogated and commissioned in a completely non-intrusive way. This allows, for example, the possibility of making adjustments to a 'live' actuator within hazardous and wet areas (operational conditions permitting). A liquid crystal display on the actuator shows its status digitally. LEDs also show, for example: green—fully closed, yellow—any intermediate position and red—fully open. The handheld infra-red setting tool can confirm torque settings and perform simple diagnostic procedures to reveal why an actuator may not be functioning correctly. Power-supply faults, interlocks and other interruptions can be identified. Torque levels, limit settings and the configuration of the actuator may also be changed. Each time the actuator is powered up, it automatically tests its operational circuit's memory devices.

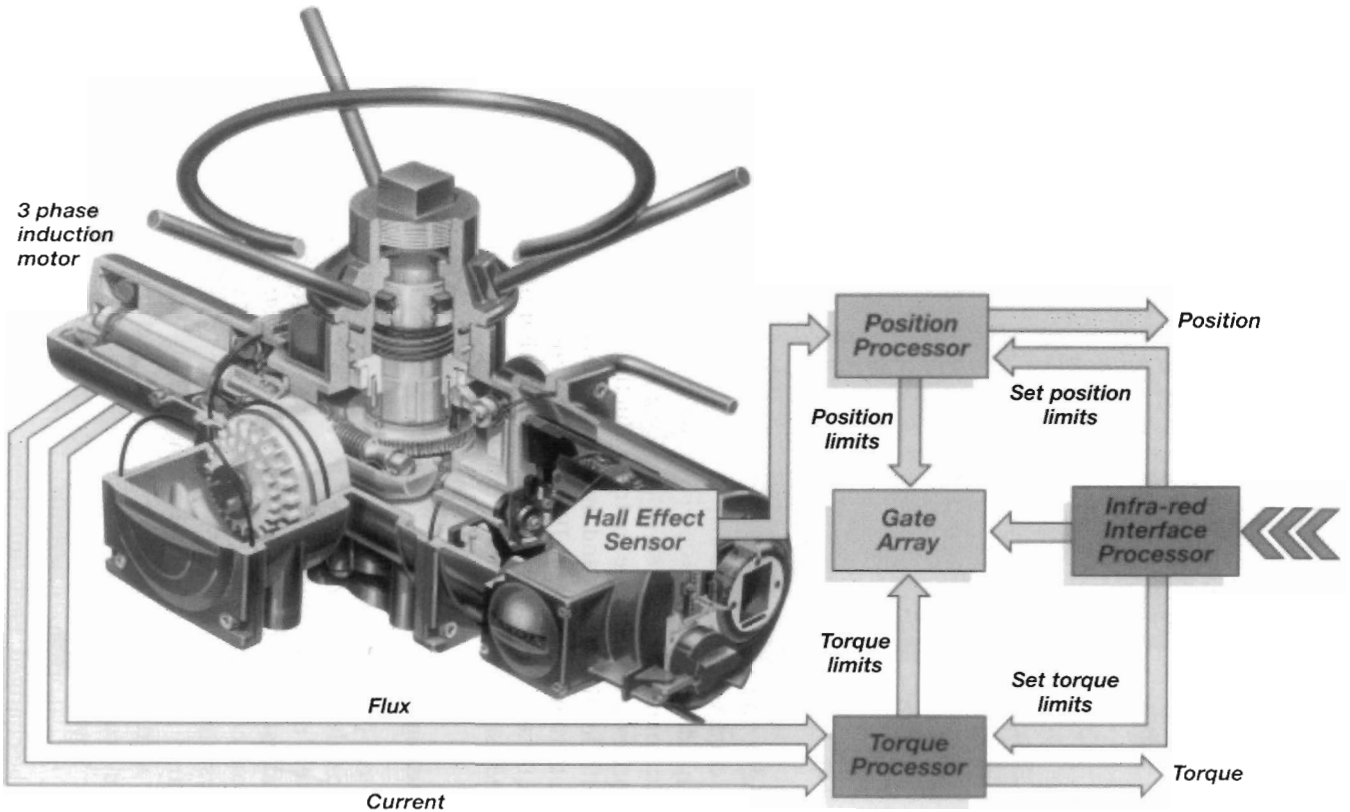


Figure 11. Electrically-operated, electronically-controlled intelligent actuator.

Handheld interrogation computers allow actuators to be assessed via an infra-red link which is connected to the handheld computer and attached to the actuator indication window (Figure 12).

This unit carries out all the functions previously described and downloads them for analysis. Historical information such as operator actions and output torque profiles can also be downloaded for analysis and to provide a view of operating events that can be viewed in groups or as traces. Details of a valve's last opening/closing cycle profile and its historical average opening/closing profile are also captured. From these, the latest profile could be compared with the average, giving an idea of changes in the valve torque requirement.

Communication and supervisory control

The major milestone in flow-control development and technology has been the introduction of fieldbus control systems.

Modern facilities require up-to-date communications right down to plant level.

Fieldbus systems take advantage of the latest developments in low-cost micro-chip technology, allowing intelligence to be built into each device in the loop.

This intelligence allows the rapid development of networks of intelligent control devices, each communicating with each other over a common medium.

Figure 12. Handheld computer gives access to valve-actuator diagnostics and configuration.

The 'peer-to-peer' control allows operators accurately to position a valve and thus achieve the optimum process parameters, including temperature levels, pressure and other critical variables.

Each control device communicates via a protocol that has been specially developed for the reliable and quick transmission of control information, with guaranteed transmission times for high-priority messages.

Fieldbus systems promise greater process control coupled with increased accuracy, efficiency, cost savings and plant reliability. The diagnostic role of fieldbus means that it can also give advance warning of potential problem areas, thus enabling preventative action to be taken.

Two-wire loop systems

Two-wire communication systems provide the link between valve actuator and supervisory control. Systems generally have three essential elements—field units, the 2-wire loop and a master station.

Field control units are typically mounted within the actuator's housing. Variable parameters such as the field unit address and baud rate are set non-intrusively using an infra-red communications link. Changes to the parameters can usually only be made when the field unit is in 'loopback' mode. An EEPROM holds the address and communication speed data, and a detector senses the loop current. The field unit does not interfere with the actuator local controls which remain operable in the event of field-unit malfunction.

The 2-wire loop carries a current loop signal which is modulated by a master station to send and receive data from field control units. The cable is a single twisted pair with an overall protective screen. The loop is capable of being installed in an electrically hostile environment where large surge currents can induce transient currents in the cables (i.e. lightning storms). The use of a 2-wire system greatly reduces the number of cable cores to transfer signals from the actuator to the control centre.

The two wires are connected to, and taken from, each field control unit in turn. They originate from and return to the master station to create a single twisted-pair, 2-wire loop.

As each device may be accessed from either direction, a redundant communications path is available. The integrity of the 2-wire cable is continuously checked whilst the system is running. Should communication fail, the master station ceases transmission and every field unit asserts its 'loopback' circuit. After a short period, the master station begins communication to each field unit in turn, extending the current loop until the fault location is revealed.

The master station is typically equipped with two processors, one to control the loop data and the other to handle the host communications, screen display and keypad. All messages passed over the network are under the control of the master station. A field unit may not transmit any data unless it receives a

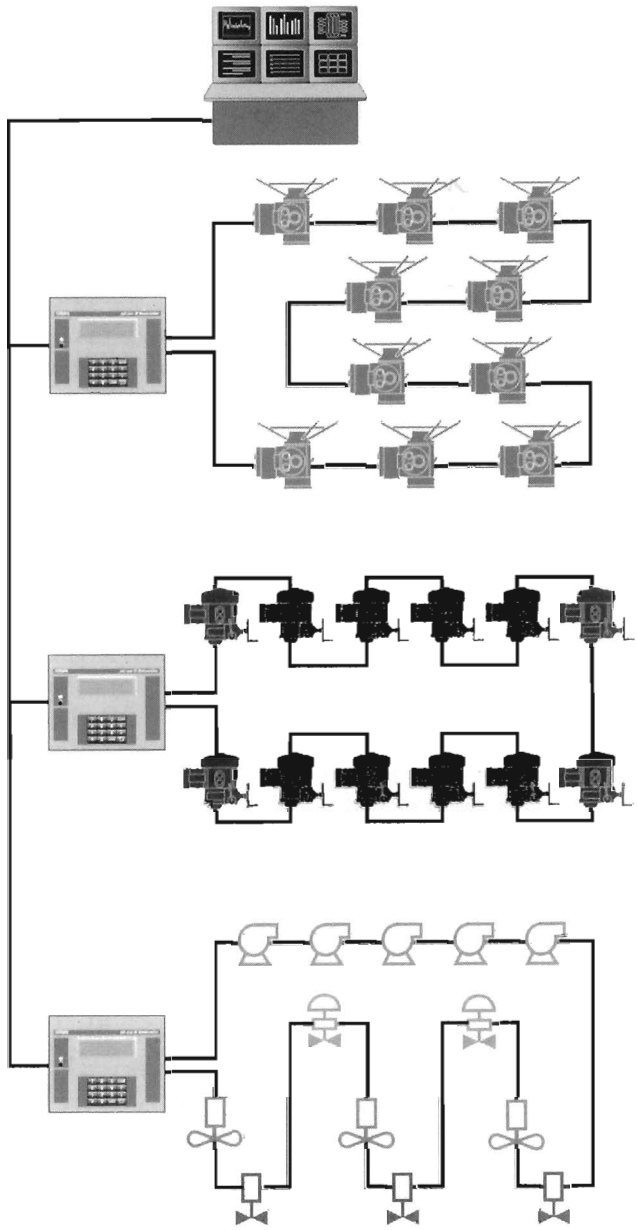


Figure 13. Advanced 2-wire loop-network communication system.

request from the master station. The host system may be a DCS, PLC or SCADA system. The information is typically passed using a universally accepted fieldbus communicator standard, e.g. Modbus, HART, INTERBUS, etc., protocol.

Information is continuously gathered by the master station from the field units, so ensuring that information requests by the host system are serviced with an intermediate reply from the internal data base.

Command instructions from the host have priority and are processed immediately by passing the message to the field unit concerned.

Advances in this technology also provide for high levels of system safety and security, including hot standby, cable fault protection and field unit failure protection, as well as logic and sequencing capabilities of a PLC, and Direct Operator Panels where operatives require push buttons and indicators for valve positions and graphical interfaces to the valves and plant using mimic diagrams to show the plant layout.

Any valve may be controlled and navigation through the application is by mouse control. Systems of this type can operate with a single network covering 240 devices over a 20 km loop length, without restriction on inter-node distances.

Some examples of layouts showing the control of actuators by Bus system are shown in Figures 14 and 15.

Electronic controllers have reached a high stage of development and sources within industry consider that the Fieldbus specification may be too complex in attempting an all-embracing standard. Problems are possible in migration between Fieldbus variants and integration with distributed control systems.

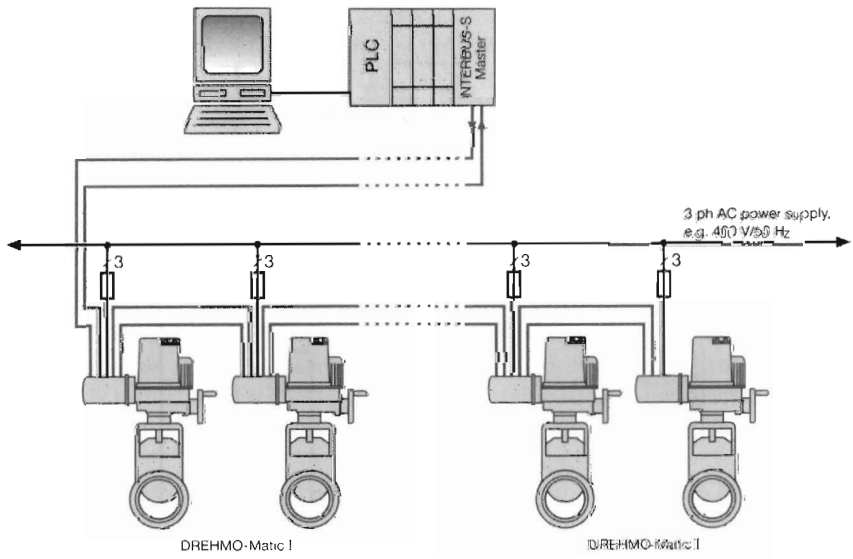


Figure 14. Controlling the actuators by BUS system: Interbus-S.

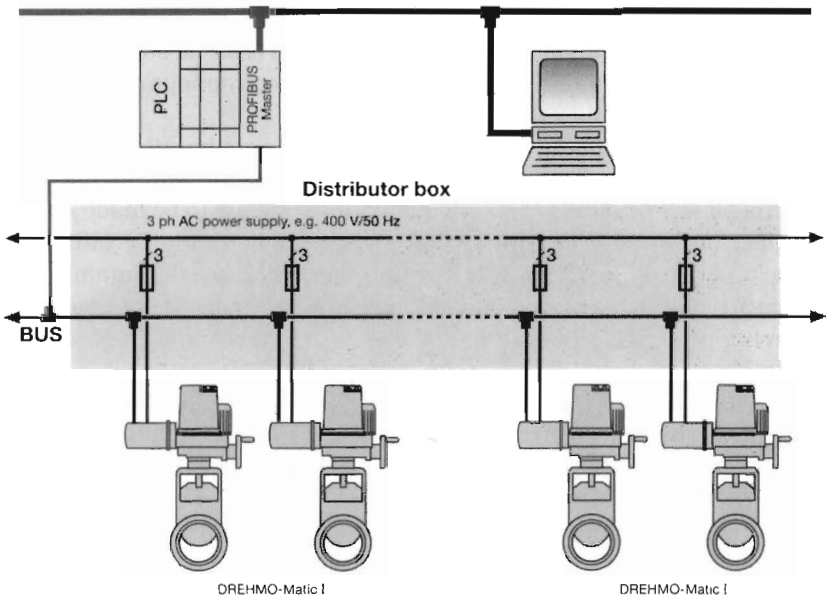


Figure 15. Controlling the actuators by BUS system: Profibus.

This is important where a transparent interface between the intelligent 'smart' valve and the Distributed Control System is required.

There is also concern that lightning strikes could cause failure of the microprocessors in the positioner. Manufacturers are actively working in this area developing their own intelligent electronics systems such as Fieldview, Starpak, Smart Valve Interface, Pakscan, ISMO, TZID, Keydig and Matic.

Valve positioning

There are two basic requirements in the opening and closing of valves: when closing, to be sure that the valve is properly and tightly seated, yet without excessive force being applied; when opening, to be certain that the valve is fully opened without excessive overrun or strain on the backseating.

A positioner is a device for varying and maintaining an actuator position in control valve applications. The positioner compares the actual actuator position with respect to the given input signal and adjusts the pressure applied on the actuator until the desired position is attained. Positioners can be pneumatic or electropneumatic, single- or double-acting and capable of being used on both rotary and linear actuators. Typically, a pneumatic positioner is a single-stage, force-balance device that can regulate virtually any actuator stepless from 0 to 100%. In basic form it consists of a flapper and nozzle, spool

pilot valve, an adjustable range and reversing mechanical feedback. Generally, the electropneumatic positioner's action is based on the principle of analogue electronic comparison. More advanced electropneumatic positioners are low-powered high-flow switching devices.

Using menu-driven button control pads or remote communications devices, the operator selects from a wide range of pre-set or automated control characteristics. User configuration enables adjustments to be made manually so that parameters can match specific process conditions. Certain systems have the ability to adjust the valve's position using a static or dynamic option. Static setting allows the fixed adjustment of the actuator's upper and lower limits, while the dynamic option enables the valve position to be altered to match the individual installation requirements.

The valve positioner shown in Figure 16 is an intelligent digital device that combines micro-processor technology with a piezo-electric interface. The instrument can be connected to 2-, 3- or 4-wire systems and checks to establish what it is connected to and what is required of it, then calibrates the basic settings accordingly. Some positioners incorporate or can accommodate a gauge block directly onto the positioner for a continuous indication of the input and output air pressure of the actuator and the positioner.

Electric modulating actuator for control valves and damper applications.

Programmable positioner for quarter-turn actuators.

Figure 16. Electropneumatic valve positioner incorporating digital technology.

Limit switches

A limit switch is a device connected to an actuator or valve that transmits a signal when the valve reaches a pre-established position.

A typical limit-switch box for pneumatic actuators is fitted with two switches. These are activated by two adjustable cams mounted on the drive shaft. A direct coupling with the actuator drive shaft provides an exact indication of the valve's position.

The switches can normally be set independently of each other to provide an open/closed signal of the drive shaft and thus the position of the valve to the control room.

Gear operators

There are three main types of gear operators. These are of worm gear, bevel gear and spur gear design. Gear operators are generally suitable for both manual and motorised use (Figure 17).

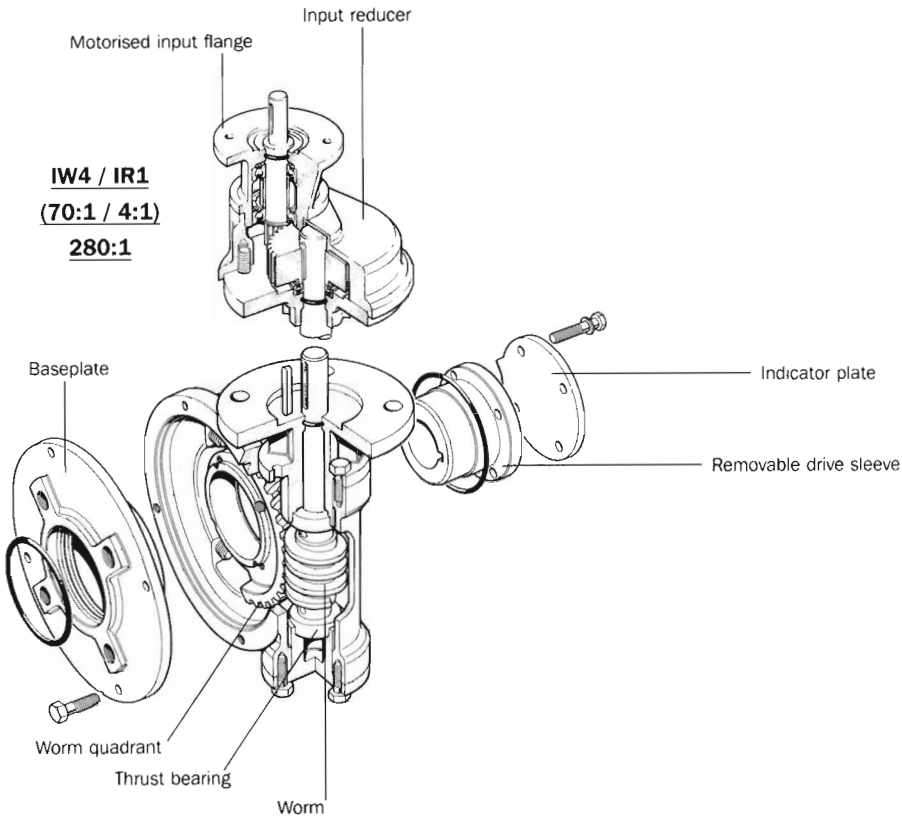


Figure 17. Quarter-turn worm-gear operator.

Worm-gear operators tend to be used with butterfly and ball valves and dampers, as well as other applications where keyed shafts are used to operate equipment.

Spur, bevel and multi-turn worm-gear operators are for use on gate, globe, sluice and penstock valves, as well as other applications where screwed or keyed shafts are used to operate equipment. Applications include low and high temperatures, submersible duties, buried service, marinised duty, water works specification and special indication.

Efficiency

It has been said already that some valve motor drives are mechanically inefficient—giving only 10% useful energy when, for instance, they are driving through a worm gear and the nut-and-screw of, say, a gate valve, and not much higher when driving a butterfly valve through self-locking gears. Wearing of inefficient gears or stem nuts is the primary limitation on frequency and continuity of operation of such drives, and this also limits the practical speed of operation of large screw-operated valves and penstocks. Nevertheless, the many advantages of control, power source, interfacing with supervisory control and instrumentation and so on compensate for the mechanical inefficiency, provided the actuator duty is properly considered.

Portable valve actuators

Portable valve actuators or valve wrenches can be used to provide portable turning power to replace manual effort in opening or closing valves on pipeline systems not fitted with permanent valve actuators. For example, water distribution piping systems generally have no permanent actuators installed, opening and closing of valves, when required, being by manpower.

An advantage of portable valve actuators is that they permit implementation of valve-exercising programmes designed to service and operate valves in order to keep them in good condition, e.g. eliminate 'valve seizure' problems which can arise when valves are left in one position for long periods. This applies particularly in water systems.

Portable valve actuators and valve wrenches may be designed for operation by electricity (i.e. powered by electric motors), compressed air or hydraulic power, and are normally adaptable for fitting a wide range of standard valves. The best designs provide operation 'feel', as well as speed control, reversibility and the ability to make instant stops and starts and reverses needed to free up sluggish gate valves, hydrants and sluice gates, etc. Typically, speeds of up to 20 to 25 r/min may be provided, with operating torques up to 1360 Nm (1000 lbf/ft) for handling valves in the size range 152 to 1524 mm (6 to 60 in).

The majority of such models are readily portable, i.e. weigh less than 18 to 23 kg (40 to 50 lb). Larger, heavier models may be trolley- or truck-mounted.

Control Valves

In general terms, a control valve may be described as a power-actuated valve, capable of throttling or modulating the flow, and used as a final control element in a control loop. Control valves operate automatically, receiving signals from an external controller. They may incorporate several different types of valve including globe, butterfly, ball and diaphragm (Figure 1).

Their operation can be vacuum, pneumatic, electromagnetic and hydraulic.

Within the area of control valves, most developments have taken place with the internal components such as the trim, which may well be of the cage type (hollow cylindrical trim), with retained seat, instead of contoured plugs with threaded seats.

Development in control valves has been driven by a demand for higher temperatures and pressures within the chemical, oil and power industries. Transcontinental pipelines, offshore oil and gas platforms and under-sea modules have been important driving forces.

Developments for control valves point to electronic packages located on valves which can be called up for remote interrogation. 'Smart valves' accessible by a

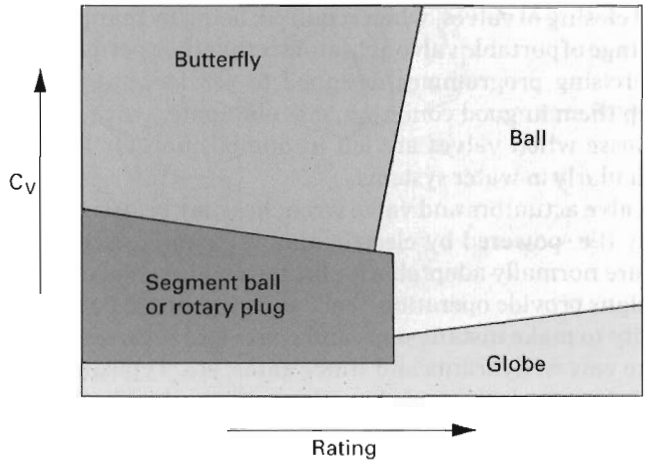
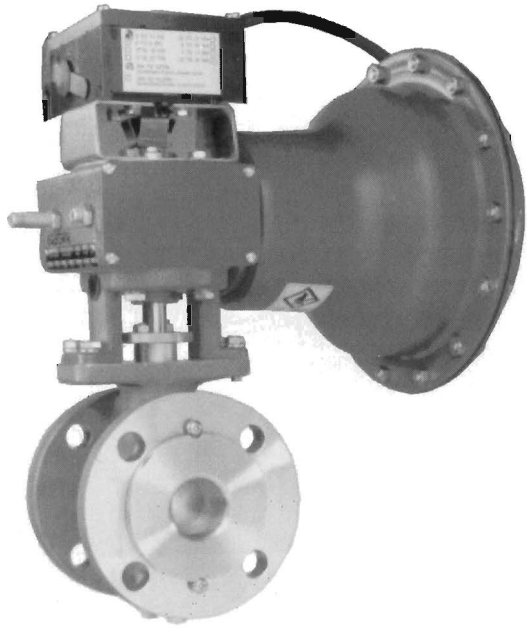
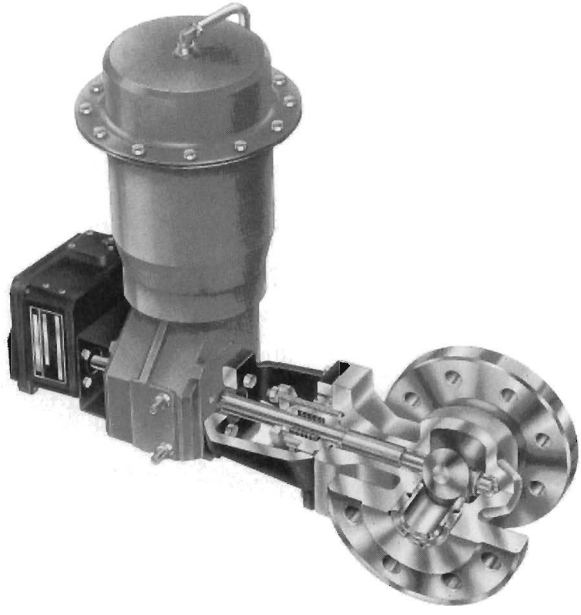


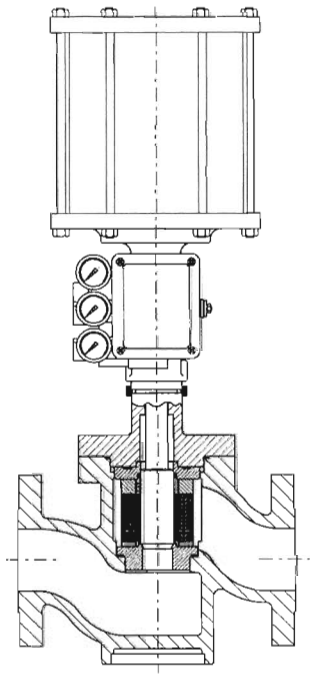
Figure 1. Control valve types.



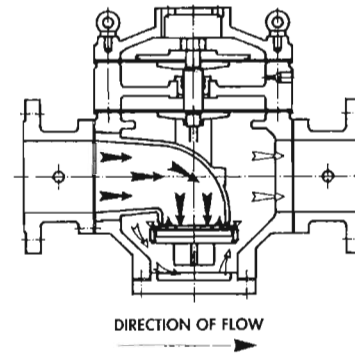
Control valve.



Rotary control valve.



Severe-service control valve for oil and gas duties.



Pressure control valve.

Flow control valve.

digital link receive and transmit commands that can indicate a stroke check of the valve, recording pressure vs valve travel as the valve is stroked. With an additional sensor for stem and shaft position, the data can be used to evaluate the condition of the actuator and accessories under various parameters based on an investigation of the valve's stored history. Digital communications to the valve can measure input signal, pneumatic pressure and valve travel, comparing the data with stored, expected values and recommending corrective action.

Current difficulties arise over the fieldbus communications standard. While the concept of valve intelligence does not depend on digital communications, the reality is that some form of digital fieldbus is essential.

Control valve sizing

A number of valve manufacturers have produced control valve sizing programs that can be used to select a control valve with optimum controllability and control accuracy for each process application. Typically, these programs are based on the flow characteristic curve and gain curve of the installed valve.

Inherent and installed flow characteristics

The selection of a control valve of optimum size and type begins with the valve's flow characteristic. This has been defined as the curve relating percentage of flow to percentage of valve travel, i.e. rotation of the ball or the butterfly disc or linear movement of the globe valve disc.

'Inherent flow characteristic' applies to situations when constant pressure drop is maintained across the valve.

'Installed flow characteristic' takes into account the variations in the pressure drop caused by conditions in the system where the valve is installed.

There are two common flow characteristics for control valves. In the equal percentage characteristic, a given fraction of valve opening changes flow by a certain percentage of previous flow. In the linear characteristic, a given fraction of opening changes flow by the same fraction of maximum flow.

Figure 2 shows the most common valve inherent flow characteristics as a function of the relative flow coefficient (ϕ) and the relative travel (h).

A typical installed flow characteristic curve for a butterfly valve in a process application is illustrated in Figure 3.

Overshoot

An important function of control valve performance is 'overshoot'.

As the control valve responds to a step change in signal, overshoot is the amount of travel beyond the final steady-state position. While in most systems it is important that a control valve responds quickly to changes in signal, it is equally important that this response does not destabilise the operation.

Excessive overshoot can contribute to loop nonlinearity, as well as increase loop instability and affect control-loop performance.

With a signal of 5%, a control valve with zero overshoot will travel directly to the required position. A valve with up to 20% overshoot will pass beyond the proper position by 1% and require time for adjustment to the new position. A control valve with the least amount of overshoot will provide the system with the best opportunity to respond to changes in process demands.

Percentage overshoot should be less than or equal to 20% of the step magnitude for steps ranging from 10% of travel down to steps equal to the backlash/stiction limit +1%. Speed of response needs to be viewed in conjunction with how accurately the control valve responds to a change in input signal and the percentage of valve overshoot. Quick response by itself without a high level of accuracy and with too much overshoot will destabilise system performance. Control valve speed of response is typically determined by four major criteria:

- Dead time (Td)—the time it takes to respond after the signal is initiated. It is measured in fractions of a second.
- T63—the time it takes the valve to reach 63% of its new position. It is measured in seconds or fractions of a second.

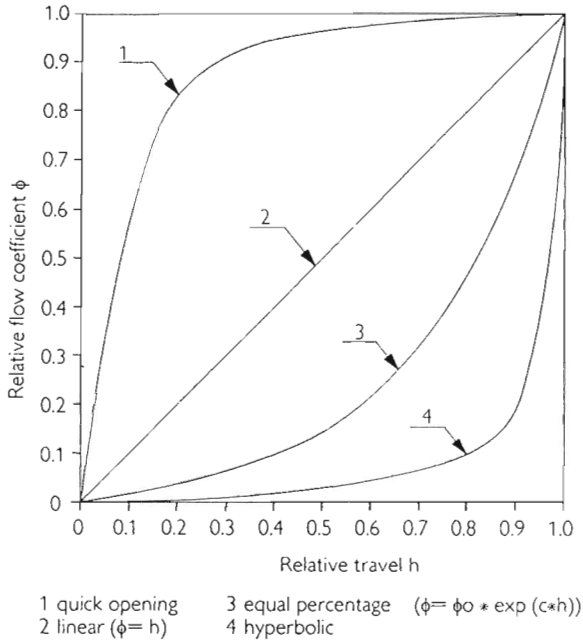


Figure 2. Valve inherent flow characteristics.

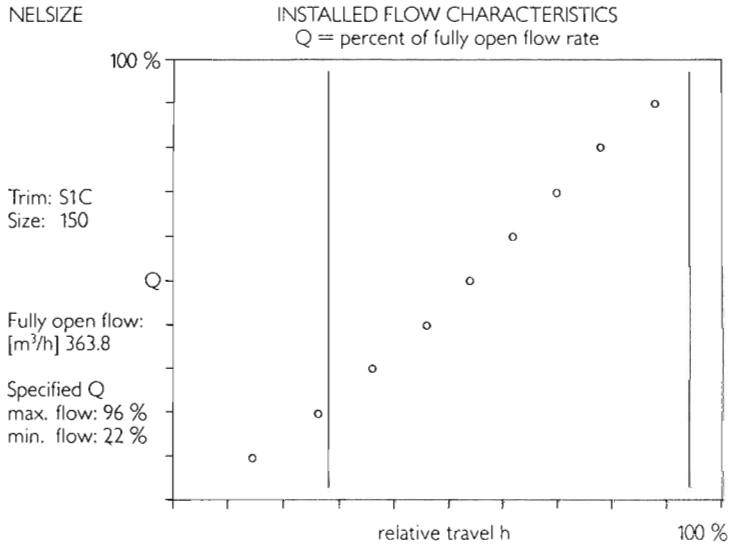


Figure 3. Typical installed flow characteristic for a butterfly-control valve.

- T98—the time it takes the valve to reach 98% of its new position. It is measured in seconds or fractions of a second.
- Band width—the frequency at which the plug position amplitude is diminished by 6 dB (difficult to verify).

The control valve shown in Figure 4 has been designed for highly erosive services and with simple maintenance procedures without special tools. The valve can be used with sodium chlorate, wet chlorine, terepthalic and hot acetic acid because it has a tiodyed titanium seat and plug, a ceramic-coated titanium shaft and titanium bearings with Kalrez®* seals.

The plug and seat are self-aligning and bi-directional flow capability helps to prolong valve life. The valve operates over a 90° range of motion and can

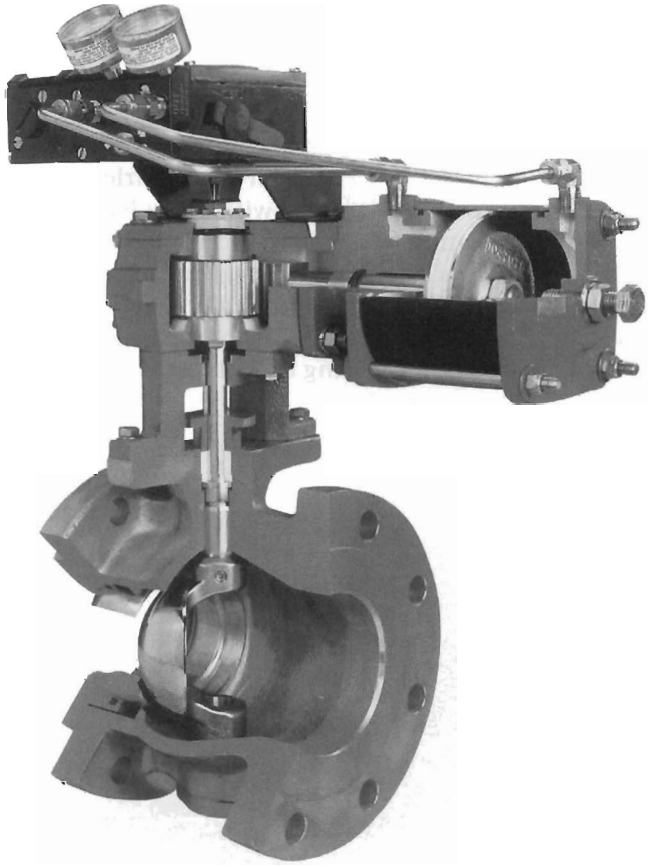


Figure 4. Rotary control valve for highly erosive services.

*Dupont registered trade mark.

withstand high pressure drops. Typical products being handled include digester gas off, Kaolin slurry, fly-ash slurry, titanium dioxide slurry and steam.

Segment control valve

This type of valve may be considered to be a special category of single-seated control valve (Figure 5). Segment valves have a concentric V-shaped trim on the side of a rotary ball segment (Figure 6). They are typically designed as high-capacity, general-purpose valves with equal percentage flow characteristic. An almost linear characteristic can be obtained using the non-V-shaped cheek of the ball.

The metal-seated butterfly control valve shown in Figure 7 is equipped with a flow-balancing trim. The trim is located on the downstream side of the valve body and is effectively a perforated plate partially covering the valve outlet to reduce noise and cavitation, stabilise the flow pattern and reduce dynamic torque on the disc. Valve sizes range from DN 150 to DN 100 (6 in to 40 in).

The concept of this design is to transfer fluid forces out of the disc to the body. Figures 8 and 9 illustrate flow treatments with a concentric-type, conventional butterfly valve compared with a valve fitted with a flow-balancing trim.

Figure 10 shows the seating principle of this butterfly control valve. The disc of the valve is machined to close tolerances to create an elliptical shape similar to an oblique slice taken from a solid metal cone.

When the valve is closed, the elliptical disc at the major axis displaces the seat ring outwards, causing the seat ring to contact the disc at the minor axis.

Figure 5. Segmented control valve.

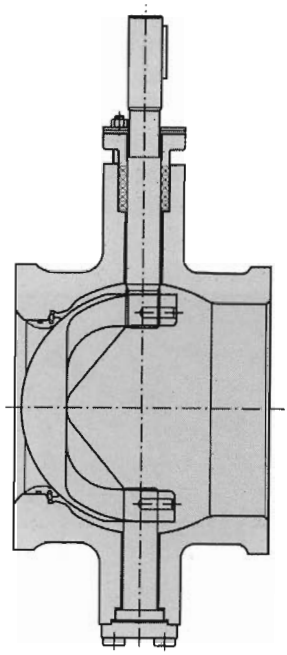


Figure 6. Concentric 'V'-shaped trim on side of rotary ball segment.

Figure 7. Metal-seated butterfly-control valve with flow-balancing trim.

When the valve is opened, the contact is released and the seat ring returns to its original circular shape.

Double-seat valves

This type of valve (Figure 11) employs two seats with an optimally dimensioned leakage chamber between them so that any seal leakage drains directly to atmosphere.

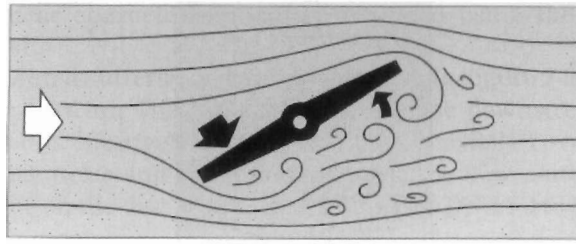


Figure 8. Conventional concentric-type valve flow treatment.

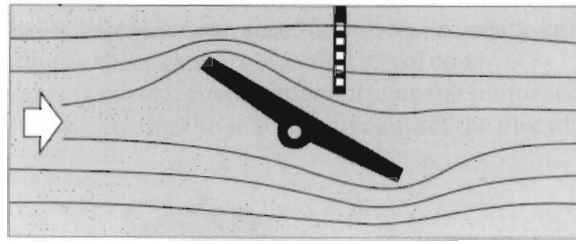


Figure 9. S-DISC flow treatment.

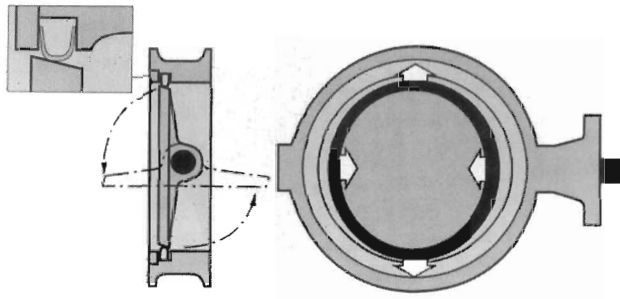


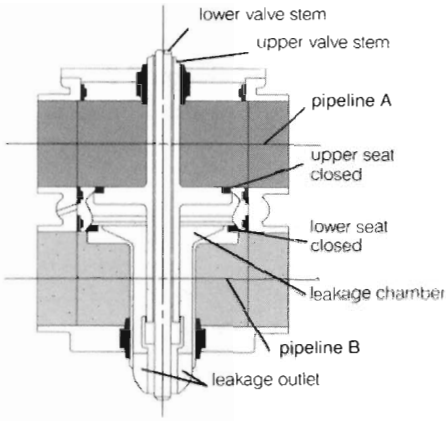
Figure 10. Seating principle.

The valve is pneumatically operated and suited for applications in brewing, beverage, dairy, food, pharmaceutical and chemical plants.

The method of operation is shown in Figure 12. The valve is designed for cleaning in place (CIP), as outlined in Figure 13. Double-seat valves typically allow for the design of 'totally contained flow systems', eliminating the need for manual swing bends for product and cleaning lines, thereby simplifying the processes of flow automation.

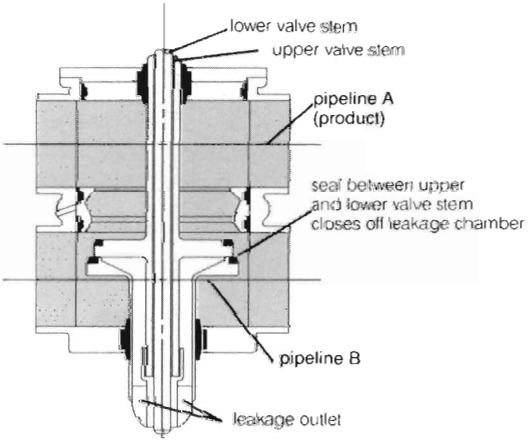
Figure 11. Double-seat-type control valve.

Double Seat Valve Operation



VALVE IN CLOSED POSITION.

Upper and lower valve seats are closed and separated by the leakage chamber open to atmosphere In this position, two fluid streams (pipeline A and pipeline B) may pass through the valve without a chance of intermixing.

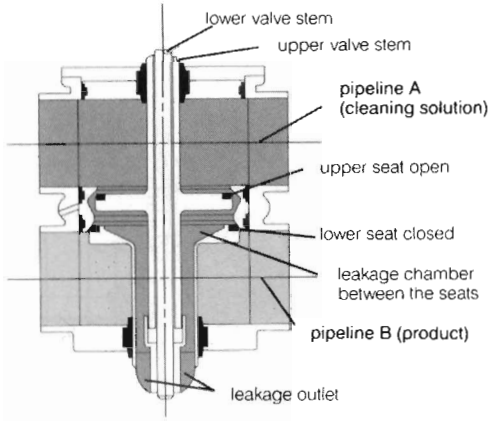


VALVE IN OPEN POSITION.

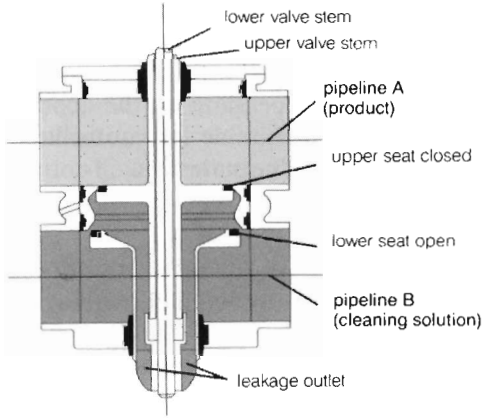
Upper valve stem moves down towards the lower one and presses it from its seat. At the same time its seal closes off the leakage chamber and separates it safely from the product area. In this position, fluid streams (pipeline A and pipeline B) are open to each other.

Figure 12.

Double Seat Valve Cleaning



UPPER VALVE SEAT AREA.
The upper valve stem is momentarily opened by the seat lift actuator. Cleaning solution is allowed to flush the upper seal and seat area as well as the leakage chamber.



LOWER VALVE SEAT AREA.
The lower valve stem is momentarily opened by the seat lift actuator. This allows cleaning solution to flush the lower seal and seat area as well as the leakage chamber.

Figure 13.

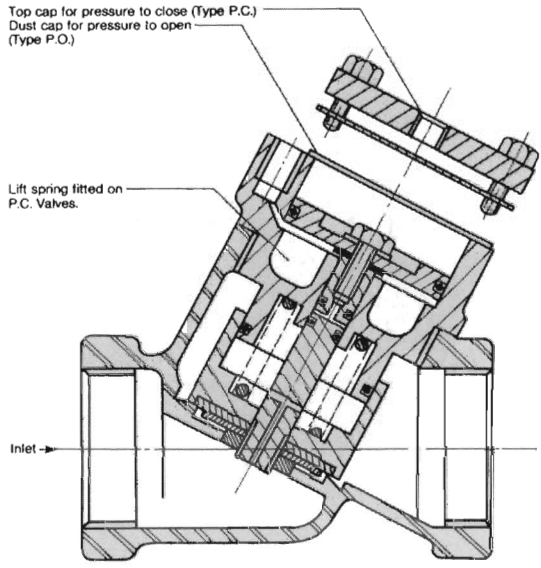


Figure 14. Piston-operated control valve.

Piston-operated control valves

The piston-operated control valve shown in Figure 14 is another valve developed to meet the needs of the processing industries. Power is applied through integral piston operators and the operating source can be pneumatic, hydraulic or line pressure itself, depending on the application. The valve is non-concussive in operation and suitable for controlling water, gases and other liquids compatible with the valve materials.

Modulating control valves

Control valves of this type are generally available with a comprehensive range of options.

They have a vertical pneumatic piston-type actuator with integral electronic controller/positioner housed in the head. The control head consists of an electronic processor that enables the valve to operate in either a 'positioner' or 'controller' mode (Figure 15).

Curve characteristics and signal scaling are set by means of dip switches.

The electronic controller's built-in software generates an adoptive response to changing process conditions, reducing hunting and overrunning.

The pneumatic-diaphragm type provides conventional mechanical control.

Control valves are used for a multitude of applications, e.g.: