CA0000022

VALVE PACKING MANUAL
A MAINTENANCE APPLICATION GUIDE

J.A. Aikin
AECL
Chalk River Laboratories
Mechanical Equipment Development Branch
Chalk River, Ontario
K0J 1J0

R.G. McCutcheon
Ontario Hydro
Nuclear Technology Services

D. Cumming
Ontario Hydro
Bruce B Nuclear Generating Division

C.G. Spence
Ontario Hydro
Darlington Nuclear Generating Division

ABSTRACT

Since 1970, AECL Chalk River Mechanical Equipment Development (MED) branch has invested over 175 person years in testing related to improving valve packing performance. Successful developments, including, "live-loading", reduced packing heights, and performance-based packing qualification testing have been implemented. Since 1986, MED and the Integrated Valve Actuator Program Task Force - Valve Packing Steering Committee (IVAP-VPSC) have been involved in the development of combination die-formed graphite packing for use in CANDU®[1] plants. Many reports, articles, and specifications have been issued. Due to the large amount of test data and reports, a more user-friendly document has been prepared for everyday use. The Valve Packing Manual is based on many years of MED research and testing, as well as operating experience from CANDU nuclear generating stations (NGS). Since 1986, packing research and testing has been funded by the CANDU Owners Group (COG), the Electric Power Research Institute (EPRI), and participating valve packing manufacturers.

The Valve Packing Manual (VPM) provides topical summaries of all work related to valve packing done since 1985. It includes advances in configuration design, stem packing friction, materials specifications, and installation procedures. This paper provides an overview on the application of the VPM with a focus on qualification testing, packing configuration, and stem packing friction.

INTRODUCTION

Since 1970, the Mechanical Equipment Development (MED) branch of Chalk River Laboratories, AECL, has invested over 175 person years in research and testing related to improving valve packing performance. Successful developments such as live-loading, (Figure 1) reduced height stuffing boxes, and performance based packing qualification testing have been implemented. Since 1986, MED has been involved in the development of combination die-formed graphite packing configurations for use in CANDU stations. Many reports, articles, and specifications have been issued. The Valve Packing Manual (VPM) condenses a large

1 CANDU® CANada Deuterium Uranium. Registered Trademark.

amount of test data and numerous reports into a document suitable for everyday use. The Valve Packing Manual is based on the many years of MED research and testing, as well as operating experience from CANDU nuclear generating stations (NGS). Since 1986, packing research and testing has been funded by the CANDU Owners Group (COG), the Electric Power Research Institute (EPRI), and participating valve packing manufacturers.

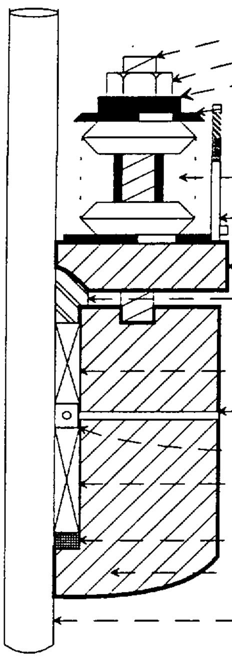

FIGURE 1
Cross-Section of Double-Packed Live-Loaded Stuffing Box

WHY A VALVE PACKING MANUAL?

Prior to 1985, braided asbestos packing was universally used for high pressure, high temperature applications. Due to restrictions on the use of asbestos, much effort has gone into the search to find alternative packing materials. Many of the products developed initially were not acceptable. Deep stuffing boxes using large numbers of packing rings (10-20), inconsistent installation techniques, poor gland loading, and unsuitable packing materials and components have all caused forced outages. The packing materials on the market today are less forgiving than the braided asbestos styles. Through testing and field experience there is now a better understanding of packing performance limits and applications. The VPM is set up to be a reference source and to provide a basic understanding of valve packing. When used appropriately, the VPM can enhance the communication between the-Mechanical Maintainers, the Packing Program Engineer and the Design and System Responsible Engineers. However, the VPM can only be a part of the equation leading to a successful packing program.

INSIDE THE VPM

The VPM provides a topical summary of the valve packing-related work since 1985, including advances in configuration design, stem packing friction, specifications, and procedures. It also includes an overview of pre-1985 valve packing development work. Each section contains a list of references that can be used to obtain further and detailed information. It is not the intent of the manual to provide detailed test data but rather to summarize the results and findings. A brief summary of the sections follows:

Introduction:
This section discusses the requirements for a good stem seal, factors affecting packing performance, and highlights from past AECL valve packing tests (pre-1985).

Performance/Qualification Testing :
Post-1985 performance testing conducted by AECL addressed the need to find suitable alternatives to replace the asbestos-based valve packing John Crane (JC) 187I. Discussions cover the EPRI-funded test report and qualification testing of both braided and die-formed graphite packing.

Packing Configurations:
Configuration testing was required to develop better installation procedures and configuration design for qualified packing materials. Results of configuration testing, including stem leakage, friction and packing consolidation are discussed. A list of preferred packing configurations for use in most nuclear generating stations (NGS) is also provided.

Stuffing Box Components:
This chapter addresses design issues for the critical components that comprise the overall packing configuration assembly.

Stem Packing Friction:
Stem packing friction is a significant consideration when selecting a packing configuration. Studies at AECL have developed and improved the stem friction data base. The chapter on stem friction introduces the fundamental concepts which affect stem packing friction, discusses the basic formulas used to calculate it and provides supporting test results.

Live-Loading:
A brief outline on the application and design of live-loading is provided.

Packing Installation:
Without proper installation, the best packing will not perform properly. This section covers effects of gland nut torque, packing consolidation, live-loading, stuffing box components and some general guidelines to follow.

Documentation:
For many years, little or no documentation on valve packing maintenance was available. Often it was not known what packing was in a valve. It is now recognized that such documentation is an essential part of any successful valve packing program. Tracking of valve packing performance has been shown to determine where corrective action is required. This section discusses essential documentation requirements and provides samples and guidelines from operating CANDU NGS.

VPM HIGHLIGHTS

Clearly space does not permit a full discussion of the above VPM chapters. The following pages highlight three aspects of the valve packing manual: performance testing, packing configurations, including recent studies on rough stems, and stem packing friction.

PERFORMANCE TESTING

Need for Qualification:
Valve packing qualification can be viewed as a first step towards leak-free valve packing performance. Without a universal standard for comparing valve packing product performance or packing tests, the end user had difficulty comparing packing recommendations from the packing manufacturers. To verify manufacturers' claims, the Integrated Valve Actuator Performance Task Force Valve Packing Steering Committee (IVAP-VPSC) established performance test specifications for valve stem packing materials, including qualification test data. All valve packings used for critical service in Ontario Hydro (OH) NGS must now be qualified under these criteria. (Ontario Hydro standard specification, "Graphite Valve Stem Packing Materials & Associated Components", M-724-94.)

MSS Follows:
The large variations in the performance of supposedly similar packing products has resulted in the Manufacturers Standards Society of Valves and Fittings (MSS) recognizing the need for *valve packing standards. The MSS has issued* performance testing guidelines for valve packing modelled after the AECL/OH guidelines, (MSS-SP-121, "Qualification Testing Methods For Stem Packing For Rising Stem Steel Valves", 1997 February). The MSS specification is based on valve rating whereas the CANDU specification is based on PHT design conditions. (AECL specification "Standard and Live Loaded Packing Assemblies for Valves,." 98-30830-TS-003.)

CANDU Qualification Criteria

- Packing rings must not induce unacceptable levels of corrosion of the valve stem, stuffing box, and gland follower, nor introduce contaminants into the system fluid.

- Packing rings must be compatible with heavy water at operating conditions of 10 MPa (1450 psi) and 295°C (565°F). Radiation exposure is expected to exceed 2×10^5 Rads.

- Packing rings must retain elasticity (not harden) when exposed to the operating conditions given above and have no shelf-life effects.

- Packing rings must show minimum relaxation with time. Exposure to pressure, temperature, and operating loads must not cause them to collapse.

- Packing rings must not induce excessive stem friction at operating conditions and under effective sealing loads.

A list and description of the approved or recommended packing products can be found in the VPM.

PACKING CONFIGURATIONS

Knowing that the packing products meet given performance criteria is not enough. Packing sets must also be configured in such a way that valve operability is not affected. Hundreds of test hours on different packing configurations and procedures have been done to find solutions to various packing configuration problems. The VPM uses graphics, such as shown in Figure 2, to illustrate several different packing configurations applicable for use in CANDU plants including braided sets, combination die-formed, and reduced height sets. It is recommended that packing configurations outside those illustrated in the VPM be properly reviewed by station packing supervisors prior to installation. Testing has shown that, one packing size or particular design does not fit all applications, such as rough stems and oversized stuff boxes.

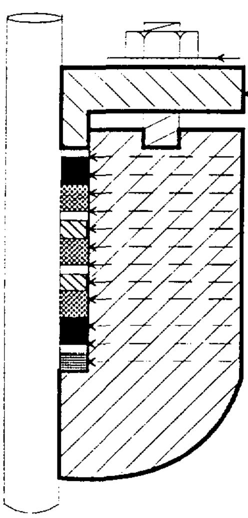

FIGURE 2
Typical Configuration Drawing

Rough Stems & Oversized Stuff Boxes:
Conventional side valves in CANDU stations often present the maintainer with a greater range of clearances and stuffing box conditions than those found for heavy water valves. COG-funded testing has shown that combination die-formed graphite with composite end rings may not perform well under these conditions. New stand-alone packing products, recently evaluated, show promise of being more forgiving for commonly found stem and stuffing box conditions on the secondary side of CANDU stations.

Outage Dilemma:
During outages, it is not uncommon to discover problem stuffing boxes and stems (Figure 3). Time available to repair damaged stuffing boxes and stems during the outage is limited. An assessment must be made to determine valve condition and any corrective actions that may be

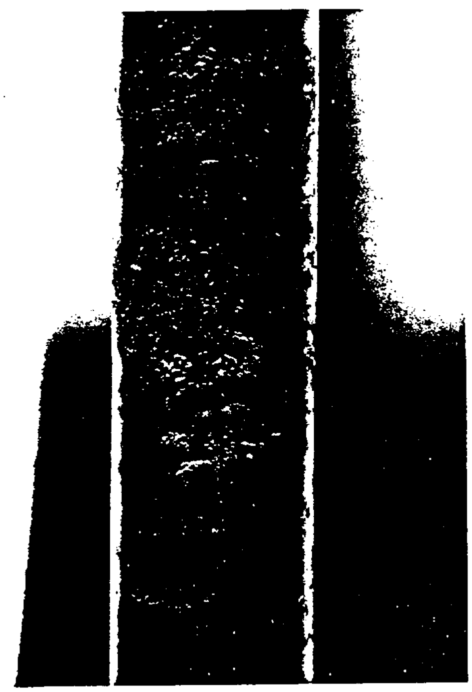

FIGURE 3
Badly Pitted Stem

required. Machining the stuffing box is difficult, time consuming and may require design approval. Once the valve has been completely disassembled, stem repair is reasonably fast using spray welding techniques. Fabricating replacement precision components can often be the faster repair process.

Test Program:
The rough stem/stuffing box test program evaluated the following scenario:

- a stuffing box diameter that is out of specification (too large);

- a stem that is in poor condition and time does not allow a repair (pitted and/or scored);
- precision internal components are readily available.

Clearances of test component in contact with the packing (graphite bushings) were:

Inside Diameter:

Minimum:	Ds + 0.007 inch. (0.18 mm)
Maximum:	Ds + 0.013 inch. (0.33 mm)

Outside Diameter:

Minimum:	Db - 0.013 inch. (0.33 mm)
Maximum	Db - 0.007 inch. (0.18 mm)

where
Ds = stem diameter
Db = stuff box diameter (Ds + (2 x 0.375 inch.) + 0.050 inch.)

The 0.050 inches represents the maximum of the diameter tolerance for 3/8 inch packing before going to the next size in packing i.e., 7/16 inch.

For valves outside these tolerances it is recommended that over-sized packing sets be used, such as the CDDCC set used where the set was made to fit the stuffing box.

Test Results:

- A 5-Ring Argo Style 5000 braided graphite packing was the only product that provided effective sealing with the badly pitted stem, and limited success with a scored stem.
- The triple composite configuration (CDDCC) using Argo 6000 and 6300J provided effective sealing performance with the rough pitted stem, but did not seal with the scored stem.
- A 5-Ring LATTYgraf 6117 did not meet the leakage criteria with either the pitted or scored stem.
- None of the packing sets tested will effectively seal long axial score marks on the stem.

The test program demonstrated that for very poor stem conditions and over-sized stuffing boxes, which may be found on MOV's and manual valves, temporary sealing solutions based on packing configurations are available. Although packing configurations for use with poor condition stems and stuffing boxes have been identified, this resort is not good practice and components in poor condition should be repaired at the first available opportunity. The solutions found from this test program are not recommended for application on stem diameters commonly found on AOV's. Poor stems for these valves must be returned to design conditions prior to start-up.

STEM PACKING FRICTION

The extensive use of graphite valve packing combined with improved valve actuator diagnostic equipment has generated a need for better valve stem packing friction data.

Optimum stem friction can be viewed as the trade-off between maintaining effective stem sealing and acceptable valve operation.

When the packing is compressed, the applied gland load generates a radial squeeze on the stem. When this radial squeeze equals the fluid pressure, leakage is stopped. This radial force also results in friction that resists axial or rotary motion of the valve stem.

Various factors can affect packing friction, such as gland stress, packing materials, installation, and operating conditions. For example even with correct gland bolt torques, friction may still be low if the applied gland load is not transmitted to the packing, a possible result of a gland follower being over-sized or poor installation techniques. Packing stress must be sufficient to squeeze the packing around the stem to seal during stem actuation. Temperature, fluid viscosity, and system pressure can also affect stem friction.

Friction Types:
Friction can manifest itself in several ways during valve actuation.

Static friction or break-away friction is the force required to start movement between two surfaces at rest. It is generally the highest friction seen.

Running friction or dynamic friction is the friction force between packing and stem while the stem is moving (during stem actuation). Running friction is always less than static friction.

Stiction occurs when there is a high ratio between static friction and dynamic friction. (The effect of stiction should not be confused with process control "hunting".) Stiction can be a significant problem for air operated valves. With stiction, a small change in the input signal to the actuator results in no change in stem movement. As the actuation force becomes larger and exceeds static friction, the stem suddenly moves and the friction load drops. This causes a sudden jump, or jerky motion, of the stem. A stick/slip ratio of 1 is ideal, but as the ratio increases, the problem worsens.

It should be noted that stiction problems can be associated with actuator sizing, binding of the actuator, improper packing design, stem finish, stem guide components, and over-torquing (loading) of components.

Friction Calculation:
The packing friction load is a function of the applied gland stress, the internal pressures in the valve and the coefficients of friction between the packing and the stem and bonnet. Simplified versions of more complex formulas can be used for estimating stem packing friction for most applications. For non-rotating linear stem movement, the stem packing friction can be estimated by the following equation:

$F = G_s \cdot P_h \cdot D_s \cdot \pi \cdot Y \cdot f$ (pounds force or Newtons)

For rotating non-rising stems:

$T = G_s \cdot P_h \cdot D_s \cdot \pi \cdot Y \cdot f \cdot R_s$
(inch-pounds or Newton-meters)

where:

G_s = applied gland stress

This is the level of gland stress (psi) applied to the packing through the gland bolts. This stress is usually based on the measured torque applied to the gland studs or nuts. The actual gland stress to the packing can vary considerably. Depending on the stud and gland nut condition, lubrication and torquing procedures, using the torque measurement to estimate gland stress can introduce a serious discrepancy with the true applied load. The applied stress or gland load can be more accurately determined by using calibrated spring stacks on the gland studs.

P_h = effective packing height

The effective packing height is the compressed height of those rings in the packing configuration that generate enough radial stem contact to cause packing friction.

D_s = stem diameter

R_s = stem radius = $D_s/2$

Y = transfer ratio of axial stress to average radial stress

This ratio varies depending on the density of the packing material, the configuration design and the installation procedure used.

f = friction coefficient

The coefficient of friction of the packing material against the valve stem used in most calculations and in this manual is that measured during tests at ambient conditions. The aim of the packing designer is to keep the friction coefficient as low as possible while maintaining appropriate sealing performance. The coefficient of friction is influenced by those material and physical properties which can change with temperature, stem conditions, and applied load.

Friction Test Highlights:
Results from AECL's friction evaluation program have provided a range of values for the non-dimensional parameter of product $f \cdot Y$ (fY) for one-ring up to five-ring configurations. From this data, the friction for most packing configuration used in CANDU stations can be determined. Significant results from the program showed that:

- For gland stresses up to 41 MPa (6,000 psi), composite end-rings showed no contribution to friction. Therefore, composite rings should not be included in the calculation of the effective packing height (P_h).

- P_h can be decreased by system pressure due to the wetting effect of the fluid on the lower packing rings, resulting in lower friction values.

- Stem friction from one- to five-ring sets is a linear function of the number of rings and gland stress in the range of 2,000 to 6,000 psi (limits of test program).

RAIN FOREST TO DESERT

Much effort has gone into valve packing research and the application of that knowledge by Mechanical Maintainers. Typical evidence of using and developing good packing procedures, training and management control can been seen in the success at Bruce-B and Darlington. Both stations have successful packing programs based on the co-operative effort between R&D, the suppliers, and a station commitment to eliminate packing-related problems. Figure 4 shows a classic examples of the "rain forest" effect where steam leaks were large, and Figure 5 the clean and dry view "desert".

APPLICATION GUIDE

The VPM should be viewed as a living document, updated yearly as new test data and field experience are gained. The manual is a reference tool and application guide to be used to help maintain a successful packing program. The manual alone, however, is not enough: a commitment to excellence, configuration management and training must also be implemented

FIGURE 4
8-41840-MV110
Steam Leak Prior to Implementing Practices From VPM

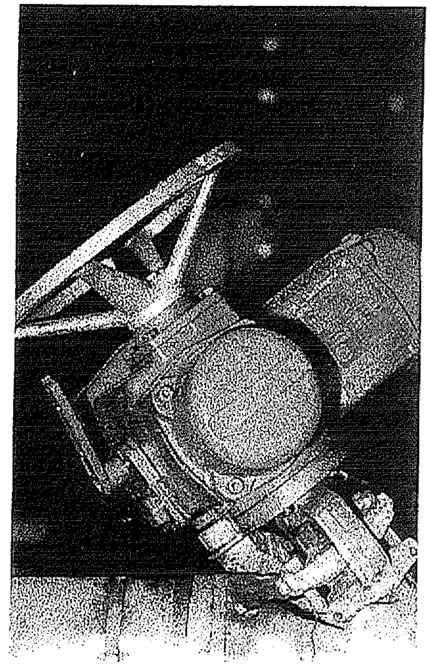

FIGURE 5
8-41840-MV110
Implementing Practices Recommended in VPM

ACKNOWLEDGEMENTS

The authors respectively acknowledge to testing support from MED Branch.

REFERENCES

Aikin, J.A., "Valve Packing Manual", COG-97-019, 1997 February.

Aikin, J.A. and Lade, C.R., "Evaluation of Graphite Valve Packing Configuration on Poor Stem and Stuffing Box Conditions", COG-97-183, 1997 March.

Spence, G.S., "Darlington NGD Valve Packing Program, Third International Conference CANDU Maintenance, Nov. 19-21, Holiday Inn on King, Toronto, Ontario.

Cumming, D, "BNGS Valve Packing Program", Third International Conference CANDU Maintenance, Nov. 19-21, Holiday Inn on King, Toronto, Ontario.