ENSURING MOV RELIABILITY
Through Material Qualification and Testing

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SUMMARY

Safety systems in nuclear plants must have a high degree of assurance of operability when called upon. In turn, the individual safety system components must have a high degree of reliability. Motor Operated Valves (MOVs) are of particular concern. To ensure reliable operation over the entire operating life of the plant, these major components require sound material qualification and test support data. Over the past 10 years, Atomic Energy of Canada Limited (AECL) has worked in partnership with the station design and maintenance support groups to address generic MOV material qualification issues.

Recent technological advancements have helped to ensure reliable MOV operation. These include diagnostic equipment, improved lubrication, better elastomers, proven packing materials and configurations, validated coefficient of friction (COF) data for hardfacing materials and computer software to perform thrust and torque calculations. The knowledge gained has resulted in significant improvements to the design specifications used to purchase new valves and spare parts.

This paper highlights the work on coefficient of friction (COF) for nickel-based hardfacing alloys, the improvements in valve stem packing and the valve stem nut lubrication studies. These research and development (R&D) efforts illustrate the importance of working with station maintenance and engineering staff to address all critical MOV components. Application of the knowledge gained in support of improving CANDU®[1] station reliability is discussed.

INTRODUCTION

Safety systems in nuclear plants must have a high degree of assurance of operability when called upon. In turn, the individual safety system components must have a high degree of reliability. Motor Operated Valves (MOVs) are of particular concern. These major components require sound material qualification and test support data to ensure reliable and safe operation over the entire operating life of the plant. Over the past decade, AECL has worked in partnership with the station design and maintenance support groups to address generic MOV material qualification issues.

Certain technological advancements have helped to ensure reliable MOV operation. These include: diagnostic equipment, improved lubrication, better elastomers, proven packing materials and configurations, validated coefficient of friction (COF) data for hardfacing materials and computer software to perform thrust and torque calculations. The knowledge gained has resulted in significant

[1] CANDU is a registered trademark.

improvements to the design specifications used to purchase new valves and spare parts.

This paper focuses on three key areas of MOV technology. They are: (a) materials for hardsurfacing valve discs and seat rings, (b) valve stem seal materials, and (c) stem thread lubricants. The results of recent tests on the nickel-based hardfacing alloys performed at Battelle's tribology testing facilities are reviewed as well as their application to stem thrust calculations for safety-related gate valves. Improvements in MOV reliability achieved though the application of improved stem seal configurations and stem packing friction calculations are discussed. The work done on stem thread lubrication is included to illustrate how the R&D partnership has addressed the complete MOV. Application of the knowledge gained in support of improved CANDU station reliability is discussed.

COF of NICKEL-BASED ALLOYS

Hardfacing alloys weld deposited on gate valve discs, seats and disc guides should have the following characteristics:

- corrosion resistance to the wetted field media,
- strength and hardness to resist, mechanical damage,
- weldability for ease of fabrication and field repair,
- known coefficient of friction (for actuator sizing),
- resistance to adhesive wear/galling, and
- assured commercial availability.

For safety-related MOVs it is good practice to demonstrate proper valve operation under design basis conditions (DBC). Unfortunately, many safety-related valves cannot be tested insitu under DBC. To address this problem, computer models have been developed to predict the stem thrust and/or torque required to operate valves which cannot be tested. COF data for internal components such as seats, gates and guides are required inputs. Stellite 6®[2] is the only valve hardfacing material for which complete and validated friction data were available [1].

Stellite 6 is a cobalt-based material. In an effort to reduce the cobalt burden in reactors (and consequently, occupational radiation exposure), many critical valves in existing CANDU stations use nickel-based hardfacing materials such as Deloro Alloys 40 and 50 (see Table 1). Recently it has been found that these nickel-based alloys are susceptible to corrosion in low pH water and during some system decontamination practices [2]. Validated COF data for nickel-based hardfacings were also very limited [3].

Table 1:
List of Gate Valve Hardfacing Materials Found in CANDU Process Systems

ALLOY	Product Form, Valve Type and Supplier	
	GTAW/OAW Weld Deposits	PTAW Weld Deposits
Colmonoy 4	GEC Gate Valves	
Colmonoy 5	GEC Gate valves	
Deloro 40	GEC Gate Valves Velan Gate Valves	Velan Gate Valves
Deloro 50	GEC Gate and Check Valves Velan Gate and Check Valves	Velan Gate and Check Valves
Stellite 6	GEC Gate and Check Valves Velan Gate and Check Valves	Velan Gate and Check Valves
Platnam A	Hopkinson Gate Valves	

OAW = Oxy-Acetylene Welding
GTAW = Gas Tungsten Arc Welding
PTAW = Plasma Transferred Arc welding
GEC = Guelph Engineering Co.

In order to confidently use the available stem thrust calculation methodologies for MOVs with nickel-based hardfacing, usable friction data for these materials were required.

Battelle Testing

A CANDU Owners Group (COG) funded COF test program was established between AECL and Battelle Memorial Institute in Columbus, Ohio. The Battelle facility was selected due to their extensive testing experience from the EPRI-funded MOV-Performance Prediction Program (PPP). The test objective, of the COG-funded

[2] Stellite is a registered trademark.

program, was to obtain COF and galling resistance data for a series of nickel-based hardfacing alloys used in CANDU nuclear generating stations.

The tribology group at Battelle operates two test rigs specifically designed and constructed for evaluation of materials in environments and geometries that are representative of the sliding contact between the disk and seat ring or wedge guides of gate valves. One rig is for testing under ambient pressure conditions. The autoclave rig is for testing under high temperature, high pressure conditions.

The COG-funded testing used a contact stress of 5 and 10 ksi (35 and 69 MPa) for the ambient temperature rigs. The test medium was water at a pH of 10 to 10.5 (LiOH) at 70-200°F (21-93°C). The autoclave testing used a contact stress of 5 ksi (35 MPa). Operating conditions were 1,450 psig @ 590°F (10 MPa @ 310°C). *Contact stress is the applied stress between the stationary pieces (seat ring) and the moving part (wedge).*

Summary of Battelle Results

The following provides an overview of the test results from the nickel-based COF testing [4].

Stellite 6

This alloy was the best of the materials tested and was the control sample.

- No galling under any test conditions.
- Maximum COF at 200°F was 0.6.

Stellite 6 on Deloro 50

Performed well. This combination was tested to cover the case where Stellite-coated gates replace nickel-based hardsurfaced gates and will run against nickel-based alloy seat rings. This is a possible solution to the existing hardsurfacing degradation in some stations.

- No galling under any circumstances.
- Moderate COF (0.62) when pre-autoclaved to form an oxide film and tested at 590°F (310°C).
- Higher COF (0.86) when pre-autoclaved and tested at 200°F @ 10 ksi (93°C @ 69 MPa).

Self-mated Deloro 50

Performed well under limited conditions.

- No galling at 5 ksi (35 MPa).
- Surface damage at 10 ksi @ 70°F (69 MPa @ 21°C), after the surface became highly polished and COF had risen to 0.79.
- Pre-autoclaved samples did not gall, but COF was high (0.9 - 1.0).

Deloro 50 on Deloro 40

Performed well under very limited conditions.

- No galling at 5 ksi (35 MPa), room temperature (RT); max. COF ~0.8.
- Galling at 10 ksi (69 MPa) @ RT, and at 5 ksi @ 200°F (35 MPa @ 93°C).
- Pre-autoclaved samples showed high COF >0.9 and galled after the oxide was removed (26 strokes).

Platnam A and Platnam A

Did not perform well at 5 ksi (35 MPa) @ 70°F (21°C). Testing stopped due to galling (COF >0.8).

Colmonoy 5 on Colmonoy 4

Did not perform well at all.

- Galling occurred in all testing within 3 strokes except in the autoclave tests.
- Testing stopped due to galling (COF >0.9). Autoclave testing showed COF of 0.6 @ 5 ksi (35 MPa).

Application

The COG-funded Battelle testing was reviewed and compared to the EPRI test results from the "Friction Separate Effects Testing", EPRI Report TR-103119. The EPRI tests indicated that the COF of Stellite 6 decreases with increased temperature. The COG-funded Battelle work and earlier evaluations by others also exhibits the same trend for non-cobalt hardfacing materials [3,4]. This allows the use of ambient temperature test results to predict COF values for higher operating temperatures. Table 2 tabulates the comparison and establishes material factors for distribution adjustment of the EPRI data.

These values are used with other test conditions to determine the required valve factors for design basis review (DBR) needed to ensure reliable operation of CANDU safety related valves.

Table 2
COF Valves for Nickel-Base Alloys Normalized to Stellite 6

Hardfacing Material	Trended COF at 70°F (21°C)	% Difference at 70°F (21°C)	Material Factor
Stellite 6 - Stellite 6	0.632	0	1.00
Colmonoy 5 - Colmonoy 4	0.614	-3	0.97
Deloro 50 - Deloro 40	0.708	12	1.12
Platnam A - Platnam A	0.877	39	1.39

VALVE PACKING

Valve packing tends to be viewed as a simple component. However, replacement of asbestos-based packing requires new methods of handling non-asbestos valve packing products. Failure to implement these new packing methodologies can result in poor valve performance.

Performance Testing

Valve packing qualification is the first step towards leak free valve stem seal performance. When testing new valve stem packing products was first initiated, there was no universal standard for comparing product performance. The end user had difficulty comparing packing recommendations from the packing manufacturers. To verify manufacturers' claims, AECL and the stations established performance test specifications for valve stem packing materials, including qualification testing. All valve packings used for critical service in CANDU stations must be qualified under these criteria [5].

Previous testing had shown that supposedly similar valve stem packing materials exhibit large variations in their performance. Recognizing the need for a valve packing standard, the Manufacturers Standardization Society (MSS) for the Valves and Fittings Industry issued performance testing guidelines for valve packing (MSS-Standard Practice (SP)-121, "Qualification Testing Methods For Stem Packing For Rising Stem Steel Valves". February 1997). This document is modeled after the AECL/CANDU guidelines. The most significant difference is that test conditions specified in the MSS document are based on valve rating as per ANSI-B16.34; whereas the CANDU specification is based on primary heat transport (HTS) design conditions.

CANDU Qualification Criteria

The minimum performance requirements for valve packing materials established by AECL for CANDU stations are shown below:

- Packing rings must not induce unacceptable levels of corrosion of the valve stem, stuffing box, or gland follower.
- Packing rings must be compatible with heavy water at operating conditions of 1,450 psi (10 MPa) and 565°F (295°C). Radiation exposure is expected to exceed $2x10^5$ Rads (2 kGy).
- Packing rings must retain elasticity (not harden) when exposed to the operating conditions given above and must have no limiting shelf life effects.
- Packing rings must show a 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.

AECL's Mechanical Equipment and Seal Development (MESD) Branch has tested over 40 packing products claimed to be suitable for the above criteria. For CANDU use there is now a list of 13 approved valve stem packing products [5].

Packing Configurations

Knowing that the packing product meets given specific performance criteria is not enough. One packing size or particular configuration design does not necessarily suit all applications. The COG-funded test program included a number of packing configurations. Based on this testing, AECL and Ontario Power Generation (OPG), through their Integrated Improvement Program (IIP) for valve packing, have approved the following seven basic configurations for use in CANDU stations:

- single-packed; using die-formed graphite sealing rings and composite end rings,

- single-packed; using braided graphite rings,
- double-packed; using die-formed graphite sealing rings and composite end rings,
- double-packed; with braided graphite rings,
- sandwich style for control valves.
- single-packed; with braided Teflon,
- Original Manufacturers Equipment (OEM) Teflon style configurations, such as V-Ring sets.

A number of minor modifications to these configurations are allowed. For example, the size and number of the carbon bushings may be modified for a particular application.

Stem Packing Friction

The packing friction load is a function of the applied gland stress, the stem seal dimensions and the packing friction factor. Equations 1 and 2 are used to calculate the thrust or torque that must be applied to the stem to overcome packing friction.

Linear Action .... (1)

$$F = G_s \cdot P_h \cdot D_s \cdot \pi \cdot fY \quad \text{(lbf or N)}$$

Rotating Action ...... (2)
(Axial load effects are ignored.)

$$T = G_s \cdot P_h \cdot D_s \cdot \pi \cdot fY \cdot R_s \quad \text{(in-lbf or N.m)}$$

where:

G_s = applied gland stress
P_h = effective packing height
D_s = stem diameter
R_s = stem radius = $D_s/2$
fY = packing friction factor
T = Stem Torque
F = Stem Thrust

For all safety related MOVs, the valve packing station specialist (VPS) can calculate three packing friction values:

- design friction, which is the maximum expected friction during stem actuation,
- expected friction at low operating temperatures,
- expected friction at high operating temperatures.

Design friction factor fY_d, has a multiplier of 1.30 times the maximum friction determined during valve packing qualification testing. Expected friction is highest at low temperatures (below 300°F (150°C)). Expected packing friction is calculated using upper and lower limit friction factors (fY_{eu} and fY_{el}, respectively).

Each of the approved stem packing configurations has its own friction factor. For example, the values for an approved braided graphite product are: $fY_d = 0.113$; $fY_{eu} = 0.080$; and $fY_{el} = 0.040$.

The VPS can quickly calculate the friction for any of the approved packing configurations using the input parameters from the COG, AECL and OPG supported programs. Field testing and diagnostics are showing that the calculated valves are within 20% of the field measured data. The use of the approved configurations has resulted in a significant reduction in stem packing leakage, uniformity in stem packing friction calculations and improved valve packing maintenance.

STEM THREAD LUBRICATION

In MOVs with rising stems, torque generated by an electric motor is applied to the stem nut and the rotation of the stem nut produces stem thrust. The efficiency of the torque/thrust conversion is a function of stem/stem nut geometry and the coefficient of friction between the stem and stem nut.

For given loading conditions, the stem/stem nut friction coefficient is directly related to the properties of the lubricant used on the stem threads. Changes in lubricant condition can have a significant effect on the thrust delivered for a given torque. Increasing stem/stem nut friction coefficients can result in stem thrusts that are not sufficient to operate the valve.

Grease is used on the stem threads to reduce corrosion, friction and wear. Reducing friction ensures that torque developed by the actuator is efficiently converted into the thrust required to actuate the valve stem. The efficiency of the thrust to torque conversion is greatly affected by the type of grease used and the effect of thermal aging, mechanical aging and other environmental parameters, such as temperature or radiation, on grease condition.

One of the many challenges facing nuclear power plant operators is trying to improve MOV lubricants to maintain long-term component operability and reduce costs associated with MOV maintenance programs. Valve stem re-greasing intervals or torque limit switch resetting intervals of less than one or two years are no longer acceptable to most stations considering the large number of MOVs in service. The use of very stable, low friction greases for stem thread lubrication is the key to long-term valve operability and limited maintenance costs.

Lubricant Evaluation Objectives
To address this need for performance assessment methodology, a COG-funded program, with support from Electricité du France (EDF), was initiated. The two principle objectives were:

1. To develop a test rig that closely reproduced the MOV operating conditions (under both normal operating and accident conditions).

2. To develop a test procedure for representative thermal aging and irradiation of the candidate greases prior to MOV testing.

Results
Specific procedures have been developed by AECL, EDF and OPG for thermal aging and MOV testing of grease candidates. The assessment also includes MOV grease testing for temperatures and irradiation levels that are typical of accident conditions [6,7].

A large number of greases were studied, and the following general trends were observed according to the type of grease tested:

- The stem/stem nut friction coefficients measured for the various candidate greases ranged from 0.10 to 0.17.
- The greases that offered the best resistance to mechanical aging combine a mineral oil and a lithium complex thickener.
- Lowest friction coefficients were for greases that combine lower friction coefficients were obtained for greases that combine a Polyalphaoleifin (PAO) oil and a clay thickener.
- The use of Extreme Pressure (EP) additives in the grease was not detrimental but did not seem to be absolutely required for optimum stem/stem nut lubrication.
- The five-year aged formulations of the greases were less resistant to mechanical aging than the unaged formulations.
- Most high temperature greases were suitable for short-term exposure at 329°F (165°C) and for prolonged exposure at 230-248°F (110-120°C). Several irradiated greases were suitable for stem/stem nut lubrication, even for levels of up to 850 kGy ($8.5x10^7$ Rads).

Overall, the screening process proved to be successful. From a thermal stability point-of-view, only nine grease candidates out of an initial list of twenty-four were declared suitable for a 5-year re-greasing interval. Following testing in the MOV rig, only five of these greases met the majority of requirements for optimum MOV stem/stem nut lubrication (mostly high temperature greases). Only one grease met all requirements and was also suitable for specific low friction coefficient applications.

SUMMARY

R&D testing has successfully supported efforts by station maintenance and engineering staff to improve the reliability and performance of MOVs in CANDU stations. The support has resulted in improved design specifications for replacement components and reliable valve operation. To remain competitive in the new deregulated sale of power, R&D and operations must continue to work together to define improvements in valve operation to improve safety and reduce costs.

ACKNOWLEDGMENTS

The authors respectfully acknowledge the following generous funding support:

The hardfacing program was funded by COG, R&D Program: Chemistry, Materials and Components, WPIR #62-0115. The valve packing program was partially funded by COG R&D Program, Working Party #1, (Process Systems and Equipment), WPIR 0739 and AECL commercial testing programs. The lubrication program was partly funded by COG R&D Program, Working Party #1 (Process Systems and Equipment), WPIR 0153 and by Electricité de France.

The special testing skills of the technical support staff in the Components and Systems (C&S) Division are fully recognized and thanked.

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