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VALVE PACKINGS SEATING STRESS

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ABSTRACT

This paper studies the seating stress required to assure the sealability in valve stems used in high pressure steam service. A test device that simulates the valve stuffing box and a test protocol are proposed. Actual field tests conducted according to a procedure developed from the laboratory tests are also reported.

INTRODUCTION

Traditionally braided packings used in valves are installed without controlling the seating stress. Standard organizations like the American Petroleum Institute (API) do not have packing installation procedures [1, 2] as part of their valve standards or as a separate document. Packings are usually installed by tightening the gland bolts to the point where heavy resistance to wrenching is felt. Then, the valve stem is turned back and forth to determine ease of turning. The main concern is to avoid torque down to the point where the stem will not turn. This procedure is highly dependent on the skill of the installation personnel. It does not assure a uniform seating stress from one operator to the other; a very common situation in plant shut-downs when hundreds or thousands of valves must be repacked in a very short period of time. It can easily be observed in the field that for the same valve and packing size and style the torque to open or close the valve varies significantly indicating that the packing stress is not the same.

As a consequence the sealability is not assured. Especially in high pressure steam service that once a leak is initiated it is very difficult to stop. The high pressure steam flow creates leak paths which are difficult or almost impossible to seal by just re-tightening the gland. In most cases when shut-down is not allowed to repack the valve, sealant has to be injected to stop the steam leak making the valve inoperable until the next plant shut-down.

Manufacturers and trade organizations like the Fluid Sealing Association (FSA) and The European Sealing Association (ESA) have published the Pump & Valve Installation Procedures [3] where there is a recommendation to "consult packing manufacturer and/or plant engineering department for guidance on torque specifications or percent of compression". However, there is no published procedure to determine the required installation torque.

In order to assure sealability and avoid the high costs of injecting sealant or having to turn-off the line and repack the valve, it was decided to investigate the possibility to develop a procedure similar to that of flange gaskets where the initial tightening is calculated to insure a minimum leak operation.

MINIMUM SEATING STRESS TEST RIG

A test rig was developed to determine the minimum seating stress to insure the packing sealability. This stress is the pressure, applied by the valve gland, required to seat the packing so it fills all the voids between the stem and the stuffing box. The test rig simulates a valve stuffing box, with a stem and a gland follower. Five rings are used in each test. Figure 1 shows a schematic diagram of the test rig.

The test gas is introduced at the bottom of the rig and leak rate is monitored at the gland with a Mass Spectrometer. For this study Helium was used however, another gas or steam can be used to simulate an actual field application.

The load is applied with a hydraulic press and the force monitored with a load cell. Figure 2 shows the rig installed in the hydraulic press and the mass spectrometer used to measure the Helium leak rate.

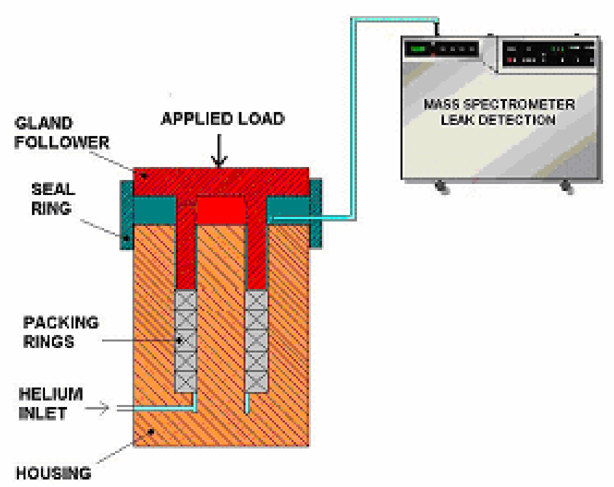


FIGURE 1 – MINUMUM SEATING STRESS TEST RIG

FIGURE 3 – TEST RIG, HYDRAULIC PRESS AND He MASS SPECTOMETER

MINIMUM SEATING STRESS TEST PROCEDURE

EN13555 defines the minimum seating stress for gaskets, $Q_{min(L)}$, as: "minimum gasket surface pressure on assembly required at ambient temperature in order to seat the gasket into the flange facing roughness and close the internal leakage channels so that the tightness class is to the required level L for the internal test procedure". Based on this concept, a similar procedure for packings was developed.

The leak rates for flange gaskets are determined in Standard DIN EN 13555[4] in tightness classes. For this study it was decided to use the $L_{0,01}$ class, which is the lower class specified. The $L_{0,01}$ corresponds to a leak rate of 0,001mg/(s-m) for Nitrogen or 0,001mbar-l/s for Helium adjusted for the packing diameter.

For the determination of the packing minimum seating stress, $S_{min(0,01)}$, the test pressure was established as 7bar (101psi) and Helium as the test media.

The following procedure was developed to determine the mechanical packing minimum seating stress $S_{min(0,01)}$. Packings with cross-section of 6,4mm (1/4") were used.

- Cut the packing rings from a spool with 45º ends
- Install the five rings with the ends 90º apart
- Install the Test Rig in the Hydraulic Press
- Apply an initial seating stress of 5MPa (725psi)
- Pressurize the Test Rig with 7bar (101psi) Helium pressure and start to monitor the leak rate.
- The seating stress is raised in 5MPa (725psi) increments and leak rates recorded.
- If the leak rate is equal or less than 0.001mbar-l/sec record the seating stress and finish the test.

PACKINGS TESTED

Two tests were performed for each of the packing styles described below, and their minimum seating stresses, $S_{min(0,01)}$ was established. Packings with cross-section of 6,4mm (1/4") were used.

Style A - Flexible Graphite Yarn reinforced with an Inconel wire mesh.

Style B - Flexible Graphite Yarn reinforced with an Inconel wire.

Style C - Carbon and Flexible Graphite Yarn with Graphite impregnation

Style D – Expanded PTFE filled with Barium Sulphate.

Figures 3, 4, 5 and 6 show the test results.

FIGURE 3 – STYLE A: LEAK RATE X PACKING STRESS

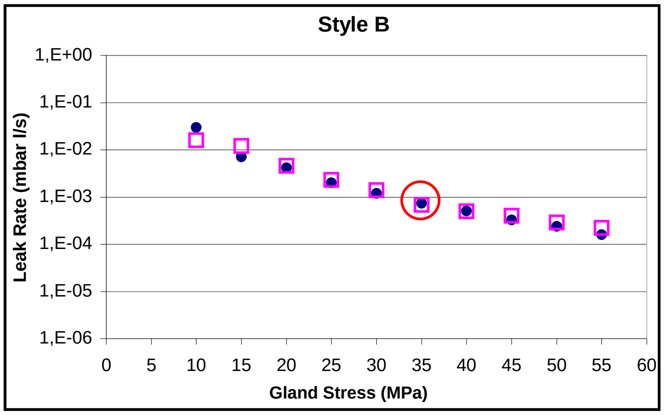


FIGURE 4 – STYLE B: LEAK RATE X PACKING STRESS

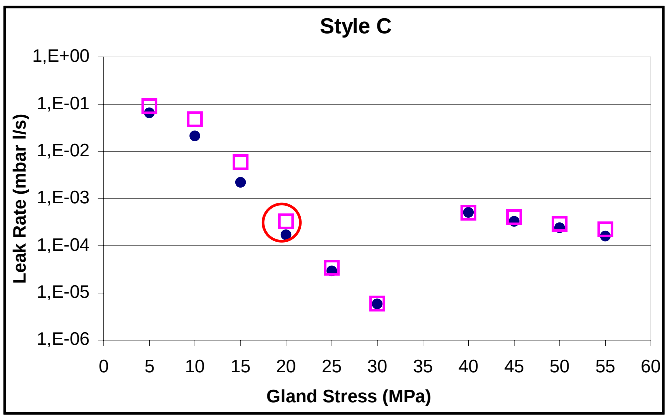


FIGURE 5 – STYLE C: LEAK RATE X PACKING STRESS

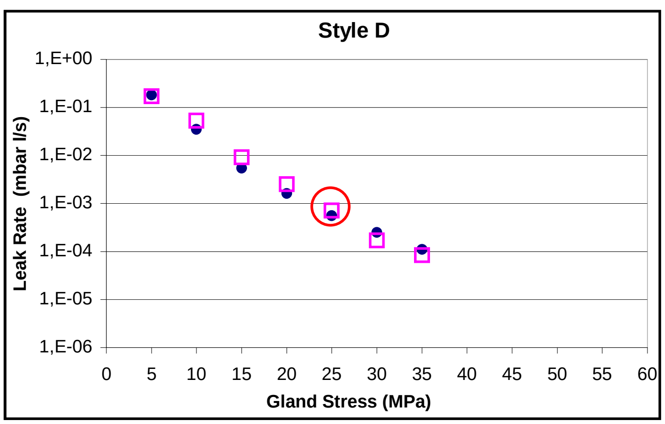


FIGURE 6 – STYLE D: LEAK RATE X PACKING STRESS

From the above graphs, the $S_{min(0,01)}$ values were determined for all four styles and are shown in Table 1.

TABLE 1 - $S_{min(0,01)}$ VALUES

	$S_{min(0,01)}$	
Packing Style	**MPa**	**psi**
A	55	7975
B	35	5075
C	20	2900
D	25	3625

PACKINGS TIGHTENING STRESS

Once the minimum seating stress was established, the next step was the determination of the installation stress.

For this test, valves mostly used in the Brazilian market were used to evaluate the stem torque. The valves were:

- Globe Valve, 3in, Class 150psi;
- Globe Valve, 8in, Class 300psi;
- Gate Valve, 4in, Class 300psi.

FIGURE 7 – TEST VALVES

The minimum seating stress ($S_{min(0,01)}$) was applied and the internal Helium pressure was increased while the packing behavior was monitored. The leak rate increased considerably as the Helium pressure reached high values. The results were not found satisfactory.

Another test consisted in keeping the leak rate constant and increasing the packing stress as the Helium pressure is increasing. This test led to packing stress values that were too high and the stem torque was not applicable under actual conditions.

The results found satisfactory were accomplished when the minimum seating stress ($S_{min(0,01)}$) was applied and raised by the same value of the test media. Figure 8 shows the leak rate when the gland pressure was increased by the same value as the Helium pressure.

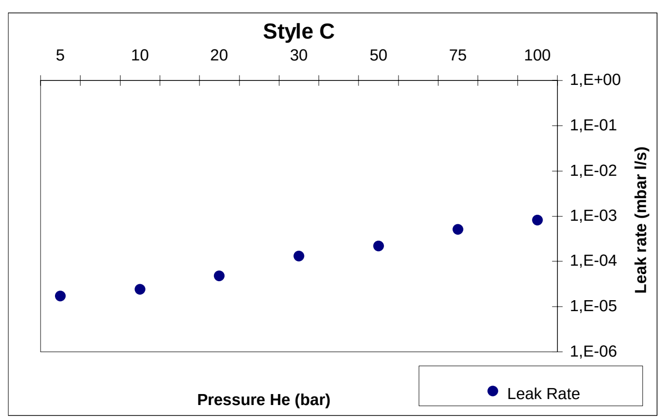


FIGURE 8 – INCREASING GLAND PRESSURE AND HELLIUM PRESSURE

The laboratory results indicated that the gland seating stress is according to the following formula:

$$S_s = S_{min(0,01)} + P$$

Where:

S_s = packing installation seating stress

$S_{min(0,01)}$ = minimum seating stress

P = media pressure

LABORATORY VALVE TESTS

In order to evaluate the effectiveness of the packing installation seating stress (S_s) a series of laboratory tests were performed on gate and control valves simulating actual field conditions. These tests included both thermal and mechanical cycles.

For the valve tests, the leak rate was monitored using a Toxic Vapor Analyzer - TVA1000 with Methane as test gas. This leak measurement method was adopted to minimize the gap between lab testing and field-testing.

GATE VALVE TESTS

The packings were tested under the following parameters:

- Test Valve: Gate Valve, 4 in, Class 300 psi.
- Packing Size: 6.4mm (1/4")
- Number of Rings: 05
- Packing Installation Seating Stress: $S_{min(0,01)}$ + P
- Test Media: Methane gas
- Media Pressure: 4,1MPa (600 psi)
- Test Temperature: 260°C (500ºF)
- Heating Rate: 21°C (70ºF) to 177°C (351ºF), 46ºC (115ºF) per hour, 177°C (351ºF) to 260°C (500ºF), 28°C (82ºF) per hour.
- N°. of Cycles: (open/close): 2000
- Max Leakage: < 500 ppmv
- Maximum Close Torque: < 160 N.m (118 lbf.ft)

FIGURE 9 – GATE VALVE TEST BENCH

The test results for the Style A packing is presented on Figure 10.

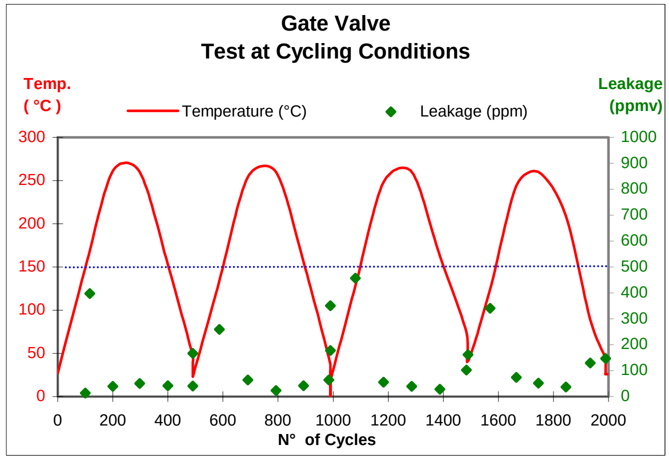


FIGURE 10 – GATE VALVE TEST RESULTS: STYLE A

The packing met the proposed criteria. The leakage did not reach 500ppmv over the 2.000 cycles being kept low during the hot phases. No re-tighten was necessary.

Packings B and C were tested as well, showing similar results.

Subsequently, the Style A packing was tested under the same protocol by an independent laboratory in the US with similar results.

CONTROL VALVE TESTS

The packings were also tested in a 2in, class 300psi control valve under a protocol that represents a demanding field application. The test consists of thermal cycles from 25ºC (77ºF) to 235ºC (455ºF) at a 7bar (102psi) constant Methane pressure, with the valve completing 180 open-close cycles an hour.

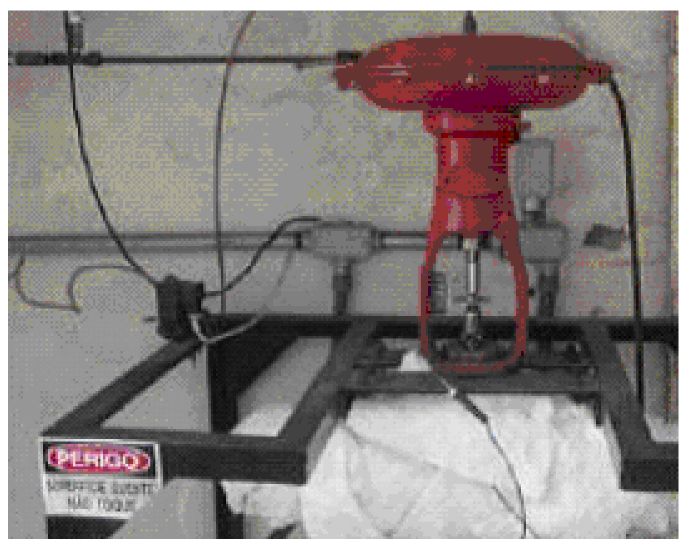


FIGURE 11 – CONTROL VALVE TEST BENCH

The packings were set with the installation seating stress (S_s) and their behavior monitored

The results for Style C with the S_s of 21MPa are shown in Figure 12.

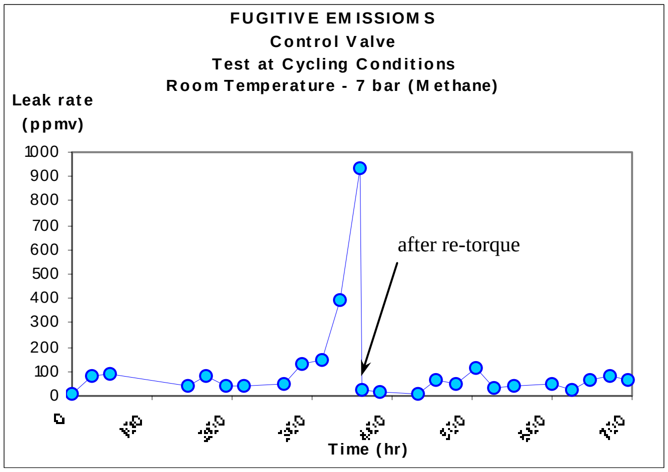


FIGURE 12 – CONTROL VALVE TEST – STYLE C WITHOUT SPRING LOAD

Due to packing wear, the seating stress decreased and after 350 hours (63.000 cycles) high leak rates were measured. The gland bolts were then re-tightened, bringing the stress on the packing to the value of the initial seating stress (S_s). Once again sealability was assured.

To guarantee that the installation seating stress (S_s) was kept constant and if its value was successful in controlling Fugitive Emissions, a new series of tests were performed using spring loads.

The results for Style C with the S_s of 21MPa are shown in Figure 13.

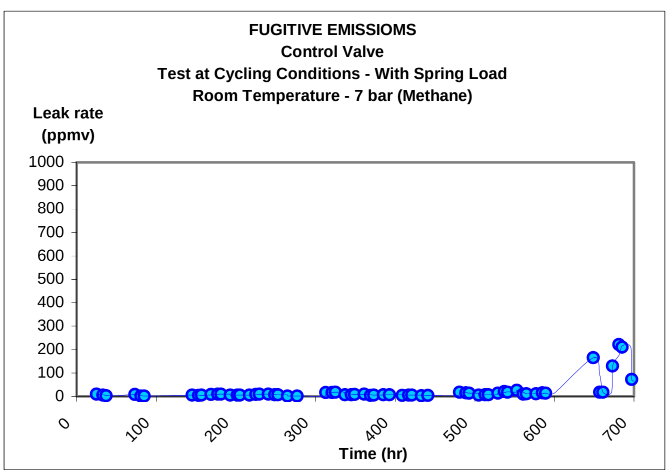


FIGURE 13 – CONTROL VALVE TEST – STYLE C WITH SPRING LOAD

The above results show that after 700 hours (126.000 cycles) the packing Style C with spring loads, maintaining the initial seating stress (S_s), kept the system leakage below 220ppmv. This was not the case when the spring loads were not used. These results were considered satisfactory. They showed that when the determined installation seating stress is maintained, the leak rates are kept at low levels.

Packing Styles A and B were not tested in the control valve since their yarns are reinforced with Inconel, and could damage the stem due to its high hardness. Inconel reinforced yarns are not suitable for applications with high mechanical cycles.

FIELD PILOT TEST

Two field tests were performed to verify if the laboratory results could be replicated in actual plant conditions. High pressure steam and hydrocarbon lines were selected for the field tests.

The steam application for the pilot test was the Copesul Steam Generation plant. This plant was chosen due to its constant history of high leaks.

Once a high steam pressure leak is initiated it is not possible to retighten or repack the valves without shutting-down the whole line. This plant presented high costs due to steam leakage as well as the several interventions to inject sealant. Up to 2.000 tons of steam was wasted every year.

FIGURE 14 – LEAKING VALVE

With the severe working condition of the plant, where valves are submitted to pressures of 140bar (2030psi) under temperatures as high as 550ºC (1022ºF), it became extremely necessary the use of a proper installation procedure of packing.

Before the installation, the old packings and/or injected seals were removed with high pressure water jet. Carbon bushings were installed at the bottom of the stuffing boxes whenever necessary to keep a maximum of six packing rings[1].

A total of 46 steam valves ranging in size from 1/2" to 16" were packed with Style A following the Pump & Valve Installation Procedures[3] with the gland stress calculated according to the formula:

$$S_s = S_{min(0,01)} + P = 69MPa$$

Where

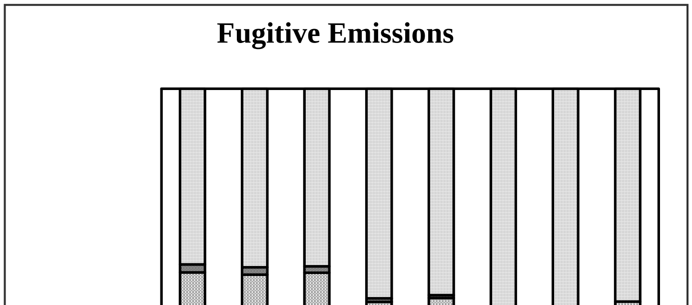
$S_{min(0,01)}$ = 55Mpa (7975psi)
P = 140bar = 14MPa (2030psi)

The packing behavior has been monitored for over 36 months until the time this paper was being edited, however the number of mechanical cycles executed by each valve was not registered due to operational conditions. In this period, no interventions were necessary, no re-torques were applied, and the old need to inject sealant was completely eliminated.

FIGURE 15 – LEAK-FREE VALVES AFTER S_S WAS APPLIED

The plant was shut down and all valves were inspected. The gland bolts were retightened to assure that all packings had the calculated installation stress (S_s) before the plant start-up. None of the packings were replaced and none of the valves showed any leaks after start-up and operation. The same installation procedure was also applied in hydrocarbon lines, with packing Style C, to control fugitive emissions. Before the application of the controlled torque, 54% of the 17.474 valves presented leakage values higher than 500ppmv. After the application of the calculated installation seating stress (S_s), 92,5% of the valves showed leak rate values under 250ppmv and a total of 94,2% under 500ppmv. The results are in Figure 16. Once re-tightened to the calculated value the fugitive emissions were back to less than 250 ppmv level

Packing Style C was used for this application.



	Angular	Butterf.	Ball	Gate	Globe	Plug	Mach	Others
<250 ppmv	242	24	820	11.176	1.574	155	7	63
>250 / <500 ppmv	11	1	29	195	23	-	-	-
>500 ppmv	54	5	181	527	104	1	-	3

FIGURE 16 – LEAKAGE x PACKED VALVES

Even though The *Minimum Seating Stress Test* was performed with 6,4mm (1/4”) cross-section packings, the concept showed to be valid for other cross sections as verified in the Field Pilot Test.

CONCLUSIONS

Laboratory and subsequent field tests performed with different packing styles, valves and media showed that, like for gaskets, it is possible to have similar installation procedures for packing valves.

The number of strokes executed by the valves on the field tests was not monitored. However, for this study, the plant past condition was taken as the basis. The improvements observed shows that it is possible to determine the minimum seating stress in laboratory tests for each packing style and an installation seating stress calculated according to a formula to assure a leak free start-up and operation.

Leak free start-up and operation generates economy, reducing product waste and eliminating expenses with the injection of sealant, besides increasing the plant personnel safety.

The calculated installation seating stress also proved to be efficient in controlling fugitive emissions, reducing air pollution and costs.

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2. American Petroleum Institute - API STD 622 - Testing of Process Valve Packing for Fugitive Emissions
3. Pump & Valve Installation Procedures, The Fluid Sealing Association/European Sealing Association, 2003
4. DIN EN 13555 – Gasket parameters and test procedures relevant to the design rules for gasketed circular flange connections.