CONF-9210204--2 EGG-M-92475

PARAMETERS AFFECTING MOV PERFORMANCE[a]

EGG-M--92475

DE93 005194

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ABSTRACT

This paper presents the background status and current research on the motor-operated valve (MOV) disc and stem factor loads. Generic Safety Issue (GSI)-87 "Failure of HPCI Steam Line Without Isolation" and Generic Letter (GL) 89-10 "Safety-Related Motor-Operated Valve Testing and Surveillance" have initiated a great deal of research on MOVs in a relatively short time. Most of this research has concentrated on the motor-operated, rising-stem, wedge gate valve, which is the predominant valve in the GSI-87 applications and is widely used in the systems covered by GL 89-10.

The Idaho National Engineering Laboratory (INEL), sponsored by the U.S. Nuclear Regulatory Commission (USNRC), is performing research to assist in the resolution of GSI-87 and the implementation of GL 89-10. This work has identified two friction loads that were not well understood and that have a significant influence on the force required to operate a valve under load. The lack of understanding of one of the friction loads has led to questions about the diagnostic testing performed on MOVs over the last few years. It is also not known how aging (time) will affect these friction loads. This is also a subject of ongoing research.

INTRODUCTION

Though the motor-operated valve (MOV) has been widely used for a long time, it has recently come under close scrutiny. The reason behind this is two fold. For valves that normally operate at or near their design basis load, the problems were discovered and solved early in the development process. For valves that are seldom required to operate at their design basis conditions, primarily isolation valves, the identification of the problem may be delayed.

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a. Work supported by the U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Division of Engineering, under DOE Idaho Field Office Contract DE-AC07-76ID01570; G. H. Weidenhamer, NRC Program Manager. Computer-generated graphics by Geraldine S. Reilly; technical editing by Julie M. Steffes.

Experience has shown that some of these isolation valves have been called upon to perform their design basis function, and the results were less than satisfactory. As a result, the INEL investigated valve performance at conditions up to the design basis to determine why a valve did not always function when called upon. The valve research found that the methods used by the industry to estimate the stem thrust required to operate a wedge-type gate valve did not always produce conservative results. This provided the potential for undersized valve motor operators.

The problems associated with estimating the stem thrust capabilities of a motor operator compound the problem of estimating the stem thrust necessary to operate a gate valve. USNRC valve research has also found that the methods used to measure the conversion of operator torque to stem thrust in a rising-stem valve did not always produce conservative operating results.

DISCUSSION

The motor-operated, rising-stem wedge gate valve is the most popular isolation valve used in nuclear plant applications. Given the two problems stated above and the popularity of the valve, considerable weight is given to the total problem. These and other factors were instrumental in the USNRC issuing Generic Letter (GL) 89-10, "Safety-Related Motor-Operated Valve Testing and Surveillance." This generic letter recommends that utilities reverify the design basis requirements for their safety-related MOVs, verify the capability of the MOV by test where practicable, and develop a methodology to maintain the capability of each MOV to perform their safety-related function.

The INEL is performing MOV research[1] in support of the implementation of GL 89-10. This research, coupled with that performed in support of the resolution of Generic Safety Issue (GSI)-87, "Failure of HPCI Steam Line Without Isolation," has provided new insight and understanding of selected parameters that affect MOV performance.

OBJECTIVES OF CONTINUED RESEARCH

The INEL valve research to date has found that both the valve and the operator respond differently than previously assumed by the industry. The methods used to estimate the stem thrust required to operate a gate valve have produced inconsistent results. Although the stem thrust is not always conservatively estimated, many valves can be cycled repeatably at design basis conditions with the valve sustaining relatively minor internal damage. The response of such a valve has been termed predictable. Our research also found that some valves sustain more than minor internal damage when operated at design basis condition. This damage can increase the stem-thrust requirements of the valve to the point that the MOV could be rendered inoperable. The response of such a valve has been termed nonpredictable. Our research not only addresses the stem thrust required to operate a predictable valve, but also discusses if limited testing can determine whether a valve will perform predictably or nonpredictably when called upon to operate at its design basis conditions.

The operator has also been found to respond differently under load than previously assumed by the industry. Some methods used to measure the conversion of operator torque to stem thrust have been shown to produce inconsistent results over the full range of operator loadings. The INEL research not only addresses this variation in the output capability of an operator but also discusses whether limited testing can determine the limits of this variation at design basis conditions.

PREDICTABLE AND NONPREDICTABLE VALVES

A predictable valve can be cycled repeatably under heavy loadings and not sustain internal damage that would keep the valve from performing its design basis function, although the stem thrust required to operate the valve may be higher than previously estimated by the industry. On the other hand, a nonpredictable valve undergoes plastic behavior, gouging and machining the valve disc, body guides, and seat as the valve opens or closes under load. As a result, no simple friction factor and linear equation can predict the performance of this valve. Research may provide a method to determine whether a valve will perform predictably or not, but it will not result in an equation to predict the thrust requirements of a nonpredictable valve. The method to determine if a valve is predictable or nonpredictable without a design basis test is, of course, a research objective, but not of this paper. The remainder of this paper will discuss predictable valves only because eventually all valves must behave predictably.

Our research has determined that the response of a predictable valve closing under load can be bounded using a linear equation and a simple sliding coefficient of friction. We found, through full-scale testing, that the peak thrust on a gate valve prior to wedging, or a like function in some parallel disc designs, occurs after flow isolation when the disc is fully riding on the body seats. At this time, the upstream pressure areas of the valve have stabilized with the inlet pressure, and the downstream areas have likewise stabilized with the downstream pressure. This does not mean that the upstream and downstream pressures have stabilized, only that the valve internal areas that are pressure sensitive have come to equilibrium with their respective pressures (no flow through the valve) and that the disc-to-seat coefficient of friction has stabilized.

It is serendipitous that the peak thrust occurs at the same point the safety function occurs. This is not the case with all high recovery valves. Because of this, though, our research found that, when the peak thrust occurs in the closing direction, there is a repeatable relationship between the normal and sliding force acting on a disc. We found from our valve testing that we could not be sure of this relationship until the disc was under a minimum loading of at least 400 lb/in^2. We expect this minimum loading threshold to be much lower; however, we have been unable to verify a lower limit because most of our testing focused on high-pressure, high-flow applications. We have obtained and analyzed selected in situ utility tests and found the threshold to be much lower. We are continuing to work with this and other low-pressure, low-flow data to determine a more encompassing minimum threshold.

We also found that the relationship between the normal and sliding force acting on a disc was influenced by the state of the fluid. Figures 1 and 2 show that fluid subcooling influenced our data fit. The coefficient of friction (slope of the data fit) for less subcooled fluids is 0.4, whereas for higher subcooled fluids, it is 0.5. This influence is associated with the lubricating ability of the fluid. This is not in the normal sense where the viscosity of the fluid influences the lubrication, but rather in the sense where the ability of a fluid to penetrate the bearing region between the sliding surfaces influences the lubrication. Based on this type of lubrication, steam can penetrate tight interfaces better than cold water, and is thus a better lubricant.

Based on this type of lubrication, we understand why the same valve materials closing under various fluid conditions will have different coefficients of friction. To date we have tested only new or refurbished material surfaces. We have not explored whether corrosion and oxide deposition can also affect the coefficient of friction; however, we are planning laboratory testing to address this question. Initially, a variation in the coefficient of friction of 0.1, or a change from 0.4 to 0.5, does not appear to be significant. However, we have found that it can have a profound effect on the stem thrust demands of a valve. For instance, an increase in the coefficient of friction from 0.4 to 0.5 will increase the required closing thrust by 25%, with all other parameters remaining the same. As such, the effect of corrosion or oxide deposition on the sliding surfaces (aging), could affect the coefficient of friction, and the resultant effect on the stem thrust could be significant.

STEM FACTOR

The stem factor (the operator torque divided by the stem thrust) quantifies the efficiency of the conversion of torque in the motor operator to thrust in the valve stem. When sizing an MOV, the industry estimates the stem factor using the proven power thread equation and a bounding coefficient of friction between the stem and the stem nut. The coefficient of friction is the only variable in the conversion of torque to thrust, provided that the stem or stem nut threads do not deform. We have measured coefficients of friction that vary from 0.1 to 0.2. Design basis motor operator sizing calculations typically use either a 0.15 or a 0.2. In most cases, a coefficient of friction of 0.2 will be conservative for a design basis calculation, but may be overly conservative in actual operation. This is because a change in the coefficient of friction from, for instance, 0.1 to 0.2 represents a significant change in output thrust of the operator.

Figure 3 shows this spread for a 6-in. rising stem, motor-operated gate valve operating at BWR primary or PWR secondary service conditions. The vertical line at roughly 255 ft-lb of torque corresponds to a reasonable torque switch setting for such an isolation valve equipped with a Limitorque SMB-0-25 motor-operator. The figure indicates that a stem-to-stem-nut coefficient of friction of 0.1 will yield 24,600 lb of thrust at torque switch

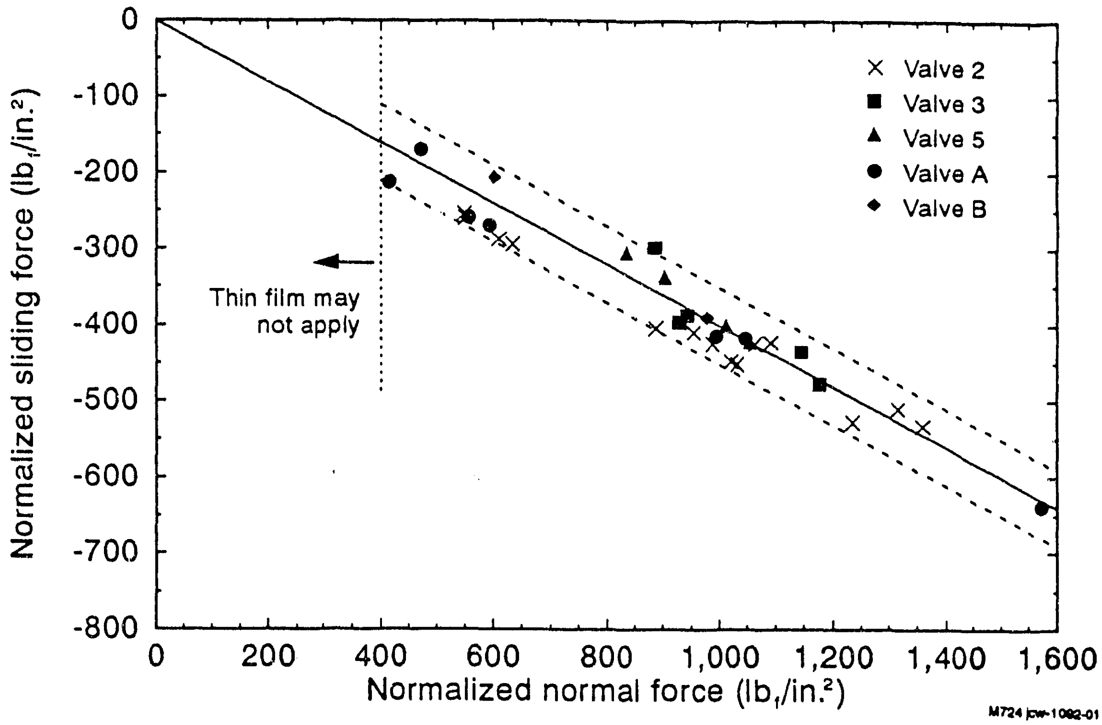

Figure 1. Correlation for less than 70°F subcooled fluid.

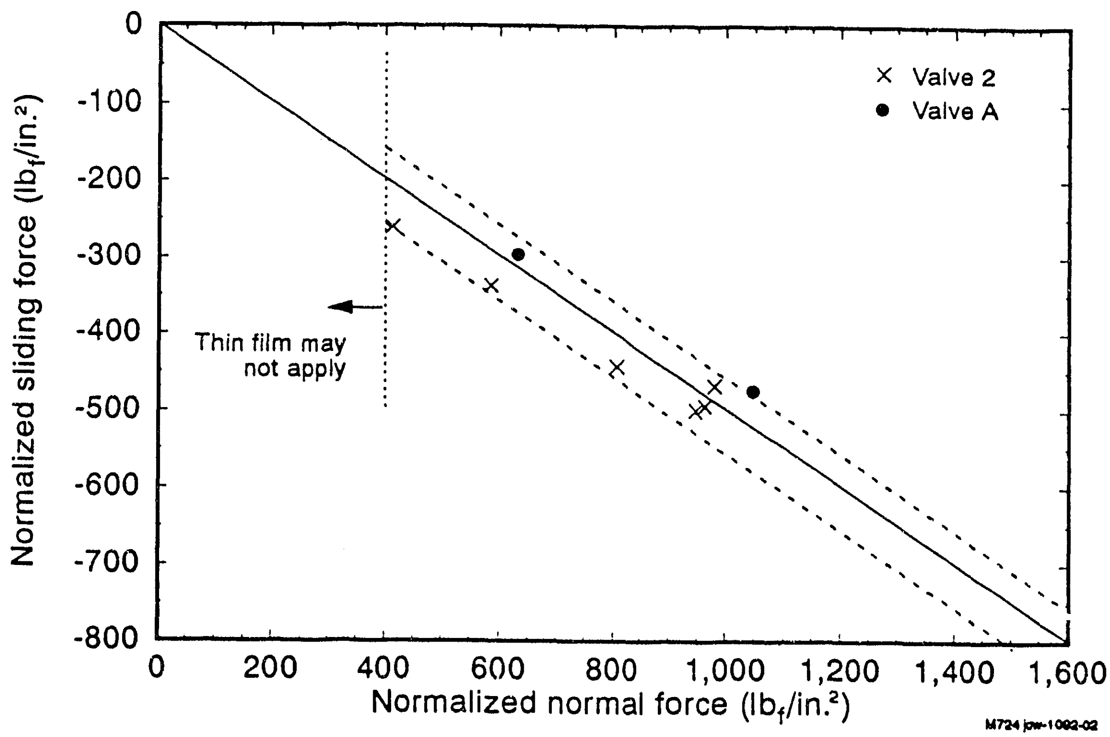

Figure 2. Correlation for 70°F or greater subcooled fluid.

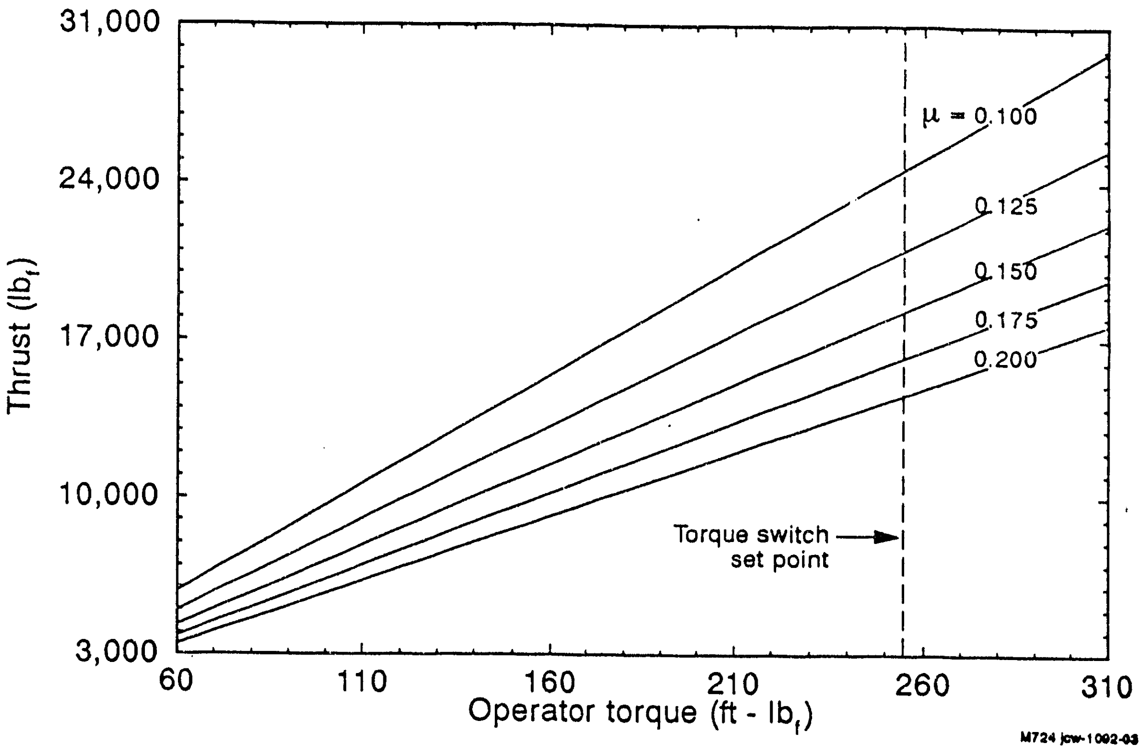

Figure 3. Operator torque to thrust conversion versus the coefficient of friction.

trip, whereas a coefficient of friction of 0.2 will yield 14,600 lb of thrust. The 10,000-lb thrust difference occurs over a credible variation in the stem-to-stem-nut coefficient of friction.

From a sizing standpoint, a coefficient of friction of 0.2 is conservative. From an operational point of view, however, this may be too conservative. Not every valve and operator can handle the high loads resulting from a lower coefficient of friction every time the valve is cycled without eventually incurring some damage. In part, this is driving the utilities to rely increasingly on MOV diagnostic equipment to help determine the actual operating requirements of their MOVs.

For those valves that can be tested using credible diagnostic test equipment, and tested both statically and dynamically at conditions up to design basis, the stem-to-stem-nut coefficient of friction for that specific unit can be determined and accommodated. However, for a similar valve performing an identical function, even if the valves are sitting right next to each other, the results from testing one MOV cannot necessarily be applied to the other MOV. We have found the stem-to-stem-nut interface and its associated coefficient of friction to be valve specific. Even so, accurately quantifying the coefficient of friction depends on the type of test being performed.

For instance, during a static test the valve is cycled without a flow and pressure load. Such a test is useful to determine the maximum possible output thrust a given motor-operator torque switch setting will supply. But the test is not representative of the stem factor under load because the seating load is the first significant load the unit experiences during such a test. As a result, the valve assembly becomes structurally stiff, and the torque switch trip point is passed through very quickly. Any time lags in the assembly, such as accelerating the worm gear and the unimpeded momentum of the operator, result in the maximum possible output thrust.

If, on the other hand, the stem load is larger and the stem nut is turning as the valve closes, the coefficient of friction between the stem and stem nut will increase as the stem load increases. As the coefficient of friction increases, the efficiency of the conversion of torque to thrust decreases and, in marginal cases, can result in insufficient thrust to close the valve. This phenomenon is shown in Figure 4, which represents four different valve closures against different flow and pressure loadings. We did not have an absolute no-load static test to compare the loaded tests with because the test stand was at an elevated temperature and pressure condition. However, we were able to perform a pressure-only closing (no flow) where the load on the stem was the result of the piston and packing loads only.

As shown in Figure 4, the 1000-psig, 530°F (no flow) closing has a 5,000-lb running load and a final seating thrust of 22,000 lb. The other three stem thrust histories are at increasing flow and pressure conditions. Two of the stem histories show that the valve was able to seat, as indicated by the almost vertical stem force trace at the end of the stroke. This almost vertical increase in thrust occurs when the valve seats and the MOV becomes structurally very stiff. Although the valve seated during the 600- and

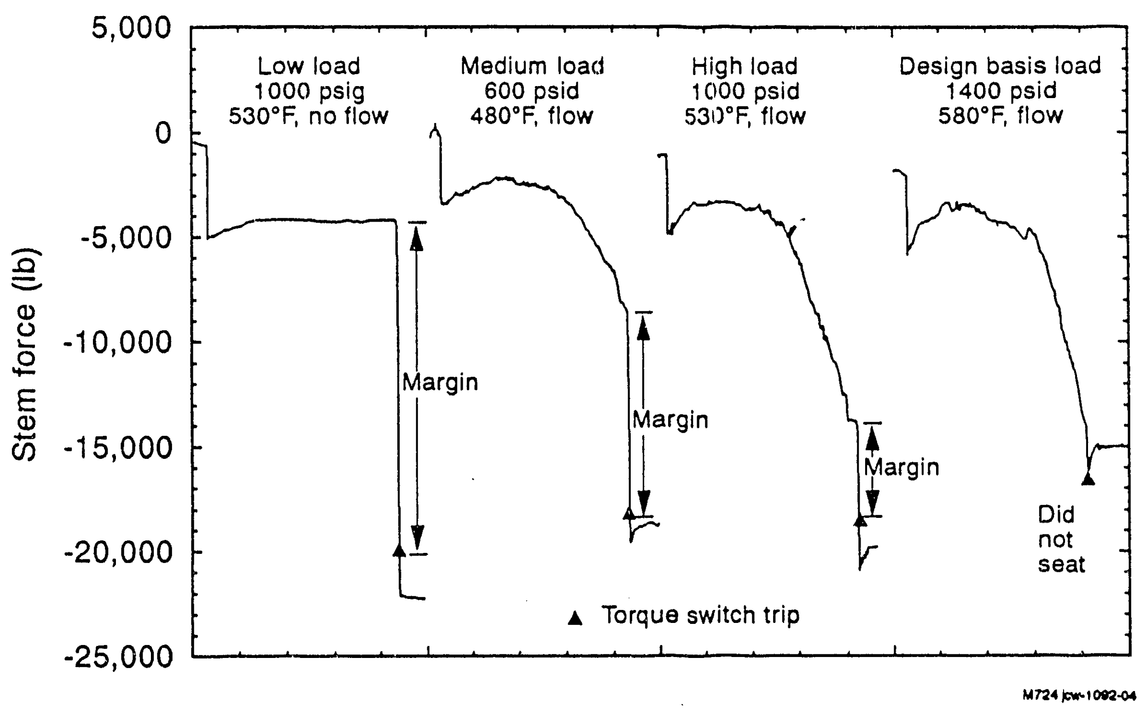

Figure 4. Valve closure against increasing flow and pressure loadings.

1000-psid tests, the force at torque switch trip decreased. During the 1400-psid test, the valve did not seat. The torque switch tripped before seating, and the subsequent thrust was much less.

We investigated this phenomenon using a laboratory device we built specifically to simulate the closing loads of a valve on the valve stem and motor-operator. This device is called the INEL motor-operated valve load simulator (MOVLS) and is shown in Figure 5. The MOVLS uses an actual motor operator, valve stem, and valve yoke. The valve load is simulated using a hydraulic cylinder that discharges to an accumulator partially filled with a liquid under a gas overpressure. The liquid level and gas pressure can be adjusted to simulate different closing loads; valve seating is simulated when the cylinder bottoms out.

Figures 6 and 7 are two series of stem thrust histories performed on the MOVLS while trying to isolate why the stem thrust varies. Figure 6 shows that the MOVLS can reproduce the same type of behavior that we observed during actual valve testing (see Figure 4). Figure 7 then shows the results of repeated low-load tests following a high-load test. Test 15 on Figure 7 is a repeat of the first test shown in Figure 6. Note that, even when the high load is removed, the margin is not as great as in Tests 16 and 17, which are also low-load tests. The torque switch trip point in Test 15 is near 14,000 lb, whereas during Tests 16 and 17, it was nearer to 18,000 lb.

Although we looked at many parameters internal to the MOV, the parameter observed to change the most was the stem-to-stem-nut coefficient of friction. Figures 8 and 9 show the coefficient of friction corresponding to the tests presented in the previous two figures. Figure 8 shows that, as the stem load increases, the coefficient of friction increases. This increase, in turn, decreases the efficiency of the conversion of torque to thrust and shows up as a decrease in thrust at torque switch trip. In fact, during Test 14, the coefficient of friction has increased, and the subsequent conversion of torque to thrust has decreased to the point that the valve, or simulator in this case, does not achieve valve closure.

Following this test, Figure 9 shows that the coefficient of friction during Tests 16 and 17 has returned to the initial level observed during Test 11. However, Test 15 is a low-load test, like Tests 16 and 17, and has a higher coefficient of friction than the most heavily loaded test. The determination of the coefficient of friction and the stem thrust increases and the subsequent response following the test that did not close the valve support a common hypothesis.

We suspect that this load-sensitive behavior is caused by the lubricant being squeezed out of the stem-to-stem-nut interface. In other words, the surface at the stem-to-stem-nut interface goes from being thick-film lubricated to near metal-to-metal contact. Following the heavily loaded test, the stem-to-stem-nut interface relubricates itself on the next cycle and thereafter is lubricated by the thick film.

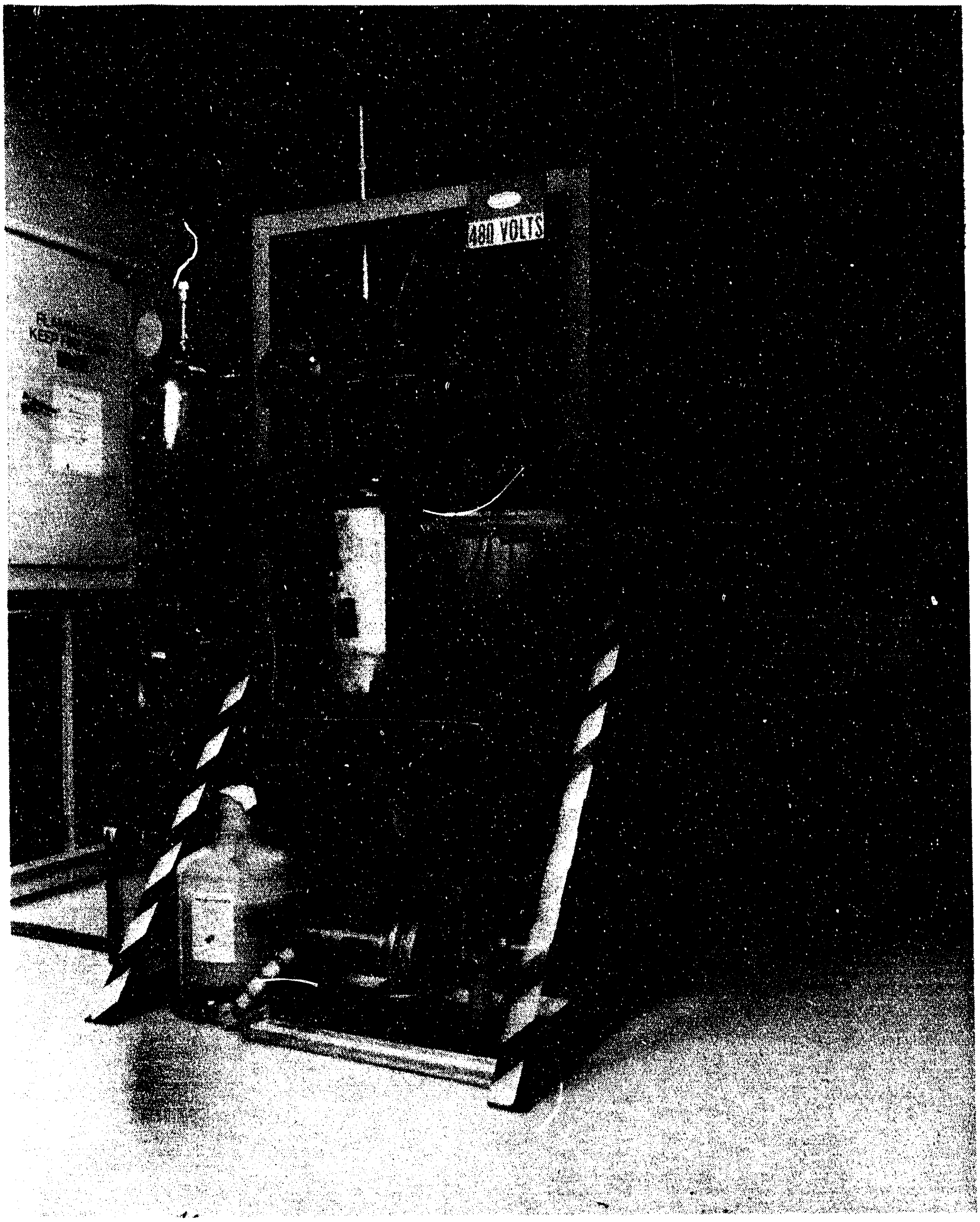

Figure 5. INEL motor-operated valve load simulator (MOVLS).

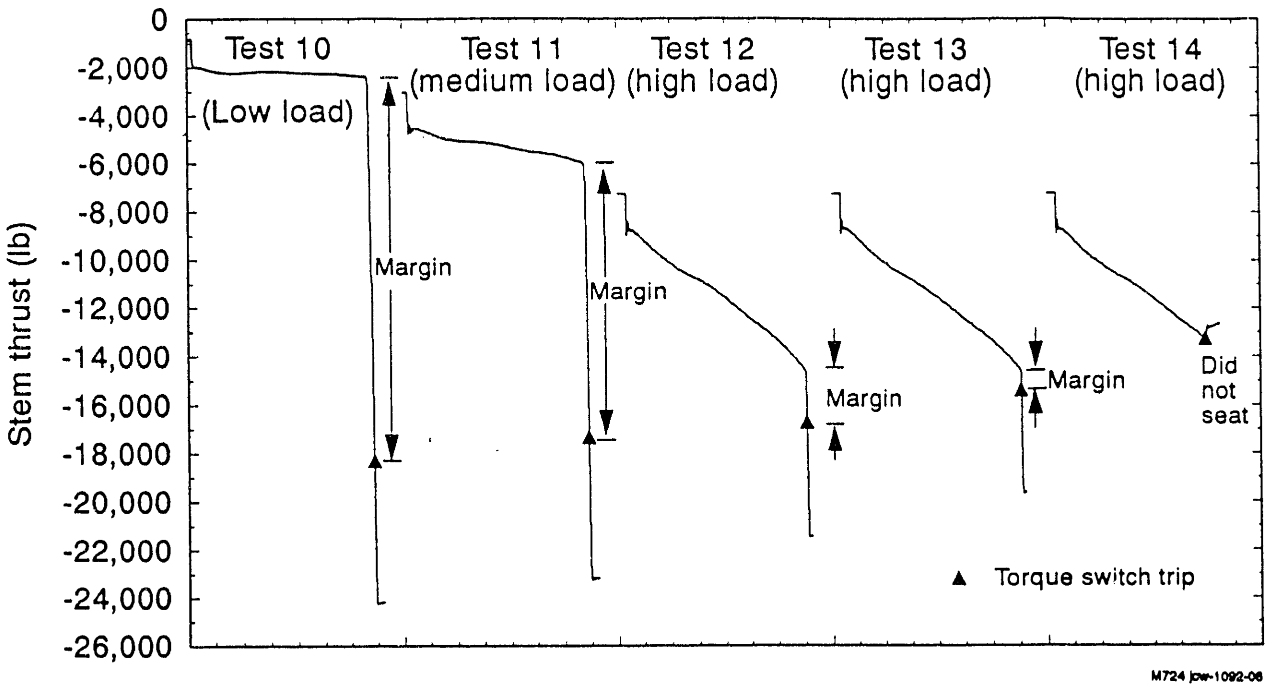

Figure 6. Valve closure against increasing flow and pressure loadings duplicated on the MOVLS.

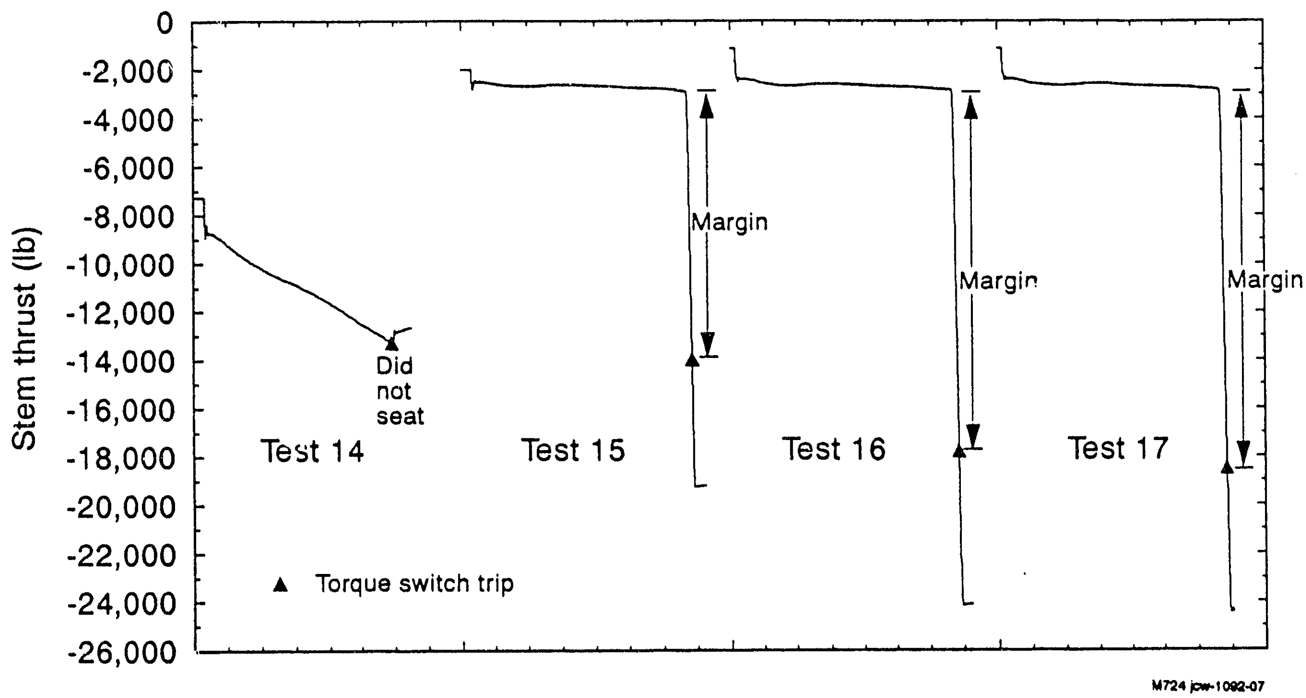

Figure 7. MOVLS closures against low loads.

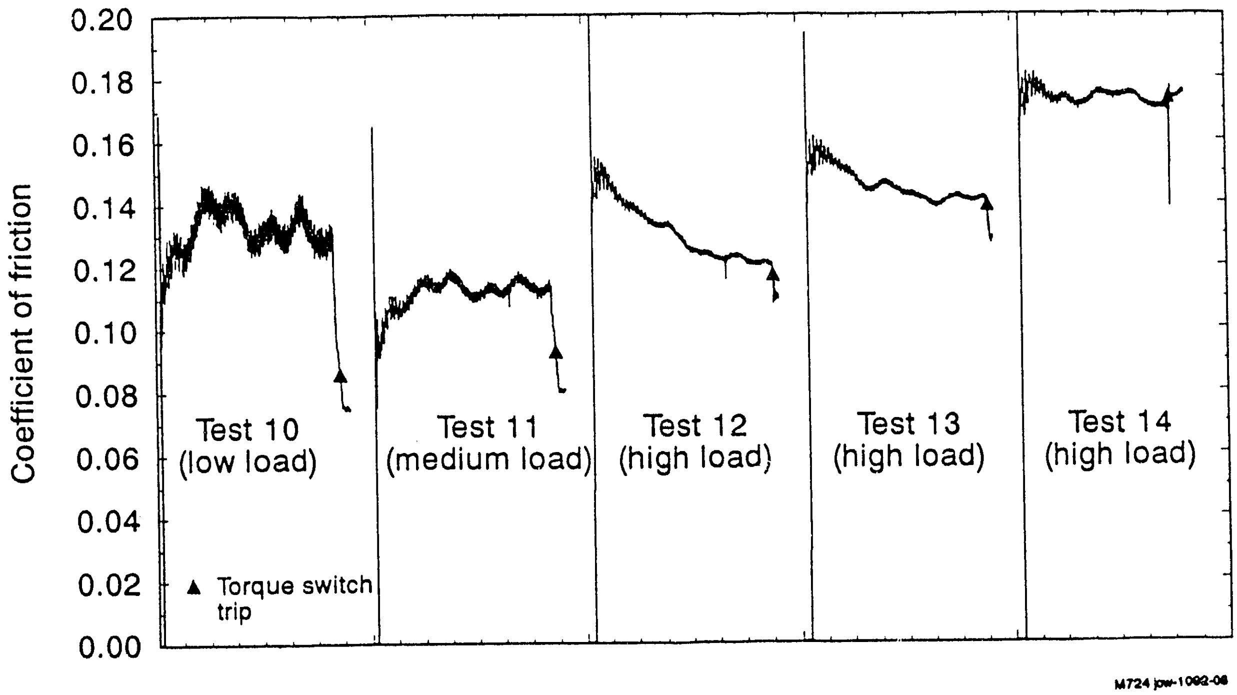

Figure 8. Coefficient of friction due to increasing flow and pressure loadings.

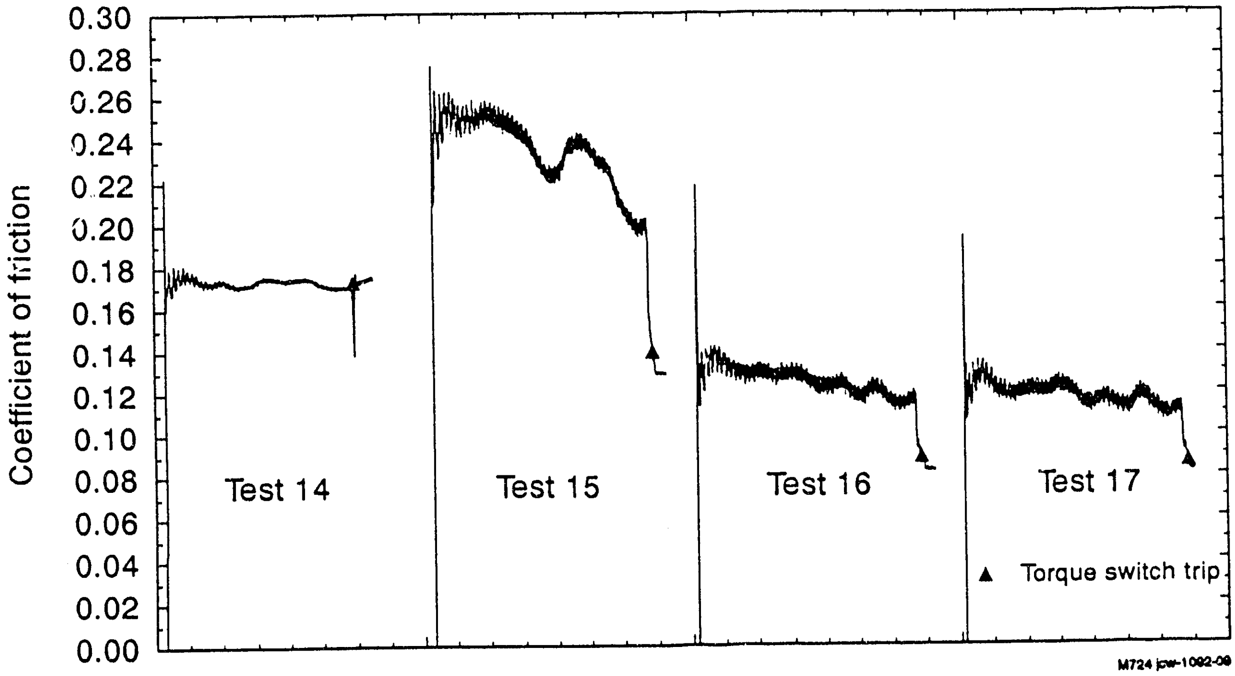

Figure 9. Coefficient of friction due to low loadings.

This variation in the stem-to-stem-nut coefficient of friction under load and with the stem nut rotating is not observed during a static test when the valve seat supplies the only significant load the operator encounters. This variation results, in part, from the lack of stem nut rotation when the valve load is encountered and the lubricant not being squeezed (wiped) out of the interface between the stem and the stem nut. During a dynamic test, the lubricant has time to squeeze out of the interface as the valve closes against a flow and pressure load. As a result, the coefficients of friction will not be the same during static and flow load testing. These different conditions are also the primary problem with the accuracy of diagnostic test equipment that predicts stem thrust from torque spring force or displacement. These diagnostic technologies are calibrated using a static test. Changes in the stem-to-stem-nut coefficient of friction are not accounted for.

CONCLUSIONS

The methods historically used to estimate the valve stem thrust demands and the capability of the motor operator to deliver this load are subject to frictional variations that make a purely analytical assessment of a MOV difficult. Relatively small changes in either coefficient of friction can have a profound effect on the thrust demands on or the thrust capability of an operator. In-plant testing would more accurately quantify the frictional components. Remember though that the resultant values may be sensitive to the effects of equipment aging, and the effect on the stem thrust could be significant.

REFERENCES

1. Steele, R., Jr., J. C. Watkins, K. G. DeWall, M. J. Russell, *Motor-Operated Valve Research Update*, NUREG/CR-5720, EGG-2643, 1992.

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