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# ERRATA

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**Instructions:** Please replace the following pages in your copy. Revisions are identified with a bar along the side of the page.

Page 3-21/3-22

Replace this page with revised page 3-21/3-22.

Page 3-31/3-32

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the disc is tipped as far as it can tip, so the pressure distribution around the disc and the resistance due to mechanical interference have been established. Thus, all of the load effects due to geometry, disc tipping, disc area, and mechanical interference are present in the best effort flow test. The area, tipping, and geometry will be the same in the higher pressure case; only the disc factor may change. We expect any change in the disc factor to be a downward change; the friction term is typically less at higher loads. Valve testing and laboratory single effects testing have confirmed that less thrust is required per pound of differential pressure at higher disc pressure loads. Because of differences among individual valves, this technique cannot be used in a grouping application, nor can the results of testing one valve be extended to other valves; this technique is valid only for the tested valve. Once best effort test data are obtained, the following equation can be used to extrapolate the results to the design basis differential pressure load:

$$F_{stem} = C_{hooking}\,\Delta P + P_{up}\,A_{stem} + F_{packing}$$

where

$F_{stem}$ = stem thrust

$C_{hooking}$ = hooking factor

$\Delta P$ = differential pressure

$P_{up}$ = upstream pressure

$A_{stem}$ = stem area

$F_{packing}$ = packing drag

Use the data from the best effort flow test as input to calculate the hooking factor. The hooking factor is a term that accounts for both the disc factor and the disc area term. Because the peak force is measured before flow isolation, the disc area (the area of the disc exposed to flow and differential pressure forces) is unknown. (In the laboratory, it is possible to use stem position data to estimate the exposed area of the disc, but in the field this would be difficult, and for the purposes of the evaluation described here, it is unnecessary.) Once the hooking factor is determined from the best effort flow test, the hooking factor is used along with the design basis pressure and differential pressure to estimate the design basis stem thrust. We believe that this procedure will bound the stem thrust at design basis conditions; as explained in the previous paragraph, the ratio of actual stem thrust (the force required to move the disc) to differential pressure decreases as the differential pressure across the disc increases, all other parameters remaining the same. Thus, the actual stem thrust required for valve operation will be lower than the stem thrust predicted using this procedure.

## 3.3 Opening Requirements

Although there are some similarities between opening and closing, there are also some important differences. The stem rejection load, which resists during closure and adds to the stem load, assists during opening. Likewise, the $F_{top}$ load, identified during our development of the INEL correlation and mentioned earlier in this report (see Figure 3-17), assists during closure but adds to the stem load during opening. As with closing responses, we observed the occurrence of atypical as well as typical opening responses. Figure 3-21 shows the typical opening response. As expected, a classic, typical opening response shows the highest load (after unwedging) to occur while the disc is sliding on the downstream valve body seat but before flow initiation. This point in the opening stroke corresponds with the point of interest in the typical closing stroke, that is, where the full area of the disc is exposed to the full differential pressure. Because of this similarity, we were able to modify the closing correlation (with sign changes for the stem rejection load and the $F_{top}$ and $F_{bot}$ loads) to predict typical opening responses.

We found atypical responses to be more common during opening than during closing. In some instances and under some conditions, valves that exhibited typical responses during closing exhibited atypical responses during opening. The

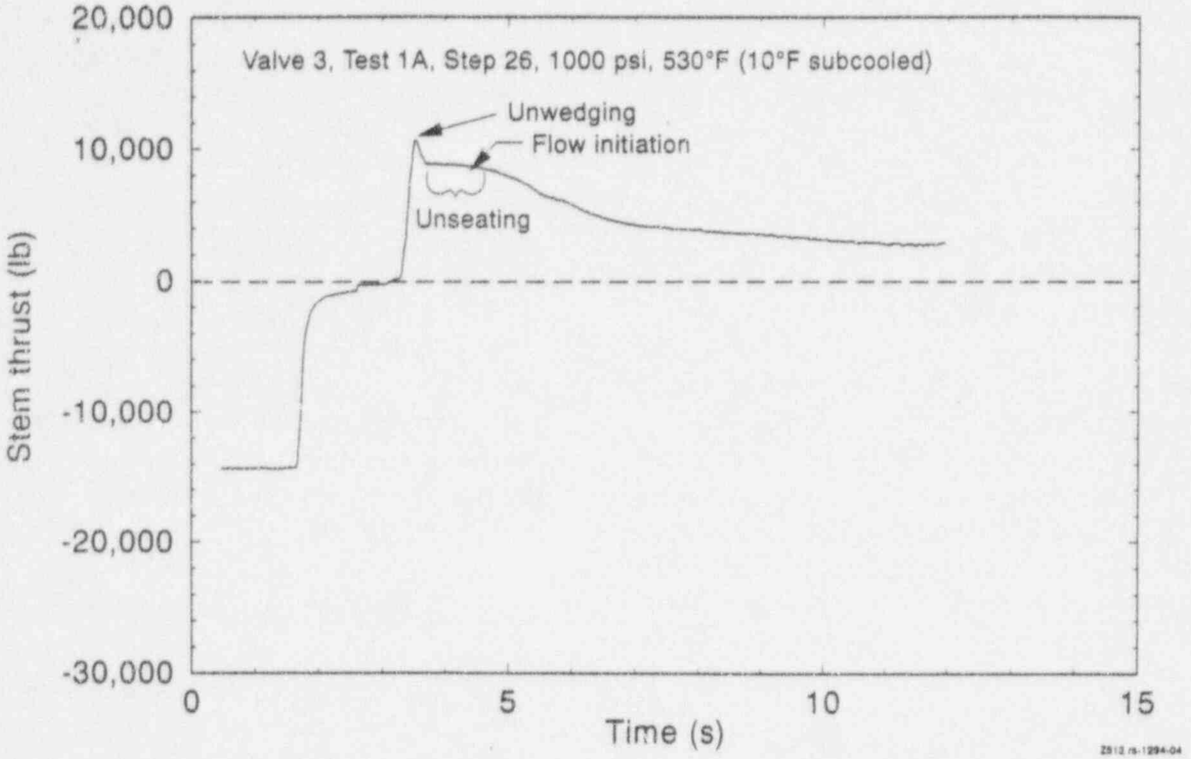

**Figure 3-21.** Stem thrust trace recorded during an opening test, showing the classic, typical response.

atypical response appeared in the stem force history as a hump in the trace after flow initiation, indicating an increase in the load instead of the expected decrease. After a careful study of the atypical opening responses from the NRC/INEL full-scale valve tests, we determined that the opening correlation we developed for typical responses also applies to atypical responses.

The following discussion first examines atypical opening responses observed in the NRC/INEL full-scale test results. Next, we present a new correlation for evaluating valve opening responses and predicting opening requirements. Then we address the applicability of the new correlation to atypical opening responses.

**3.3.1 Analysis of Full-Scale Test Results.** Before the NRC-sponsored INEL valve testing program was conducted in 1988-89, not many high-energy gate valve test results were available in the public domain. Virtually no results were available from valves tested in the opening direction. Most of the analysis presented in the following discussion is based on the results of the NRC/INEL valve test program. We have also reviewed a number of recent industry test programs, and the results of that work do not conflict with the results presented here.

In our early analysis of data from opening tests in the NRC/INEL Phase 2 full-scale test programs (reported in NUREG/CR-5558, 1990), we observed that with the larger (10-in.) valves tested with steam, the flow loads after unseating were higher than the loads during unseating. Figure 3-20 (upper plot, opening stroke) is an example of such a response. This result initially gave us the impression that for valves exhibiting atypical behavior, there was possibly not only a hook in the closing direction, but also a corresponding hump in the opening direction.

On closer examination, we found the atypical opening response to be more complicated than that. For both opening and closing, there are several mechanisms at work, each contributing to or subtracting from the total stem load. One of these mechanisms is mechanical interference between the disc and the seat, which adds resistance in the closing direction but not in the opening direction.

a method to estimate the opening response. After examining the NRC/INEL and industry valve test results in light of the effect fluid subcooling has on the peak opening response of the valve, we extracted the results of those tests where the fluid could flash (tests that produced typical responses). These results bound all the observed responses, and the use of these results avoids the difficulties of dealing with the unexpectedly low apparent friction during unseating and the subsequent increase in the stem thrust upon flow initiation, as seen in the atypical responses. Using the data thus extracted, we were able to estimate the normal and sliding loads acting on the disc and to correlate them over a wide range of differential pressure conditions. Figure 3-33 is a plot of the normalized normal versus normalized sliding loads for opening a gate valve. As with the original INEL correlation for closing, the slope of the trace represents the friction factor.

Based on this effort, we suggest that one of the following two correlations be used to estimate the peak stem thrust demands of a valve during opening. Above a normalized normal load of approximately 450 psi, the first correlation should be used, whereas below this load, the second correlation should be used. The correlations are presented on page 3-32.

Like the INEL's correlation for closing, the opening correlation is linear. However, only a single friction factor is used for the opening correlation [the nominal (best fit) value is 0.50). Another difference between the closing correlation and the opening correlation can be seen in the limits of the data scatter. The closing correlation bounded the response with a ±50 psi band at higher loads and a ±30% band on the friction factor at lower loads, whereas the opening correlation bounds the data with a ±80 psi band at higher loads and a ±35% band on the friction factor at lower loads. These values represent the terms necessary to bound actual valve performance. The closing and opening on-the-seat responses are quite similar and adds to our confidence that the opening correlations are valid.

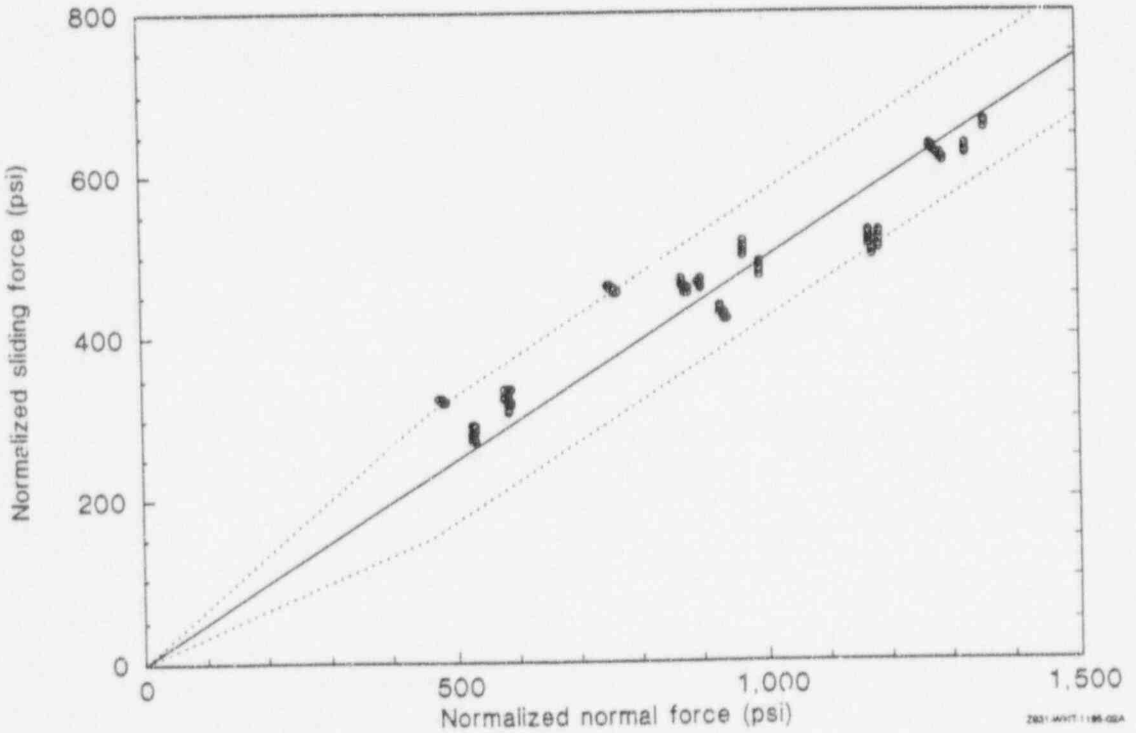

**Figure 3-33.** Normalized sliding loads versus normalized normal loads for the opening stroke for gate valves.

Disc Load

For $F_n \geq 450$ psi:

$$F_{stem} = F_{packing} + F_{top} - F_{bot} - F_{sr} + \frac{(f_o \cos\alpha - \sin\alpha)(F_{up} - F_{dn}) \pm 80 A_{ms}}{(f_o \sin\alpha + \cos\alpha)}$$

For $F_n) < 450$ psi:

$$F_{stem} = F_{packing} + F_{top} - F_{bot} - F_{sr} + \frac{[(1.0 \pm 0.35) f_o \cos\alpha - \sin\alpha](F_{up} - F_{dn})}{[(1.0 \pm 0.35) f_o \sin\alpha + \cos\alpha]}$$

where

$F_{stem}$ = stem thrust

$F_{packing}$ = packing drag

$F_{sr}$ = stem rejection load
= $P_{up} * A_{stem}$

$F_{top}$ = $P_{up} * A_{ms} * \tan\alpha$

$F_{bo}$ = $P_{dn} * A_{ms} * \tan\alpha$

$\alpha$ = valve seat angle

$F_{up}$ = $P_{up} * A_{ms}$

$F_{dn}$ = $P_{dn} * A_{ms}$

$A_{ms}$ = mean seat area
= $1/4\,\pi$ (mean seat diameter$)^2$

$A_{stem}$ = stem area
= $1/4\,\pi$ stem diameter$)^2$

$P_{up}$ = upstream pressure

$P_{dn}$ = downstream pressure

$f_o$ = 0.50

We know from our closing correlation that below a disc loading of about 400 psi, the data scatter becomes dominant. In the extension of the closing correlation to lower loads (discussed in a previous subsection), we used the data we received from utility testing, along with the publicly available data we have reviewed from other industry testing. All these data for low-pressure, low-flow testing indicate that when the disc is lightly loaded, the data scatter can be expected to fall within the bounds specified in the previous paragraph. Based on those test results, we believe that test results that fall outside the specified bounds represent valve performance that is not characteristic of the responses we have observed.

The opening correlation can be used to evaluate the test results and the opening requirements of valves that can be tested in situ at conditions less severe than design basis conditions. We propose a method similar to the one we recommend in the use of the INEL correlation for closing requirements. With this method, the results of the in situ test are not used directly in an extrapolation. Instead, the test data are evaluated to determine whether the results fall within the bounds defined by the correlation. If so, it can be assumed that the response of the valve in question is represented by the data used to develop the correlation, and that the correlation is applicable. Once applicability has been demonstrated, the upper bound of the correlation is used to estimate the stem thrust requirements at design basis conditions.

All the results of NRC/INEL valve testing and all the industry valve testing we have reviewed show that the closing thrust requirements typically exceed the opening requirements, particularly in smaller valves. In our examination of the various loads that contribute to the total stem loads for opening and closing, we have found that the only load that causes an increase in the opening load compared to the closing load is the load due to the pressure on the top of the disc ($F_{top}$ in Figure 3-17). This load assists during closing and resists during opening. In valves smaller than about 6 in., the effect of this load is offset by the stem rejection load, which resists closing and assists opening. In addition, any tipping of the disc will reduce the $F_{top}$ load.

A first principles evaluation of the normal versus sliding loads reveals another difference between opening and closing. Theoretically, if the force and the friction were operating on the same

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