Edward Valves

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Design Basis Qualification of Equiwedge™ Gate Valves For Safety-Related MOV Applications

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By
E. A. Bake,
Research Manager,
Edward Valves
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The Equiwedge Solution

ABSTRACT

In NRC Generic Letter 89-10, the U.S. Nuclear Regulatory Commission states that performance of safety-related MOVs cannot be reliably extrapolated from static or low-flow test results. Valves that have passed these tests have often failed under realistic DBE test conditions. MOVs that cannot meet new standards must be upgraded or replaced. Equiwedge gate valves, which combine advantageous features of both wedge and parallel-slide valves, provide a third alternative to these other MOV designs. These gate valves from Edward are designed and test-proven to perform reliably in safety-related MOV applications.

Introduction

Nuclear Regulatory Commission (NRC) Generic Letter 89-10[1] has had a significant impact on the U.S. nuclear power industry, and its testing requirements will lead to the need for repair or replacement of many safety-related motor operated valves (MOVs). Nuclear plant engineers face two challenges: how to qualify existing valves for performance under design basis event (DBE) "blowdown" conditions and how to solve problems discovered during qualification tests. NRC-sponsored tests[2] of representative gate valves like those used in many U.S. nuclear power plants have shown that some valves are "unpredictable" and subject to functional failure or damage under DBE conditions. Thus, problems will certainly be encountered with some conventional gate valves in the course of tests required by 89-10.

The nuclear plant MOV concerns have raised legitimate questions about the reliability of conventional wedge gate valves. This paper discusses an alternate design. The Equiwedge gate valve was developed and introduced by Edward Valves, Inc. (formerly part of Rockwell International) in 1975, so it is not a "new" design. Since it was not offered for nuclear service until after orders had been placed for valves for most U.S. nuclear plants, relatively few Equiwedge MOVs exist in these plants. Nevertheless, the Equiwedge design was subjected to extensive DBE testing to qualify it for service as a main steam isolation valve (MSIV), and Equiwedge MSIVs are employed in nuclear power plants on three continents. Except for use of linear actuators, the MSIV application involves basically the same DBE operational requirements as an MOV. Two test programs on Equiwedge MOVs have demonstrated reliability similar to that which had been proven in MSIV simulation tests.

Background

NRC concerns with safety-related MOVs can be traced back many years, but they were intensified by the Three Mile Island incident in 1979, where valves were held partially responsible for the problems. All types of valves have been studied, but the emphasis has been on gate valves recently, because they are very widely used in nuclear plants.

Of the many basic types of isolation (stop) valves, two types – globe and gate – predominate in high pressure, high temperature applications in power plants. There are many applications where globe valves have advantages, such as for throttling and flow control; however, gate valves have straight-through flow passages which offer an advantage over conventional globe valves in minimizing flow resistance.

Gate valves also offer an at least theoretical advantage over globe valves in lower operating force requirements. While a globe valve disk has to buck the full differential pressure force head-on to either open or close, the gate in a gate valve appears to need only overcome frictional forces induced by pressure pushing it against the guides or seats as it slides across the flow stream.

These advantages led to widespread use of state-of-the-art gate valves in fossil-fueled power plants early in the twentieth century, and many of the same valves found their way into applications in nuclear power plants starting in the late 1950s. While the valves for nuclear plants required a "pedigree" and sometimes an N-stamp, many were of designs that were far from new. Some problems that were only nuisances in typical fossil-fueled plant applications became serious in safety-related motor-operated gate valves in nuclear plants.

One major difference in the applications in older fossil-fueled plants was that many gate valves were used for component isolation and did not require operation against high flow or differential pressure. Some were only opened or closed under shutdown conditions when there was little or no differential pressure. Many had bypass lines with globe-type bypass valves that could be used to "balance" differential pressure before opening or closing of the main valve. Traditional gate valves generally performed reasonably well in such applications; at worst, a motor actuator might require an assist from the manual over-ride to unstick a jammed valve. However, some of the safety-related nuclear plant applications involve operation under postulated accident conditions that require opening or closing under high differential "blowdown" conditions.

Edward Valves, Inc., was historically a manufacturer of primarily globe valves, but a line of conventional solid wedge gate valves (*Figure 1*) was made from approximately 1944 to 1970. While it employed some unique manufacturing processes to provide precision in guiding the gate and seating, it was not a design that would be recommended today for operation at high differential pressure. While it was relatively trouble-free and was liked by many users, production was discontinued because it was not suitable for the applications that were beginning to develop twenty years ago.

Equiwedge Gate Valve Development

Development of the Edward Equiwedge gate valve product line was undertaken in 1972, and its introduction in 1975 was accompanied by publication of a comprehensive technical paper[3]. The Equiwedge (*Figure 2*) is one of the newest basic gate valve designs in the world, but it has already accumulated an excellent service history of successful performance in thousands of applications worldwide. These applications range from common manually operated component isolation valves in fossil-fueled power plants through safety-related motor operated valves (MOVs) in nuclear power plants. Combined with Edward stored energy actuators, 160 large Equiwedge gate valves have been furnished as quick-closing main feedwater isolation valves and main steam isolation valves (MFIVs and MSIVS) or for other similar safety-related applications in nuclear power plants worldwide. Table 1 lists the power stations where these valves are employed, along with the year of actual or scheduled plant startup.

When the Equiwedge product line was first conceptualized, Edward engineers literally began with a "clean sheet of paper." Not a single part from the previous Edward gate valves was used in Equiwedge gate valves. Until the new design could be developed and proven by testing, Edward offered only globe-style isolation valves.

There was no preconceived direction that the new valves had to be of the wedge type. An innovative group of experienced valve engineers studied all types of gate valves produced worldwide, and their only goal was to produce a better valve that overcame the weak points of prior designs. Parallel-slide and one-piece "flexible wedge" design concepts were carefully considered and studied before the final Equiwedge design approach was decided upon.

Conventional Wedge Gate And Parallel-Slide Gate Valve Features

Prior wedge gate valves and parallel-slide valves each had design strengths and weaknesses. The fact that both gate valve styles had been used for many years

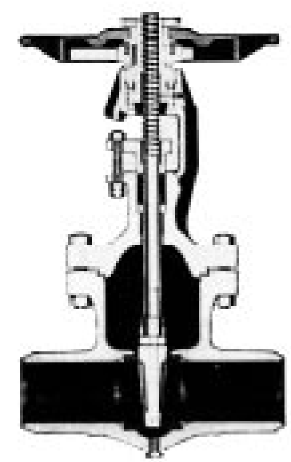

Figure 1: Old Edward Gate Valve Features

Figure 2: Equiwedge Gate Valve Features

showed that users must have been able to tolerate the weaknesses of each type in many industrial and power plant applications. However, selection of either type required compromises.

While both types had advantages that made them suitable for many services, the following features are principal disadvantages of each type:

- **Conventional Wedge Gate Valves** have a bad reputation for sticking in the closed position. Solid wedge gates can bind due to pipe loading reactions or due to thermal effects (e. g., body contraction due to cooldown after closure with hot fluid). Also, low or high pressure leakage can develop if pipe load reactions or thermal effects create "gaps" between the gate and the body seats.

  Valve designs with one-piece "flexible wedges" (*Figure 3*) clearly offer improved resistance to sticking and leakage, but the necessity of meeting acceptable stress criteria in high pressure Valves imposes a serious limitation; one-piece wedges designed for high pressures tend to be rigid, regardless of shape.

  A problem with many traditional wedge gate valves is that the gate guides, which must support loads on the gate before seating, are often too weak to support high differential pressure loads. Some are too short to support overhung loads encountered when a gate closes under blowdown conditions, and some have excessive clearances that will not provide a smooth transition of loads between the guides and seats. These features are not a concern in valves operated at low differential pressures using bypasses, but these characteristics can produce problems in operation under high differential flowing conditions.

- **Parallel-Slide Gate Valves** (*Figure 4*) have the fundamental disadvantage that the gate and body seating surfaces are in continuous contact over the full travel of the valve, from open to closed. Thus, the seating surfaces are also the guiding surfaces, and any scratches or gouges that result from wear are a source of leakage when the valve is closed.

  Since most such valves in fossil-fueled plants were normally operated with very low differential pressures (using a bypass), this characteristic usually resulted in only minor scratches; however, some users indicate that parallel-slide gate valves require more frequent seat refinishing than wedge gate valves.

  The continuous sliding of seating surfaces is a more serious concern in valves that must operate at very high differential pressures (such as safety-related MOVS, MSIVs and MFIVs in nuclear power plants). Since the high differential conditions may not be encountered in normal operation, the problem might hot be evident until a design basis event requires a safety-related valve operation. With very high contact stresses at gate-to-seat interfaces, wear damage may result in galling that can cause large leak paths and possibly even prevent full valve travel.

  Another limitation of conventional parallel-slide valves is that seat loading is often inadequate for sealing at low differential pressures. Valves that use only springs to assist the pressure load on the gate have very low seat contact, stresses at low pressure and

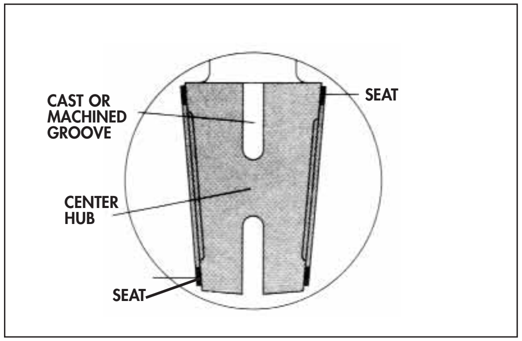

Figure 3: Flexible Wedge Gate Valve

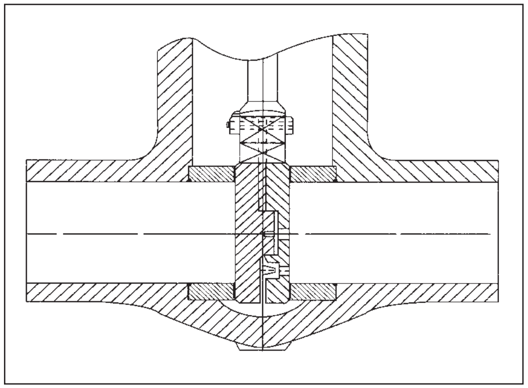

Figure 4: Parallel Slide Gate Valve

are notoriously poor in sealing under such conditions. Some valves employ internal wedge mechanisms to impart additional loading in the closed position, but this requires additional complexity; generally, they employ large wedge angles that provide loading only so long as stem load is maintained.

Edward Equiwedge Gate Valve Features

The Edward Equiwedge concept development "borrowed" the best feature of normal parallel-slide valves two separate gates (*Figure 5*) that permit better inherent flexibility and freedom of each gate to align properly with its companion body seat. However, by using the traditional wedge seat arrangement in the valve body, the Equiwedge has a major advantage in low pressure seat sealing.

The most important advantage of the Equiwedge gate valve over conventional wedge gate valves and any parallel-slide gate valve is in its gate guiding system. While some parallel-slide valves employ supplementary gate guides to minimize cocking, most depend primarily on a varying contact pattern between the gates and seats to maintain gate alignment. Wedge gate valves require separate guide systems, but studies of prior designs revealed that there are five key factors in wedge gate valves guide system design, as listed in Table 2.

It was recognized that these factors had a major bearing on the successful operation of a wedge gate valve with reasonable and predictable operating forces, particularly under high differential pressure conditions. The designers of the Equiwedge addressed all five factors and evolved a design with strong guide rails on each gate half, engaging rugged guide grooves

Figure 5: Flexible Equiwedge Gate

Figure 6: Equiwedge Guiding System

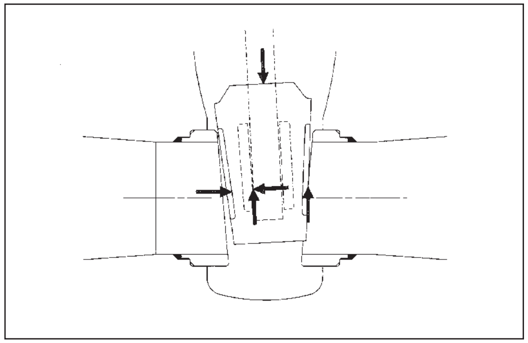

Figure 7: Gate Jamming Due To Guide Distortion

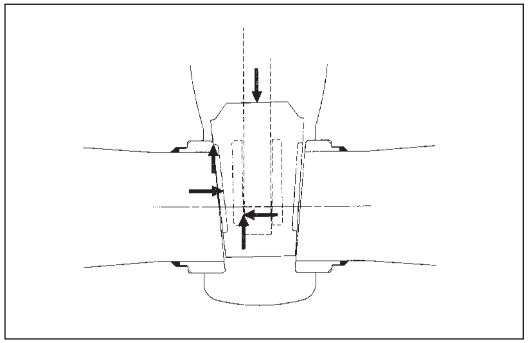

Figure 8: Gate Jamming Due To Upstream Hooking

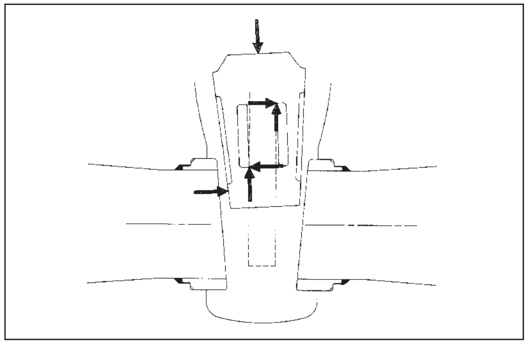

Figure 9: Gate Jamming Due To Overhung Loads

at each side of the valve body (*Figure 6*). On opening or closing, there is relative sliding motion between the gate and body seating surfaces for only a very small portion of the valve travel. Outside this range, all sliding motion occurs between the hard-faced surfaces on the gate rails and the guide groove in the valve body,

Unlike many conventional wedge gate valves, the guide surfaces in Equiwedge gate valves are designed (and test-proven) to support high differential pressure load, even when the valve is not seated. Further, the strength and geometric arrangement of the guide system assures a smooth sliding transition of gate loads from the body grooves to the seat on closing and from the seat to the body grooves on opening. Significantly, even if wear or scratching occurs on these surfaces, there is no adverse effect on seat sealing. *Figures 7, 8* and *9* illustrate serious jamming problems that can develop in wedge gate valves with inadequate guiding systems.

Equiwedge Gate Valve Qualification Tests And Experience

Substantial testing was done before the Edward Equiwedge gate valve product line was introduced in 1975. The initial test programs[3] clearly demonstrated that Equiwedge gate valves overcame the primary disadvantage attributed to prior wedge gate valves. Rigorous tests showed that these valves do not "stick" in the closed position; they require an opening force to "unwedge" the gates, but this force is predictable and within the capabilities of valve actuators sized for closing (this wedging action is an advantage, because, once the valve is closed, sustained stem load is not essential for seat sealing). The testing program also clearly demonstrated that Equiwedge gate valves provide *excellent seat sealing at both low and high differential pressures*.

In addition, demanding flow tests were conducted with water at pipe flow velocities well above the normal operating range. These tests showed very *stable flow performance with freedom from flow induced vibration*. The fully-open gate assembly has clearances in the guiding system, but there was no evidence of any excitation or "rattling" due to fluid flow.

While the initial Equiwedge qualification program was very complete, it was recognized that further testing was necessary before these valves could be offered with the confidence necessary for safety-related nuclear applications. First, since a very large portion of the thrust required to open or close a gate valve is frictional, it was necessary to have friction coefficient values that could be used with confidence for actuator sizing.

Use of a "valve factor" suggested by an actuator manufacturer was not considered to offer the necessary reliability. Since published data on friction coefficients of various valve trim materials in hot water and steam environments were inadequate when the Edward Equiwedge gate valve was developed, a friction test program was undertaken to develop an independent database[4]. A special test fixture was designed, permitting "slider bar" *friction tests* in a pressure vessel in hot pressurized water and in saturated steam *at temperatures to 550°F*.

Hundreds of material couple samples were tested to evaluate materials for various valve seating and guiding applications at contact stresses to 15,000 lb/in^2. This testing permitted combinations with serious galling tendencies to be "weeded out," and numerous "repeat tests" were conducted with successful combinations to assure consistent results. Since even the best of friction coefficient data have significant scatter, a statistical analysis was required to develop the proper coefficients for use in actuator sizing calculations. The test program led to the use of *stellite 21 hardfacing on all gate and body seating and guiding surfaces* in Equiwedge gate valves with high flow, high differential pressure operating requirements in nuclear safety-related applications (the combination is standard in all stainless steel valves, regardless of the application).

Special Equiwedge Qualification Tests For Nuclear (MSIV And MFIV) Applications

After the Equiwedge design and laboratory friction tests were complete, it remained necessary to prove that the combination would work in an actual valve under high differential operating conditions. Before quoting these valves for safety-related nuclear applications, a size 16 valve with a prototype Edward linear MSIV actuator[5] was subjected to flow interruption tests starting in 1977. Since Edward had supplied special balanced Flite-Flow MSIVs for

BWRs and PWRS, there was a natural interest in exploring applicability of Equiwedge gate valves in this market niche.

In extensive testing[4], the size 16 valve was closed repeatedly under "blowdown" conditions, typically in from three to five seconds, discharging air from a 300 ft3, 1500 psi reservoir. Instrumentation showed that *the stem thrust required for closing was consistently within calculated predictions* based on valve dimensions and friction coefficient data (friction testing of the selected valve trim materials had previously proven that valve testing with air was comparable to testing with steam). Seat leakage tests with air after numerous valve closures at high differential pressure gave excellent results at both high and low pressure (6.5 SCFH at 1500 psi, less than 0. 2 SCFH at under 100 psig – essentially negligible air leakage in a large metal-seated valve); seating surfaces showed negligible damage, proving that the Equiwedge gate guiding system performed as designed.

The successful testing of the size 16 prototype MSIV led to initial acceptance of the Edward Equiwedge gate valve and stored energy actuator for use as main steam and feedwater valve applications in many of the nuclear plants listed in Table 1. Nevertheless, the increased concern for valve safety and reliability that emerged in the early 1980s led to the demand for additional testing – on a full scale MSIV. In the 1980-1982 time period, a size 28x24x28 MSIV was subjected to two flow interruption test programs. This valve was closed repeatedly under blowdown conditions discharging air from a reservoir that had been expanded to over 900 ft3. In this program[6], *the valve demonstrated consistently successful operation* with shut-off differential pressures up to 1180 psig, even while subjected to simulated line-break pipe loading and seismic loads. Again, required actuator force was within calculated predictions.

A second full-scale Equiwedge gate valve test program was conducted in France[7] on the first size 30x24x30 MSIV constructed for 1300 megawatt Electricite de France PWR plants. These tests did not involve flow interruption testing, but they included hot functional tests (including thermal transients) that demonstrated smooth opening and closing operation through 600 full-stroke cycles and 400 exercise cycles. As in previous Equiwedge tests in the U.S., there was no evidence of valve "sticking" in the closed position. The tests in France also included static loading, seismic and resonant frequency search testing that provided further assurance of safe valve operation under extreme conditions.

Equiwedge MOV Qualification

The initial Edward interest in applying Equiwedge gate valves in safety-related nuclear service was in MSIVs and MFIVS, because this had been an Edward niche. Since Edward did not offer its older gate valve design for nuclear applications, the Edward participation in the MOV market was primarily with globe valves. Nevertheless, the success of the Equiwedge design in MSIV qualification stirred interest in using these valves with electric motor

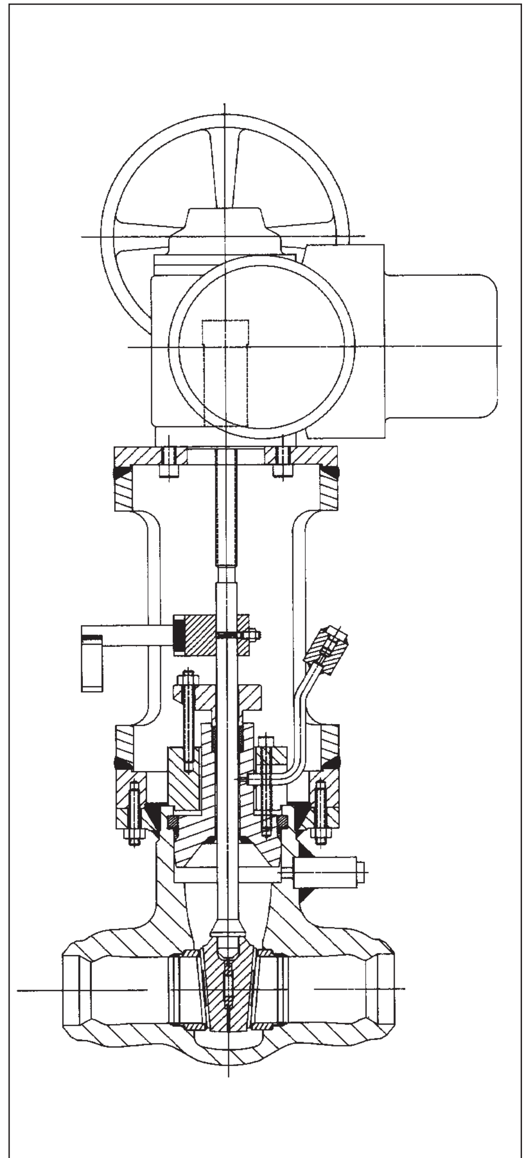

Figure 10: Cross-Section Of Palisades PORV Block Valve

actuators. Of course, Equiwedge gate valves had been used with motor actuators in fossil-fueled plants from the time the product line was introduced, so there was good commercial MOV experience to draw upon.

The application of a gate valve as an MOV involves one subtle difference from applications with linear actuators like those used with MSIVS. In the MOV, the stem thread friction torque must be reacted somewhere to produce linear stem motion. In the Equiwedge gate valve, the torque reaction is internal, and analyses and tests show that the effect is minimal with proper gate guide system geometry. Equiwedge gate valves have shown excellent performance in tests simulating requirements for block valves for power operated relief valves (PORVs).

The PORV block valve application is quite similar to the MSIV application, except that the block valves are smaller and the PWR primary system block valves must operate at up to 2500 psi differential pressure as compared to about 1000-1200 psi for a BWR or PWR MSIV. A standard size 3 Equiwedge gate valve (except for hard-faced body guide grooves) was subjected to PORV block valve simulation tests (sponsored by EPRI) at the Duke Power Marshall Steam Station in 1980, and results were quite successful[8]. Following those tests, special size 3 PORV block valves were furnished for Duke Power Catawba Units 1 and 2. In addition, a special size 4 Edward Equiwedge PORV block valve was built, qualified[9] and supplied for the Consumers Power Palisades Nuclear Plant.

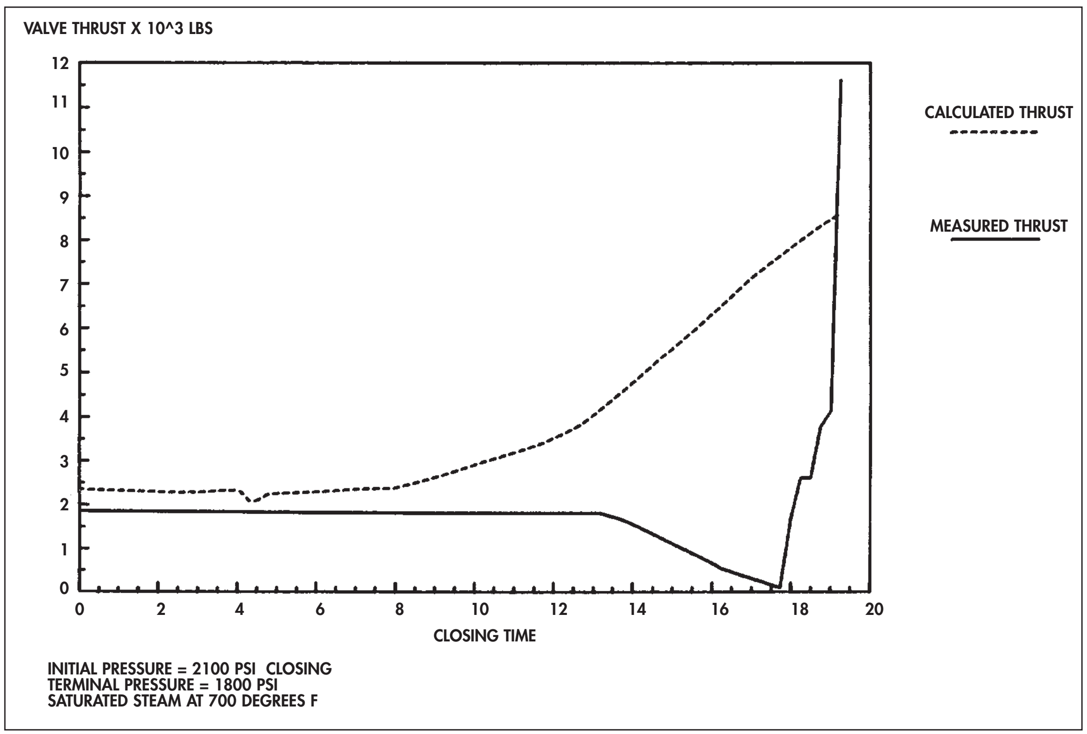

Figure 11: Closing Forces Versus Time For PORV Block Valve

The Palisades PORV block valve, *Figure 10*, was subsequently required to be subjected to proof testing on steam, and it operated successfully in blowdown tests at Wyle Laboratories (Norco, CA) in 1989[10]; stem thrust measurements showed that the required closing force was within the bounds of Edward calculations. *Figure 11* illustrates a plot of actual measured closing force versus time in one of the Wyle tests, compared to a calculation based on Edward friction data. The required force during much of the valve travel was much less than the calculated force due to dynamic effects that cannot be relied upon to assist in the final closure of a gate valve, but the required force to complete closure compares favorably with the calculation. The valve closed fully and sealed off tightly with a satisfactory closing force margin.

Knowledge developed in recent years has shown that electric motor actuator sizing and torque switch settings require consideration of rate-of-loading and similar effects, but the basic Equiwedge gate valve design that was well-qualified for MSIV and MFIV applications has been proven reliable for

TABLE 1
EDWARD EQUIWEDGE MSIV, MFIV AND SIMILAR APPLICATIONS IN NUCLEAR POWER PLANTS

Valve Size	Pressure Class	Plant	Country	Startup Year	Quantity
28x24x28	900	Vogtle 1	USA	1987	8
		Vogtle 2	USA	1989	8
18x16x18	2500	Superphenix	France	1983	8
30x24x30	900	Cattenom1	France	1987	4
		Cattenom 2	France	1987	4
		Cattenom 3	France	1989	4
		Cattenom 4	France	1991	4
		Belleville 1	France	1988	4
		Belleville 2	France	1988	4
		Nogent 1	France	1989	4
		Nogent 2	France	1990	4
		Penly 1	France	1990	4
		Penly 2	France	1992	4
		Golfech 1	France	1990	4
		Golfech 2	France	1993	4
		Chooz 1	France	1991	4
		Seabrook 1	USA	1990	4
		Seabrook 2	USA	1992	4
32x24x32	900	Quangdong	China	1992	6
8x6x8	2500	Superphenix	France	1983	4
20	2500	Superphenix	France	1983	4
18x14x18	900	Paks 1	Hungary	1983	9
		Paks 2	Hungary	1984	9
		Paks 3	Hungary	1986	9
		Paks 4	Hungary	1987	9
16x14x16	900	Kori 2	Korea	1983	2
		Kori 3	Korea	1984	3
		Kori 4	Korea	1986	3
		Yonggwang l	Korea	1987	3
		Yonggwang 2	Korea	1982	3
16x14x16	900	KRSKO	Yugoslavia	1982	2
		Phillipines 1	Phillipines	Indef.	2
24	600	Bruce A	Canada	1986	4
		Bruce B	Canada	1987	4
18x14x18	900	Mochovce	Czechoslovakia	1990	12

TABLE 2
KEY FACTORS IN WEDGE GATE VALVE GUIDE SYSTEM DESIGNS

1. **Guide Strength –** Where a high differential pressure exists across the gate when it is not in contact with the body seats, the guides must support the full differential pressure load.
2. **Gate Strength –** When all of the differential pressure reaction loads are on the guides, the gate becomes a simply supported beam.
3. **Guide Precision –** The precision of the guide system determines how the gate breaks and makes contact wit the seats during opening and closing.
4. **Guide Length –** The length of the guides and the elimination of "overhanging loads" is important to avoid gate cocking and "locking" in the guides.
5. **Guide Surface Materials –** The friction coefficient developed between these surfaces in a hostile fluid environment affects operating forces, and indentation under high localized load may lead to jamming.

NOTE. Parallel-slide gate valves depend on seating surfaces to provide most of these critical functions.

MOV applications as well. The PORV block valve tests were considered as "confirmatory" to Edward engineers who had been involved with previous Equiwedge gate valve tests in the U.S. and France.

Summary And Conclusions

Conventional wedge gate valves, while time-proven for fossil-fueled plant applications, have been found inadequate for many critical safety-related MOV services in nuclear facilities. Unlike fossil-fueled services, where these valves are generally cycled under low differential pressures, these nuclear applications require reliable operation with high differential pressure. This change required new answers from the valve manufacturing industry, and Equiwedge is Edward's answer.

In addition to the results of the test programs described in this report and in the references, field experience with Equiwedge gate valves has been excellent. After well over a decade of service in both fossil-fueled and nuclear power plants, Edward Equiwedge gate valves have earned an excellent reputation for trouble-free performances.

Edward spent most of the 1970s evaluating gate valve design options and proving the performance of the Equiwedge valve design before offering it for nuclear service. Although much of the U.S. nuclear plant construction was already committed to other products, nuclear plant construction continued in other parts of the world, and the Equiwedge design has become widely accepted for critical MSIV and MFIV applications. Equiwedge has developed a solid track record, including tests in safety-related MOV applications.

As a result, Edward can offer an existing product to meet the challenge of NRC Generic Letter 89-10. With Equiwedge, nuclear plant engineers can replace questionable safety-related MOVS, within the required compliance period, with a product already proven and qualified to satisfy the most demanding requirements.

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FLOWSERVE CORPORATION
FLOW CONTROL DIVISION
Edward Valves
1900 South Saunders Street
Raleigh, NC 27603 USA

Toll- Free Telephone Service
(U. S. and Canada)
Day: 1-800-225-6989

After Hours Customer Service
1-800-543-3927

US Sales Offices
Phone: 919-832-0525
Facsimile: 919-831-3369
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