FLOWSERVE

Edward Valves

Edward Valves

Quick-Closing Isolation Valves – The Equiwedge™ Alternative

V-Rep 78-4

Quick-Closing Isolation Valves–The Equiwedge™ Alternative

by
E. A. Bake
Manager, Development Engineering, Flow Control Division
and
R. L. Clapper
Development Engineer, Flow Control Division
Rockwell International
First Published 1978

Background

Over the last two decades, nuclear power plants have become important contributors to the power requirements of the United States and other countries worldwide. These plants have an excellent record from the standpoint of safety. Nevertheless, there has been increasing concern for safety in the event of unlikely, but credible, accidents. One such potential accident–the rupture of a main steam or feedwater line–has led to demand for large, quick-closing isolation valves. The requirements for these valves have presented a challenge to the valve industry, and the Flow Control Division of Rockwell International has been a leader in meeting this challenge. As a result of continuous development related to these difficult applications, Rockwell Equiwedge gate valves are now available as an alternative to other valves offered for this service. *Figure1* illustrates a typical valve of this type with its stored-energy actuator.

The design, performance and reliability requirements for these quick-closing valves have changed steadily to meet developing needs. No single valve/actuator combination will satisfy the requirements for all types of nuclear reactors and power plant arrangements. Consequently, it is necessary to consider the merits of a number of types.

Uni-directional Valves

Initial quick-closing valves for Boiler Water Reactor (BWR) main steam line isolation were required to close with flow in only one direction (from the reactor toward the turbine). While the problems faced in developing required closure speed and reliability for large valves of this type were not minor, they were overcome with relatively simple balanced globe valves using "air-spring" actuators. Using a balanced main disk controlled by a relatively small pilot disk and stem, these valves can be opened or closed with actuators having a fraction of the force output required by conventional valves. Air-spring actuators combine assemblies of coil springs, arranged to close the valve, with a pneumatic cylinder to open the valve and compress the springs. An essential feature of these actuators is a hydraulic cylinder in tandem with the pneumatic cylinder to assure consistent speed control.

Bi-directional Valves

While the relatively simple unidirectional globe valves have been suitable for some Pressurized Water Reactor (PWR) plant arrangements, most PWR applications have required capability for closure in the event of line rupture on either side of the valve-with flow in either direction. Variations of the balanced globe valve were developed, enabling such valves to close with flow in either direction; such bidirectional valves found wide acceptance in PWR plants, but it was soon found that the combination of operating force requirements [1][1] and tougher seismic design requirements made bidirectional globe valves with air-spring actuators larger and more costly than unidirectional valves.

Later development of stored energy actuators, using compressed gas instead of coil

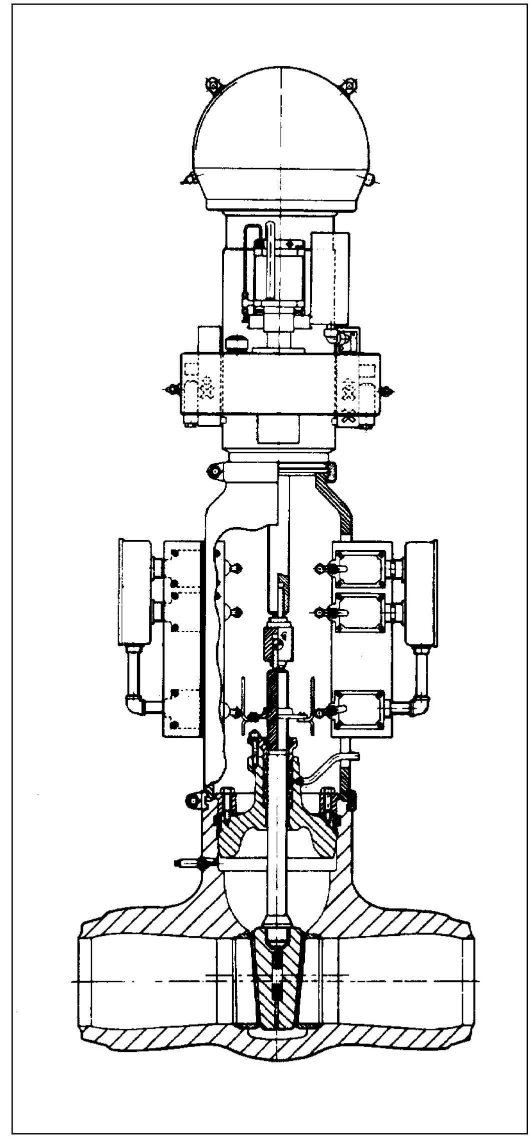

Figure1: Cross-sectional drawing of the Rockwell Equiwedge gate valve with Type A actuator.

[1] Numbers in brackets designate references listed at end of paper.

springs to provide closing force [2], permitted major reduction in size and cost of large bidirectional valves. Such valve/actuator combinations remain attractive for many applications, but Rockwell engineers have continued to search for more desirable alternatives.

Changes in fundamental valve design required careful consideration, because Rockwell had invested considerable engineering effort in development and qualification of balanced globe valves and actuators. The test log on full scale valves included flow tests, hot functional tests, flow interruption tests and seismic tests. This was in addition to tests of smaller scale models and prototypes. The production experience in shipping more than 300 quick-closing balanced globe valves for main steam and feedwater isolation applications was not taken lightly. Nevertheless, the maturation of the Rockwell Equiwedge gate valve provided a recognized opportunity.

The Equiwedge Alternative

The Equiwedge gate valve was developed initially for conventional applications in both fossil and nuclear power plants [3]. However, from the beginning, suitability for safety-related nuclear applications was in mind. While basic valve designs were guided by ANSI B16.34, requirements of Section III of the ASME Boiler and Pressure Vessel Code and relevant code cases were followed closely.

The gate valve was recognized as having several significant advantages over the globe valve, but there were some challenges as well. A balanced engineering program was undertaken to take advantage of the strong points of the gate valve while assuring that all questions concerning safety and reliability were answered.

Gate Valve Advantages

The foremost advantage of the gate valve over the globe valve, long recognized for normal applications, is that the gate valve offers less pressure drop at normal flow conditions. While Rockwell research on globe valve flow passage designs led to flow optimization in balanced globe valves, similar flow research led to even better flow characteristics in Equiwedge valves. The low pressure drop feature of the gate valve may be exploited by users to reduce pumping power and increase cycle efficiency or, if desired, it may be applied to reduce capital investment by using a smaller nominal valve size (a venturi valve). A second advantage to the user following the later approach is that reduced valve size and weight simplify piping arrangement and support problems.

While it may seem obvious, the symmetry of a gate valve must be mentioned as an advantage in applications requiring bidirectional shutoff and seat tightness. A gate valve offers the same performance and seat tightness with flow and differential pressure in, either direction. While bidirectional globe valves can close with either direction of flow, such valves have different tightnesses depending on the direction of differential pressure after closure.

Gate Valve Challenges

Like many things in nature, gate valves present challenges which, unless properly addressed, may offset their advantages. These challenges were the basis for the design of the Equiwedge gate valve. Two historical complaints against gate valves were foremost in the planning of the design and prototype testing program: first, the valve should not stick in the closed position; and second, the seats should not be damage by excessive sliding under high differential pressure loading.

Rockwell engineers were not the first to face these challenges, and a review of old literature reveals that many different "answers" have been developed to the same basic questions. All have been compromises to one degree or another. Parallel slide valves offer freedom from sticking at the expense of substantial exposure of seating surfaces to damage from sliding under high loading. At the other extreme, solid wedge valves minimize sliding of seating surfaces at the risk of wedge-action sticking. The Equiwedge employs a highly flexible dual-wedge gate construction to obtain the best features of both valve types.

Rockwell Equiwedge Gate Valve – An Update

The development program which led to the introduction of the Rockwell Equiwedge gate valve has been described previously [3]. However, additional prototype tests, not previously reported, were conducted to confirm resistance against wedge sticking during thermal transient tests from as high as 1000°F (540°C). Valve performance was satisfactory throughout thermal shock tests which exposed valve seats to a 550°F (290°C) temperature differential in 25 seconds. In these tests, valve opening force never exceeded the design value; it was never more than 95% of the design force and it averaged considerably less. These additional tests add to the confidence that the Equiwedge is resistant to wedge sticking under conditions equal to, or worse than, the most severe conditions expected in service.

Production Start-up

The introduction program for Equiwedge involved usual incubation problems of transferring a successful prototype into production, but they were few in number and quickly solved. This step must be recognized as crucial, because some novel valve concepts have failed at this point of development. For this reason, Equiwedge was withheld from critical-service nuclear applications until teething problems with standard valves were solved.

One area notable for a lack of start-up problems was body casting quality; from the earliest castings produced, records show a high quality level with minimum requirements for upgrading. This experience verifies both Rockwell directional solidification casting theories and the value of "Body by Computer" design methods [4]. Pattern and core box contours are determined from requirements for: (1) flow contours and space needs to clear moving parts at inside surfaces; (2) minimum wall thickness; and (3) uniform wall thickness taper from thinner sections to gate and riser locations. Computer output is converted, by use of a plotter, directly to the core box and pattern templates. Results of this program have satisfied the most critical skeptics: Equiwedge castings have met tight QA standards with much less upgrading than normally required. This quality is important in minimizing schedule delays attributable to casting repair. This increases confidence in our ability to assure on-time delivery.

Seat tightness is a second area where production experience confirmed the Equiwedge design. Tests of actual production valves revealed seat-seal tightness equal to or better than experienced in prototype tests. Special seat tests were conducted on early production valves to verify sealing integrity before delivery to customers; tests using both gas and water produced excellent sealing performance.

Production Valve Proof Tests

As usual with new Rockwell valves, the Valve Engineering & Research laboratory in Pittsburgh received one of the earliest production Equiwedge gate valves for test and evaluation. A size 16 (400 mm), Class 1500 valve was obtained from the manufacturing plant in Raleigh for thorough shakedown tests – torture tests designed to assure that any deficiencies would be uncovered in our laboratory rather than in a customer's plant.

The valve was exposed to over 900 cycles at 3750 psig (266 bar) using room-temperature water. Leakage and torque checks were made at appropriate intervals. Throughout these tests, the valve operated freely with no evidence of binding. Operating torque was consistently within the design range, and there was no significant degradation of seat sealing.

Subsequently, the valve and an associated piping system were connected to the laboratory test boiler (*Figure 2*) and subjected to steam testing at temperatures over 600°F (315°C). The valve was cycled over 130 times using steam, and hot leakage tests were conducted at 50 and 100 cycles. As in the room-temperature tests, operating torque and seat tightness were quite satisfactory.

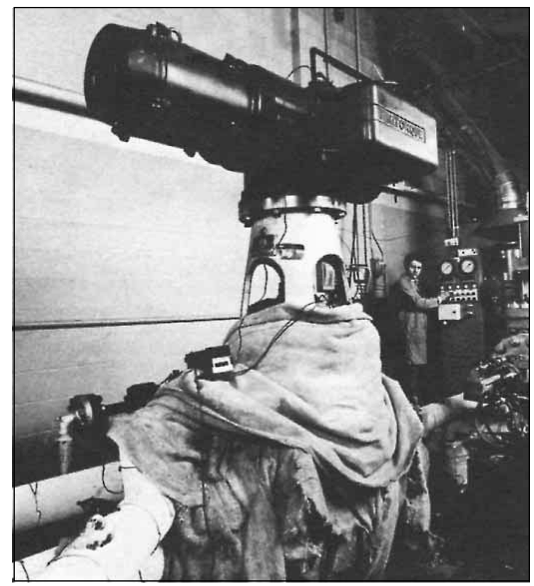

Figure 2: A size 16 (400 mm) Class 1500 Equiwedge valve with Limitorque actuator undergoes hot-functional testing at Flow Control Division's Valve Engineering and Research (VER) laboratory.

These tests of the size 16 (400 mm) valves were aimed primarily at proving the integrity of standard valves which may be cycled frequently in feedwater and steam service. The tests, however, also provide confidence in the hot functional performance of Equiwedge valves in safety-related applications in nuclear power plants. The results of these tests are most gratifying because most of them were conducted after the flow interruption tests (described in a following section of this article) with no intermediate refurbishing. Further, the production valve tests were so consistent with prototype data that there was no need to make any production design refinements based on results of these tests.

Development and Analyses for Quick-Closing Nuclear Applications

Before offering the Equiwedge gate valve to the nuclear market, Rockwell undertook a program to analyze the valve in accordance with applicable parts of Section III of the ASME Boiler and Pressure Vessel Code. All parts of the valve essential to proper operation during both normal and accident conditions were scrutinized. A number of size and pressure class combinations were evaluated in detail, and standard design evaluation methods were established for the entire product line.

Nuclear Valve Stress Analyses

When analyzed in accordance with the NB-3500 section of Section III, Equiwedge gate valve bodies proved to meet design rules and allowable stresses at typical design conditions for main steam and feedwater isolation valves (each individual application must be evaluated). In addition, the pressure seal area of the body was analyzed using FINEL (a finite element computer program developed by Rockwell). An example of a computer model for a typical body pressure seal area is shown in *Figure 3*. Loadings imposed on the computer model included design pressure and seismically induced loads.

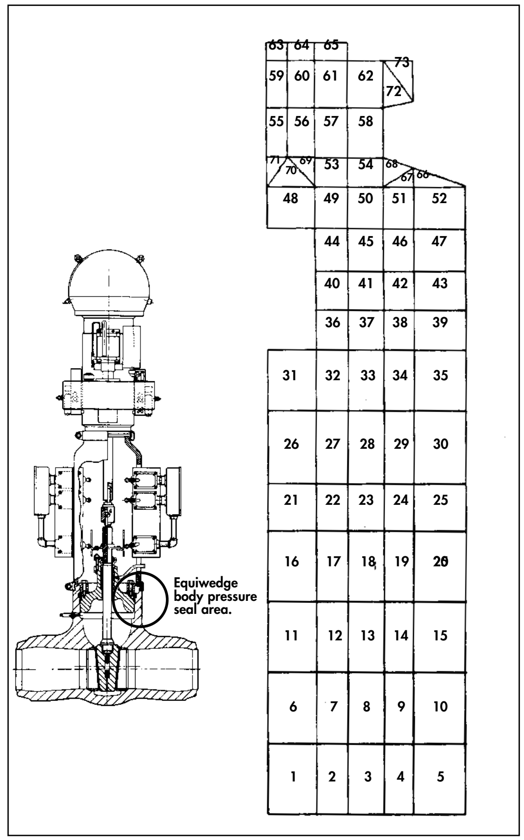

Figure 3: FINEL model of the body pressure seal area for Equiwedge gate valve.

The bonnet of the Equiwedge gate valve is a cast hemispherical type which results in reduced height and weight. The FINEL program was also used to establish stress levels in the bonnet. A typical computer model of the bonnet is shown in *Figure 4*. The stem and seat rings were also analyzed to assure that stress levels were within those allowed by Section III.

The gate used in a quick-closing nuclear valve must, under pipe rupture conditions, withstand high differential pressures during valve closure. Once seated, the gate assembly must hold line pressure and must withstand the stem loading imposed by the stored energy actuator. In order to analyze the effect of these, and other loading conditions encountered during operation, another computer program was established. This program analyzes the various gate loadings, individually and combined, to assure integrity of the gates under all modes of operation.

Friction Coefficients

Even before the first gate stress or operating force calculation was made, it was obvious that accurate friction coefficient data was essential. Frictional forces were secondary in balanced globe valves, so precise data on friction coefficients of rubbing surfaces was not so necessary. When a gate valve closes under high differential pressure, however, friction between the gate and its guide surfaces, or its seats, is the dominant resistant force. Consequently, it is necessary to know, with good statistical confidence, the range of friction coefficient in a gate valve. The maximum likely friction coefficients must be determined for actuator sizing and for conservative calculation of some stresses. The minimum likely coefficient is also necessary for conservative evaluation of other stresses, such as those involved with gate wedging forces.

Literature searches for friction coefficients of suitable materials under relevant environmental conditions revealed such broad scatter that no useful design bases could be identified. About the best that could be concluded was that friction coefficients for most material combinations in hot water and steam environments would be between 0.1 and 1.0 (most of the time). Further, no worthwhile published data was found to cover materials rubbing under the contact stresses inherent in quick-closing gate valve applications. Therefore, it was obvious that a comprehensive friction test research program was necessary to establish design data and to determine the best material combinations for water and steam service at temperatures approaching 600°F (315°C).

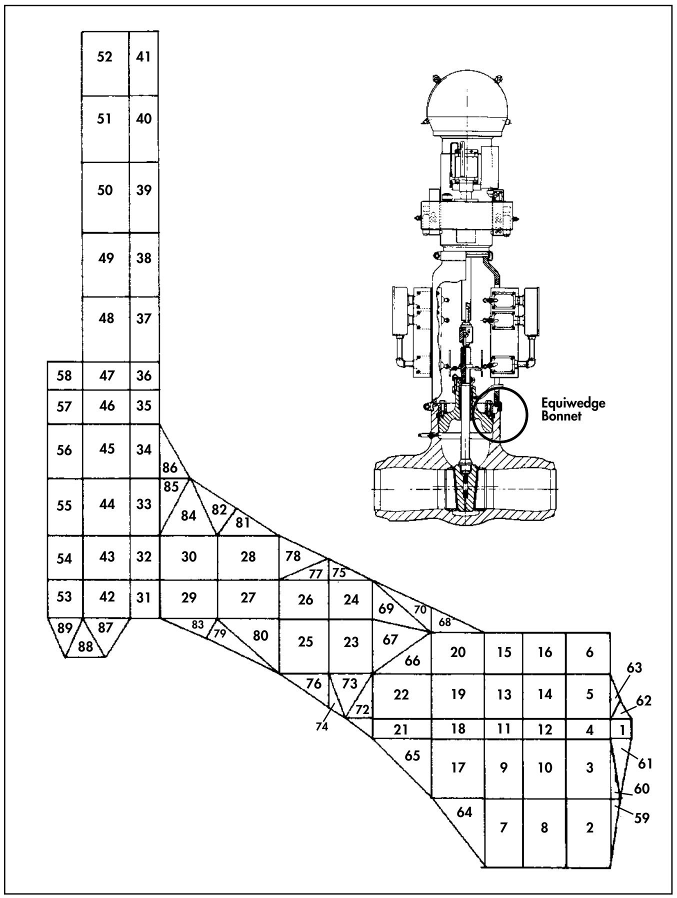

Figure 4: FINEL model of Equiwedge gate valve bonnet.

To evaluate the various material combinations, contact stresses, surface finishes, and environmental conditions, a special test fixture (*Figure 5*) was built and installed in a hot water and steam loop. This fixture is able to apply various normal loads to material samples which are subjected to typical Main Steam and Feedwater Isolation Valve design conditions. Friction coefficient values were established by measuring the force required to slide

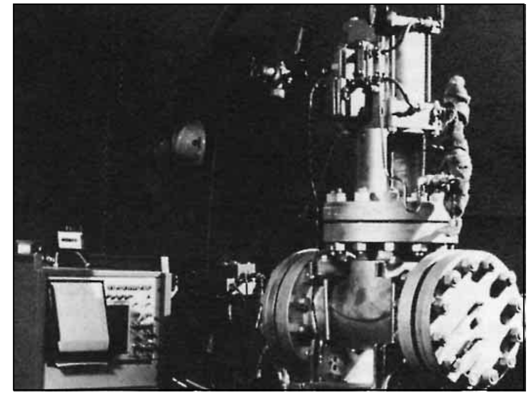

Figure 5: Part of Flow Control Division's VER laboratory is this test equipment to determine friction coefficient.

Three computer programs were developed to digest data from thousands of friction test cycles. One program calculates and tabulates the high and low friction coefficient values for each half-cycle or stroke. The other program generates plots which display the number of times a friction coefficient occurs in a given test. A third program, applied only to the most significant test data, establishes standard deviation and confidence limits.

Cobalt Alloy No. 21 was chosen to be deposited on the gate guide rails, the valve body guide grooves, and all seating surfaces of quick-closing Equiwedge gate valves. This alloy gives the best combination of a low friction coefficient and good wear characteristics. High-confidence friction coefficient design values, which are different for feedwater and steam, were established by the test program for use in stress analyses and actuator sizing.

Quick-Closing Actuators

As mentioned earlier, the first quick-closing isolation valves supplied by Rockwell utilized air-spring actuators on balanced globe valves. As closing pressure differential and seismic conditions in nuclear valve specifications became more stringent, it became difficult to offer air-spring actuators of practical size. Because of this, Rockwell undertook a program to develop gas-hydraulic actuators which offer stored energy in a more compact package.

Gas-Hydraulic Actuator Features

Gas-hydraulic actuators use a stored volume of high pressure gas to duplicate the stored energy function of springs.

The gas pressure acting on top of a piston provides the valve closing force. Hydraulic fluid acting underneath the same piston is used to recompress the gas and to provide force to open the valve. Regulated release of the hydraulic fluid provides essential closing speed control. A basic representation of the gas-hydraulic actuator concept is shown in *Figure 6*.

All gas-hydraulic actuators supplied by Rockwell include two separate manifold control assemblies, each capable of closing a Main Steam or Feedwater Isolation valve Within five seconds. One manifold contains both hydraulic "dump" and pumping circuits while the other manifold contains a redundant hydraulic dump circuit. Each dump circuit contains three basic components:

- A dump valve which, when opened, allows a fast closure of the main isolation valve. The dump valve can be triggered open by either receipt or loss of an electrical signal (depending upon the user's requirements).
- A pressure-compensated flow control valve assures consistent closure times regardless of loading conditions.
- An "exercise" valve which enables testing of the dump valve, actuator and main valve without fast closure of the main valve.

An exercise test cycle is accomplished by first closing the exercise valve which places a small orifice in series with the dump valve. A signal is then received which opens the dump valve, causing the main valve to start closing slowly. When the main valve reaches approximately 90 percent open, a limit switch is activated which closes the dump valve and returns the exercise valve to its normally-open position. The main valve will then return to the fully-open position as full hydraulic pressure is regained.

Air or electrically driven hydraulic pumps are utilized to open the actuator and valve assembly. In addition, in the unlikely event that one of the manifolds were to be torn off the actuator, an orifice in the body of the actuator would limit the closure time to between one-half and one second.

When the decision was made to offer Equiwedge gate valves for Main Steam and Feedwater Isolation valve applications, the gas-hydraulic actuator was the logical choice. Since a gate valve requires three to five times the force required for an equivalent balanced globe valve, the air-spring actuator was deemed impractical.

The Rockwell Type A Actuator

The gas-hydraulic actuators developed for globe valves [2] performed the same functions required for gate valves, but the higher thrust requirements of large gate valves made a different arrangement of parts necessary. While the globe valve actuator has been found suitable for certain smaller gate valves for feedwater lines, the Type A

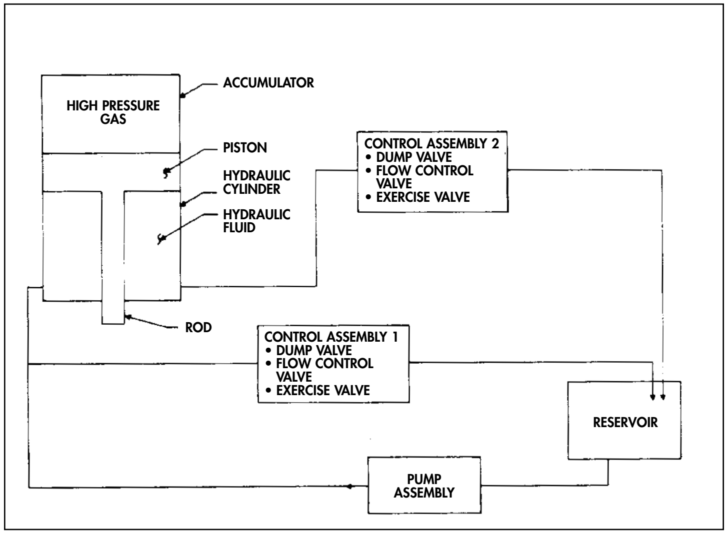

Figure 6: General schematic of gas-hydraulic actuator.

actuator was developed to provide an optional match of actuator size, thrust and weight for large Rockwell Equiwedge gate valves.

The Type A actuator employs features previously qualified for globe valve actuators. The principal difference is that compressed gas–the stored energy to assure closure of the valve–is stored in a compact, essentially spherical, reservoir atop the valve-actuating cylinder. This feature, along with optimization of external manifolds and control components, permits high-thrust actuators to be applied to Rockwell Equiwedge gate valves. The Type A actuator retains the "integral construction" feature of previous Rockwell-qualified actuators–it does not rely on external gas-storage tanks with intervening plumbing to connect the stored-energy gas with the power cylinder.

While the Type A actuator was designed on the basis of previously-qualified principles, a prototype was built to confirm new features. Base line tests confirmed design parameters, and the prototype construction experience produced many ideas with respect to better methods of construction. Later production-design actuators incorporate improvements based on experience gained in the manufacture of the prototype.

Valve-Actuator Combination

In order to mate the Type A actuator (or any other) to the Equiwedge gate valve, it is necessary to design a special yoke which accommodates the new actuator and provides for one or more sets of limit switches. The yoke must be designed to assure that the valve-actuator combination has a natural frequency more than 33 Hz and is strong enough to withstand the high seismic accelerations specified by many nuclear plant constructors.

Valve-Actuator Testing

The basic requirements for proof testing of the Rockwell Equiwedge gate valve and the Type A actuator could have been satisfied by the separate tests of the valve and actuator as described above. However, a demonstration of the combination under actual flow interruption test conditions was scheduled. The prototype Type A actuator was adapted to the size 16 (400 mm) production valve, and the assembly was installed in the air blowdown system at Rockwell's Murrysville Test Station near Pittsburgh.

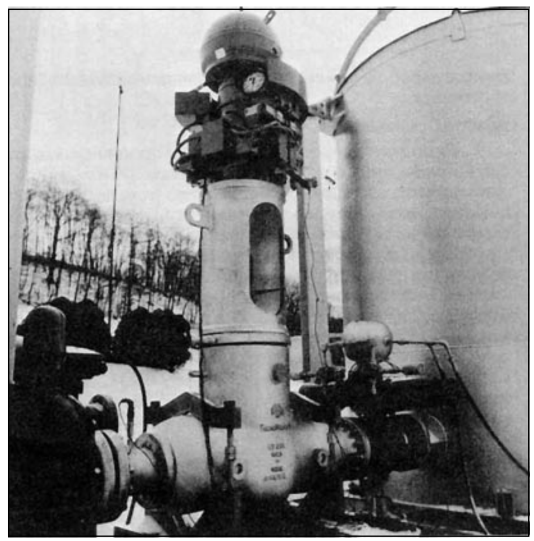

Figure 7: A size 16 (400 mm) Equiwedge gate valve with Type A actuator is readied for blow-down test at Flow Control Division's Murrysville, Pennsylvania test station.

The valve and actuator assembly, as it was installed at the Murrysville Test Station, is shown in *Figure 7*. Tests were conducted with the valve initially open, or partially open, and connected to a 300 ft^3 (8.5 M^3) air storage system pressurized at 1500 psig (103 bar). A downstream Rockwell Hypresphere ball valve is equipped with a quick-opening (<O.5 sec) actuator permitting the system to discharge freely through a muffler, simulating a line rupture. An immediate signal to close the test valve permits demonstration of capability to close under line-rupture conditions. Using this procedure, the size 16 (400 mm) valve was closed repeatedly within three seconds with terminal differential pressures up to 1200 psig (83 bar). *Figure 8* shows the system under free discharge prior to valve closure.

Following the test, the valve was disassembled for inspection prior to resumption of production valve proof tests. Due to the severity of these high differential closure tests, the need for seat refinishing was expected; however, inspection revealed no unusual wear or damage. Consequently, the valve was simply reassembled and the production valve proof tests were resumed. Seat leakage tests after the flow interruption tests revealed no significant deterioration.

Quick-Closing Isolation Valves–The Equiwedge™ Alternative

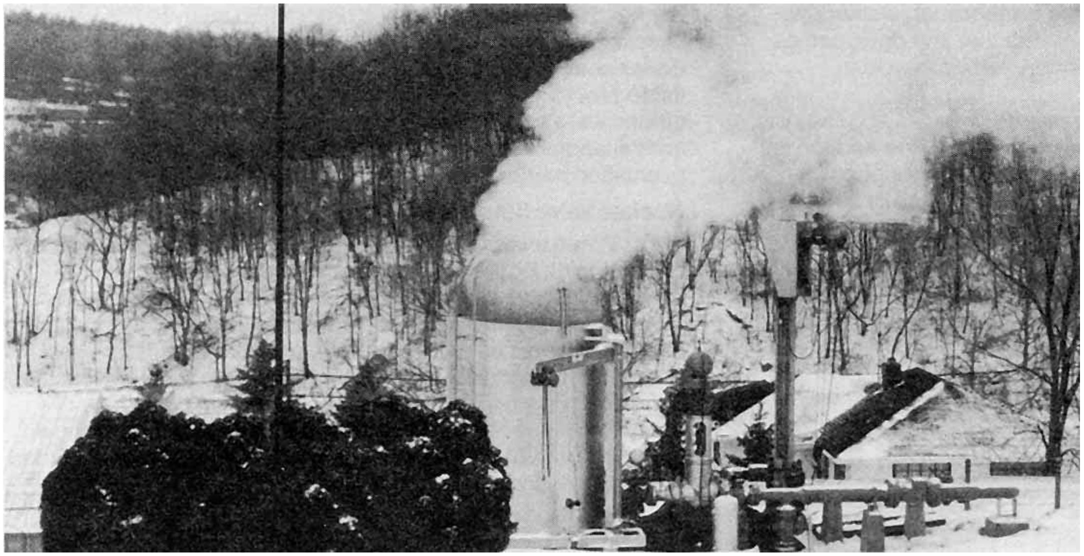

Figure 8: During the blow-down test, the size 16 (400 mm) Equiwedge gate valve closed against 1200 psig (83 bar) air in approximately three seconds.

Summary

The Rockwell Equiwedge gate valve and the Type A actuator development programs have provided a substantial data log supporting performance integrity under conditions expected in power plants. Further, analyses conducted in accordance with ASME Boiler & Pressure Vessel Code, Section III criteria support confidence in the long-term reliability of the valves in nuclear plants. Friction coefficient tests have provided data to size actuators to assure capability of closing Equiwedge valves under the severest line rupture conditions.

This valve development effort combines with work done on stored-energy actuators to assure high-integrity performance of these valves in quick-closing, safety-related applications.

The ultimate value of this work rests in the users' advantages gained from development work by the Flow Control Division of Rockwell International. The Equiwedge gate valves with quick-closing, stored energy actuators offer (1) compact size, (2) low pressure drop, (3) commendable seat tightness in either direction at both low and high differential pressure and, of course, (4) proven excellent reliability in closing quickly under line-rupture conditions.

Acknowledgements

Many people in the Valve Engineering and Research organization contributed to the extensive friction testing, valve testing and actuator development and testing which are summarized briefly in this article. However, special acknowledgement is due L. W Stoltz, who directed the flow interruption test, and P. A. Nye and his laboratory staff who conducted these tests at the Murrysville Test Station.

References

1. E. B. Pool, NUCLEAR MAIN STEAM ISOLATION VALVES, Rockwell Technical Article V Rep 76-3.
2. D. W. Duffey, QUALIFICATION OF A NUCLEAR VALVE ACTUATOR, Rockwell Technical Article V Rep 76-2.
3. R. D. Norden, DEVELOPMENT OF THE ROCKWELL EDWARD EQUIWEDGE GATE VALVE, Rockwell Technical Article V Rep 75-5.
4. J. H. Fowler and T A. Schelat, BODY BY COMPUTER, Rockwell Technical Article V Rep 76-1.

FLOWSERVE

Flowserve Corporation has established industry leadership in the design and manufacture of its products. When properly selected, this Flowserve product is designed to perform its intended function safely during its useful life. However, the purchaser or user of Flowserve products should be aware that Flowserve products might be used in numerous applications under a wide variety of industrial service conditions. Although Flowserve can (and often does) provide general guidelines, it cannot provide specific data and warnings for all possible applications. The purchaser/user must therefore assume the ultimate responsibility for the proper sizing and selection, installation, operation, and maintenance of Flowserve products. The purchaser/user should read and understand the Installation Operation Maintenance (IOM) instructions included with the product, and train its employees and contractors in the safe use of Flowserve products in connection with the specific application.

While the information and specifications contained in this literature are believed to be accurate, they are supplied for informative purposes only and should not be considered certified or as a guarantee of satisfactory results by reliance thereon. Nothing contained herein is to be construed as a warranty or guarantee, express or implied, regarding any matter with respect to this product. Because Flowserve is continually improving and upgrading its product design, the specifications, dimensions and information contained herein are subject to change without notice. Should any question arise concerning these provisions, the purchaser/user should contact Flowserve Corporation at any one of its world-wide operations or offices.

For more information about Flowserve Corporation, contact www.flowserve.com or call USA 1-800-225-6989.

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
Facsimile: 919-831-3376

Visit Our Website
www.edwardvalves.com

 V-Rep 78-4 3/03 Printed in USA