FLOWSERVE

Edward Valves

Edward Valves

The Rockwell Type A Stored Energy Actuator – Development and Qualification

V-Rep 80-3

The Rockwell Type A Stored Energy Actuator – Development and Qualification

by
E. A. Bake
Development
Engineering Manager,
Flow Control Division
Rockwell International
First Published 1980

Abstract

Until about a dozen years ago, the operating time for large (typically size 16-32), power-operated valves in power plants was usually measured in minutes. This posed few problems until safety considerations in nuclear plants changed the required time frame from minutes to seconds. Basic ground rules also changed in that valve operation under emergency conditions often had to be assured even if all normal power supplies suddenly failed. This combination of requirements demanded stored energy actuators that could assure at least one half-cycle of operation (opening or closing a valve) without dependence on external power. In just over a decade, valves and actuators for critical services have traversed several generations of development. With each generation, requirements for performance and reliability have escalated; even more, demands for proof testing or qualification increased at a rate faster than performance requirements in users' specifications.

This article will describe the development of the Rockwell Type A Stored Energy Actuator, a new line of actuators for a broad range of globe and gate valves for critical service applications in nuclear power plant feedwater and steam systems. The program included preliminary testing of a prototype – as well as a thorough qualification test on a representative production actuator. In addition, extensive proof testing of valve/actuator combinations was conducted.

Background

For about twelve years, the Flow Control Division of Rockwell International has been a leading supplier of large, quick-closing valves for main steam and feedwater lines in nuclear power plants. These valves have the safety-related function of closing rapidly (typically 3-5 seconds) in the event of a pipe rupture or any similar major system failure. While closure must be fast, speed must be controlled to prevent excessive fluid pressure surges.

In many valve product lines, a dozen years represents only half of a product life cycle, with a few improvements at intervals to keep the product competitive. In the case of Main Steam Isolation Valves (MSIVs) and Main Feedwater Isolation Valves (MFIVs), changing requirements, competitive pressures and demands for greater reliability have required a continuous engineering and development program. Each new generation of nuclear power plants has brought requirements for new features in valves and valve actuators.

First MSIVs for Boiling Water Reactor (BWR) systems were required to close with flow in only one direction (from reactor toward the turbine). These requirements could be satisfied by fairly simple balanced globe valves that did not require high closing thrusts. Air-spring actuators are sufficient for closing these valves, with spring assemblies to close the valves and pneumatic cylinders to open the valves and compress the springs; hydraulic cylinders in tandem with the pneumatic cylinders assure consistent speed control.

Later, requirements for MSIVs for many Pressurized Water Reactor (PWR) systems included the need for valves to close rapidly and reliably with flow in either direction. Adaptations of the balanced globe valve concept were developed for the new requirements, and many such valves were furnished with air-spring actuators.

However, analyses of operating force requirements [1][1] led to large actuators which presented problems in meeting new and more stringent seismic requirements. Early gas-hydraulic actuators [2] provided major improvements for later-generation balanced globe MSIVs for PWR service.

With the evolution of the Rockwell Equiwedge gate valve [3] and the subsequent development work required to qualify Equiwedge for critical nuclear applications [4], the need for new actuators became obvious. The gate type valve offers advantages in terms of (1) lower pressure drop at normal flows and (2) inherent symmetry in capability to close with flows in either direction. However, as compared to a balanced globe valve, the gate valve requires several times as much thrust from its actuator to assure shutoff at equivalent high differential pressures. From the earliest engineering studies, it was obvious that scale-ups of earliest air-spring and gas-hydraulic actuators would not be practical for large Equiwedge gate valves.

Type A Actuator Features

Closing a large gate valve against differential pressures which could develop in the event of a line rupture in a modern nuclear power plant-within three to five seconds-

---

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

involves delivery of a peak power to the valve stem in the order of 200 horsepower (150 kW). This figure is given to put the problem in perspective. Since valve closure often has to be completed without relying on external power sources, a stored energy system is necessary. After considering the alternatives, the gas-hydraulic concept was chosen as the most practical and reliable. The challenge was to find the most effective means of applying the principle.

The principle seems deceptively simply. A volume of high-pressure gas can be arranged to provide a force on one side of the piston of an actuator to provide a valve closing force. A hydraulic power unit can be arranged to pump fluid to the opposite side of the piston to open the valve; a quick-release hydraulic circuit can release the fluid from the cylinder to a reservoir, permitting the stored energy in the pressurized gas to extend the actuator and close the valve. The principle can be (and has been) applied using readily available commercial accumulators, pumps and hydraulic valves. Applying the principle in a way that satisfies the requirements for reliability and redundancy in a nuclear power plant requires something more.

The first requirement is that the stored energy in the high pressure gas must always be available. Gas stored in remotely mounted accumulators may be unavailable at the time it is needed if leakage occurs in flexible connections between the accumulators and the valve. Even when accumulators are mounted on the valve, connections between accumulators and the actuator cylinder may be subject to leaks and failures. Consequently, the Rockwell Type A actuator concept includes an integral stored gas volume.

Figure 1 illustrates the fundamental construction of the Type A actuator. There is no intermediate hydraulic circuit between the stored energy in the gas volume and the actuator. The gas acts directly on the head of the actuator piston, and the gas storage volume is arranged in an essentially spherical reservoir directly above the piston head. This arrangement assures freedom from leakage from connections between the gas storage space and the actuator, and it absolutely eliminates pressure drop between the gas volume and the actuator during stroking This integral construction feature was a part of earlier Rockwell-qualified gas-hydraulic actuators [2], but it has been enhanced with the spherical reservoirs in Type A actuators.

While actuators are often assembled from commercial pneumatic and hydraulic components, it would be inconsistent to use pressure parts for a valve actuator that are not designed to standards comparable to those applied to the valve which is intimately assembled with the actuator. In particular, gas-containing parts of Rockwell Type A actuators are designed and constructed (and stamped, as applicable) to requirements of Section VIII of the ASME Boiler and Pressure Vessel Code. Hydraulic parts (manifolds, external valves, pumps, etc.) are designed and constructed in accordance with best commercial standards and qualified for nuclear plant service as described in following sections.

The thermodynamic design basis for Rockwell Type A actuators required literature studies and checks against experimental data. Actuator extension (valve closure) is rapid and essentially adiabatic in the stored gas volume. In most applications, actuator retraction (valve opening) is slow enough to be considered essentially isothermal in the stored gas. However, the

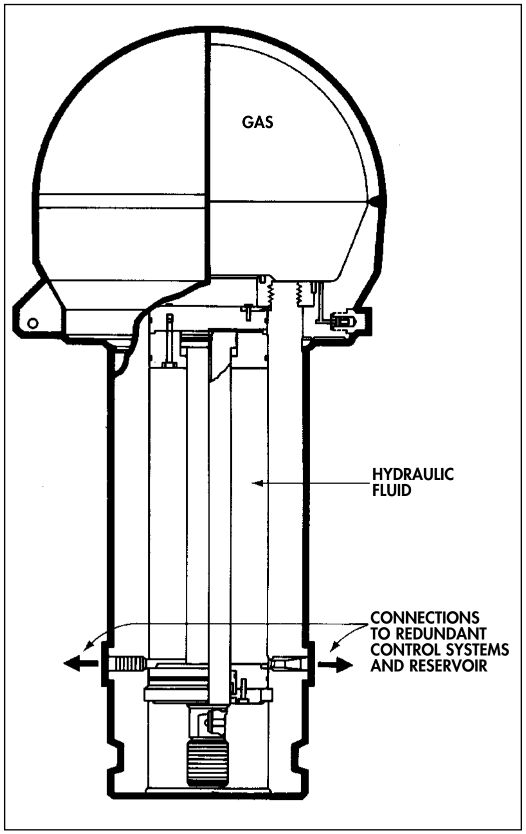

Figure 1: Cross Section of "Typical" Type A Actuator

most practical gas for use in such actuators (nitrogen/GN2) does not behave as a perfect gas at the high pressures involved in efficient stored energy reservoirs (2500 psi/170 bar). Consequently, design of quick-closing actuators involved more than an undergraduate thermodynamics class exercise. It was critical to assure sufficient pressure after a fast extension to be sure that enough thrust was available to assure valve closure. Further consideration was required to the environmental temperatures in typical customer specifications. Safe operation is required at the lowest normal temperatures (when the stored gas pressure is minimum), but pressure boundary stresses must be within Code limits at the highest normal environmental temperature (when gas pressure is maximum).

Redundancy of safety-related equipment is an often misunderstood term. Considering that the retracted Type A actuator is always ready to close a valve, redundancy is applied only to the hydraulic equipment which assures that the actuator will extend (and close the valve) when the appropriate signal is given by the control circuitry.

Redundancy is provided through two separate hydraulic manifolds (mounted on opposite sides of the actuator), containing identical sets of electrical and hydraulic equipment to assure release of hydraulic fluid from the actuator cylinder to the reservoir. *Figure 2* illustrates a typical schematic of control systems.

Valve opening is not normally considered a safety related function for MSIV and FWIV actuators. Accordingly, hydraulic pumps are not normally provided in duplicate, but special variations are considered on application. Most hydraulic pumps are pneumatically-driven, but actuators with electrically powered hydraulic pumps have been provided where no pneumatic power supply was available.

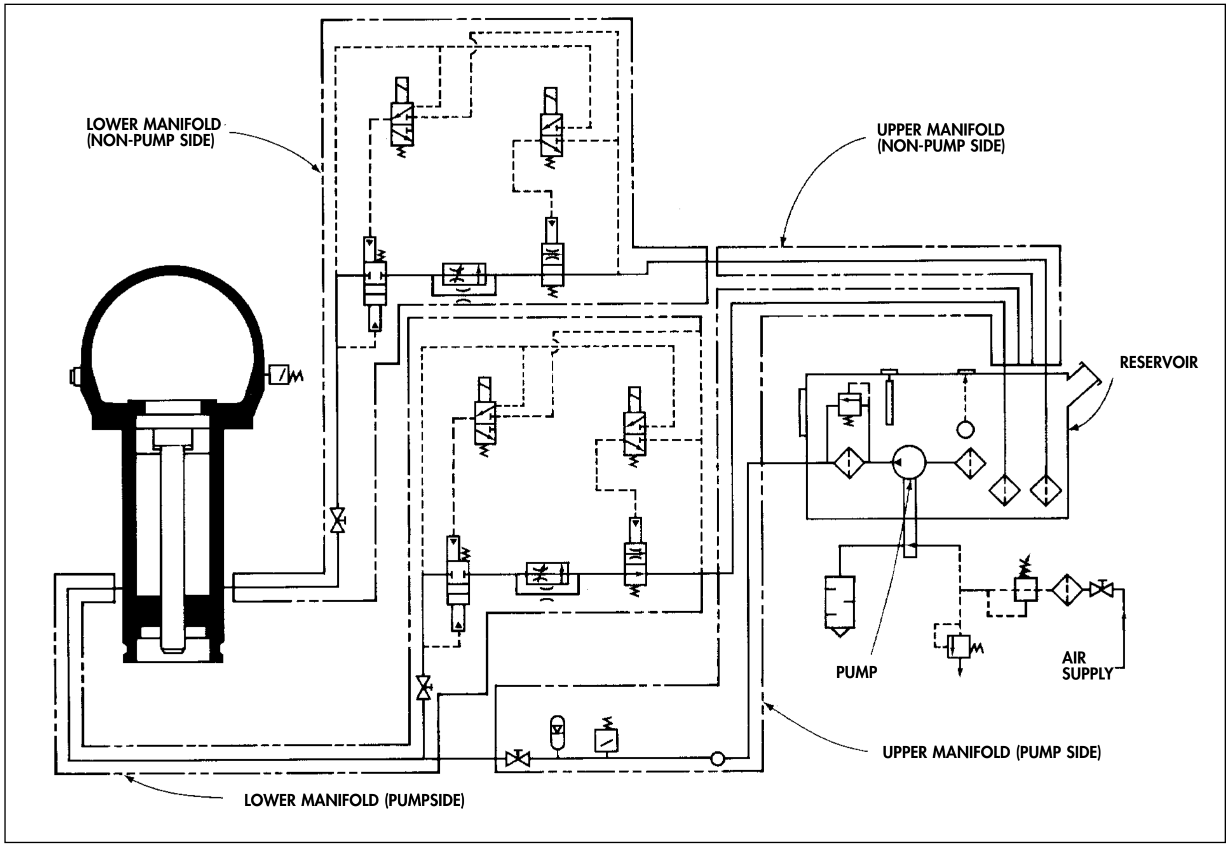

Figure 2: Typical Schematic of Type A Actuator Control System

Table I
Key Attributes A-100 - A-330

		Rockwell Actuator Designation					
Attribute	Units	A-100	A-180	A-230	A-260	A-290	A-330
Closing	lb.	21,000	63,000	90,000	130,000	160,000	205,000
Thrust	(kN)	(93)	(293)	(400)	(578)	(712)	(192)
Travel	in	4.00	7.00	9.00	10.24	11.50	13
	(mm)	(102)	(178)	(229)	(260)	(292)	(330)
Weight	lb.	720	1720	2270	2950	3940	5260
(Mass)	(kg)	(325)	(780)	(1030)	(1340)	(1790)	(2390)
Extension Time	sec.	5	5	5	5	5	5

NOTE: Values tabulated are nominal. For special applications, otherwise standard actuators may be modified for shorter or longer travel with corresponding effects on weight. Environmental temperature range of the application will influence thrust.

Since the specific requirements of different power plant valve application often vary, the control logic for actuators must be flexible. While *Figure 2* is typical, several variations have been developed to suit specific customer requirements. For example, many users ask for a fail-safe arrangement wherein solenoid valves open on loss of power to assure actuator extension and main valve closure. Others, desiring to avoid inadvertent main valve closures, ask for systems requiring a positive power signal to initiate main valve closure. In such cases, the customer must assume a part of the requirement for safety and redundancy by furnishing duplicate external power busses and control circuitry. Since such decisions are often predecided and written into specifications, they are outside Rockwell's direct control. Discussions with individual customers help to provide the best total reliability.

Prototype Construction and Testing

Before the Flow Control Division commitment to the development of Rockwell Type A actuators was made and before the first commercial quotation was submitted, a prototype actuator was designed, constructed and tested. Before the prototype was sized, a study was made of the many specifications which had been received over a span of several years. A specific range of actuator sizes (in term of thrust and travel) was established to suit the expected range required for various Rockwell balanced globe valve and Equiwedge gate valves. While minor changes were made based on specifications received subsequently, basic sizes were well covered by the originally identified range. An A-230 unit was selected for prototyping because it was well matched to a size 16, Class 1500 Equiwedge gate valve which had been selected and built for qualification testing of the basic Rockwell Equiwedge product line. The A-290 prototype actuator was, to be sure, made by Model Shop standards, under close engineering scrutiny; it was not expected to be a representative production item. Still, it was built in accordance with tolerances which were considered reasonable for production actuators.

The prototype A-230 actuator was tested on a laboratory test stand, where it met all design requirements. Subsequently, it was mounted on the aforementioned size 16, Class 1500 Equiwedge gate valve, and a series of flow interruption tests satisfied all known requirements [4].

While the A-230 prototype met expected performance requirements, experience gained through its construction and testing also revealed many high-cost construction details which made no contribution to performance or reliability. Later designs were reconfigured to be more cost-effective and to afford easier maintenance. Perhaps most important to the user, arrangements involving knuckle-busting wrench operations for maintenance of minor parts were identified and corrected by redesign.

Transfer to Production

From the earliest work on prototype actuators, close communications were demanded between development engineers and people with strong manufacturing experience. The decision to offer Type A actuators with Rockwell valves prompted intensified and even closer collaboration. The first step was preparation of a detailed Product Specification/Objective document, which was signed by key Engineering, Marketing and Manufacturing executives. Nominal actuator sizes required (loads, strokes, etc.) were agreed upon. *Table 1* shows the key attributes of the basic Type A actuator sizes.

Following selection of the Raleigh, North Carolina, plant as the Flow Control Division manufacturing base for Type A actuators, close cooperation was established, Monthly engineering meetings were held to resolve open problems and nitty-gritty questions. Out of these meetings came a plan for accelerated production of two actuators of the final design-one smaller and one larger than the A-230 prototype. An A-100 actuator (smallest in the initial line) and an A-290 actuator (next to the largest) were built under close surveillance of both Pittsburgh development engineers and Raleigh engineers who were responsible for later production units. These units were built at Rockwell expense on a schedule sufficiently ahead of production actuator schedules to allow early correction of first-run production problems.

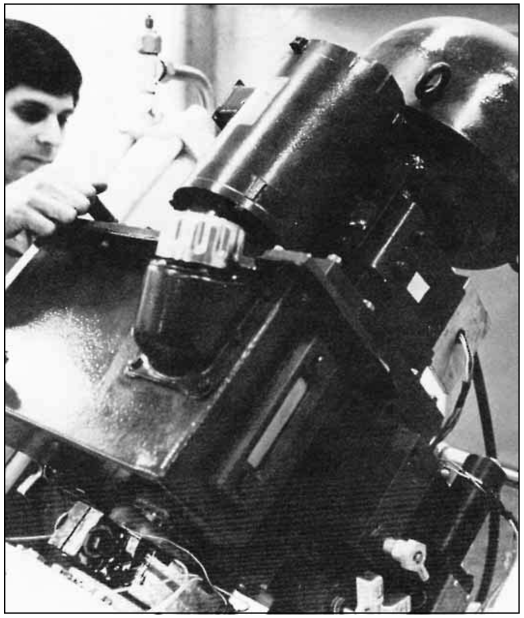

Figure 3: A-100 Actuator

The preproduction A-100 actuator (*Figure 3*), assembled entirely at Raleigh, was subjected to thorough performance testing in the Pittsburgh Valve Engineering and Research (VER) laboratory. Performance met specified requirements, but a number of minor problems (hydraulic system leaks, etc.) were identified and corrected. The first production run of A-100 units then proceeded with few problems.

The first production A-290 actuator was subjected to a similar shakedown test in the VER lab. In this case, problems were few, and feedback to the production A-290 actuators involved few changes. The principal reason for building the early A-290 production actuator was to provide a test specimen for qualification tests described on the following page.

Qualification Testing

Qualification is a word that has been recently used to describe proof testing of new equipment. As applied to safety-related valve actuators, the term is generally related to requirements defined by the Institute of Electrical and Electronic Engineers (IEEE) and the American National Standards Institute (ANSI) in a series of documents based on IEEE-382 (ANSI Draft Standard N41.6). Related standards include IEEE-323 and IEEE-344. These documents, in their most recent editions, provided the basic guidance for the test specification for generic qualification of Rockwell Type A actuators. However, it should be understood that there are many possible levels of qualification, depending on the severity of the various environmental temperature, radiation, seismic and Design Basis Event (DBE) parameters that the supplier elects to use as his standards for qualification. The term “qualified” means very little; the qualification levels are important. For Rockwell Type A actuators, an extensive survey was made of specifications which applied to inquiries which Rockwell had quoted against over several years. Based on this survey, a set of test parameters was selected which enveloped most of the worst case conditions. *Table II* describes the qualification levels.

An A-290 actuator was selected for qualification, because its size and proportions gave the best qualification coverage of the various actuators in the Type A actuator line.

While Rockwell laboratories were equipped to conduct many of the tests in the qualification program, a complete test by an independent laboratory was selected. All tests were supervised by Wyle Laboratories, Huntsville, Alabama. All tests were conducted using facilities at Wyle Laboratories except for radiation exposure tests which were conducted at Georgia Institute of Technology, under the direction of Wyle.

Table II
Qualification Levels

Parameter	Test Condition	Qualified Life
Normal Conditions		
Thermal Exposure	50 hr @ 284°F	10 yr @ 104°F
Cyclic Operation		
Full Stroke	1000	40 yr
Exercise (10% Stroke)	4000	40 yr
Normal Radiation	11.3 Mrad	10 yr./BWR Drywell
External Pressurization Cycles	15 @ 65 psi (4.5 bar)	40 yr.
Faulted Conditions (DBE)		
Radiation Exposure	10.0 Mrad	N/A
Environmental Exposure	See Fig. 6	N/A
Seismic	See Fig. 4	N/A

The intent of the qualification test program was to demonstrate that Rockwell Type A actuators are capable of performing their *safety related function under Design Basis Event (DBE)* conditions, even when the actuators are at *end of life* condition. These terms require further explanation.

- *Safety related function*—for MSIV and FWIV actuators, the safety related function is to close the associated valve, providing the necessary force and stroking within a specified maximum time period.
- *Design Basis Event (DBE)*—A DBE represents an accidental condition in a nuclear power plant under which safety-related equipment must function to assure a safe shutdown. Examples are high radiation exposures, serious earthquakes and environmental conditions resulting from a loss of coolant accident (LOCA) or a main steam line break (MSLB).
- *End-of-Life Condition*—this condition represents the condition of a piece of equipment either at the end of life of a power plant (often set at 40 years) or just prior to the end of an interval of recommended major actuator maintenance.

In order to accomplish this objective, an actuator must be subjected first to a series of accelerated aging tests to put it into an end-of-life condition. For Type A actuators, the test specification was designed to subject metal parts (which should not require replacement) to the wear equivalent of 40 years' operation; for non-metallic parts, such as elastomeric seals, which may be subject to time-oriented deterioration from effects of environmental temperature and radiation, the test specification was designed to simulate expected exposure over the 5-year recommended maintenance cycle (with a substantial margin). A very conservative result from following this procedure was that dynamic non-metallic seals received the wear equivalent of 40 years of service.

Qualification testing also involves conducting baseline tests at the outset of the test program and similar operability tests at intervals in the aging program and following DBE simulations. The baseline and operability tests provide a series of checks to determine whether any degradation in performance has occurred. For Rockwell Type A actuators, the test procedure included demonstration of performance (simulated quick closing of a MSIV or FWIV) using each hydraulic manifold individually and using the two manifolds simultaneously. Tests were conducted using minimum and maximum voltage in the electrical power supply. The baseline and operability tests also demonstrated total performance in normal operation of the actuator (valve opening and exercising).

Briefly, the aging program consisted of:

1) Baseline Test

2) Thermal Aging (with a portion of the wear aging cycles conducted at elevated temperature)

3) Wear Aging

4) Operability Test (comparison with Baseline Test)

5) Radiation Aging

6) Operability Test (comparison with Baseline Test)

7) Normal Pressurization Aging (exposure to external pressure)

8) Operability Test (comparison with Baseline Test)

9) Wear Aging (exposure to vibrations simulating inputs from normal pipeline vibration and excitation from other equipment)

The remaining tests involved the DBE simulations. The first of these involved seismic simulation — exposure to conditions simulating those involved during earthquakes. The critical requirement was to demonstrate performance during a Safe Shutdown Earthquake (SSE). However, this was preceded by exposing the actuator to the equivalent of five Operating Basis Earthquakes (OBEs). As complicated as this may sound, it hardly begins to describe the complexity of this testing. The OBE simulations involved exposure of the actuator to sinusoidal frequency sweep vibrations on a shaker table in each of three orthogonal axes, representing exposures to earthquakes that would be experienced by a nuclear power plant, under which continued operation would be expected.

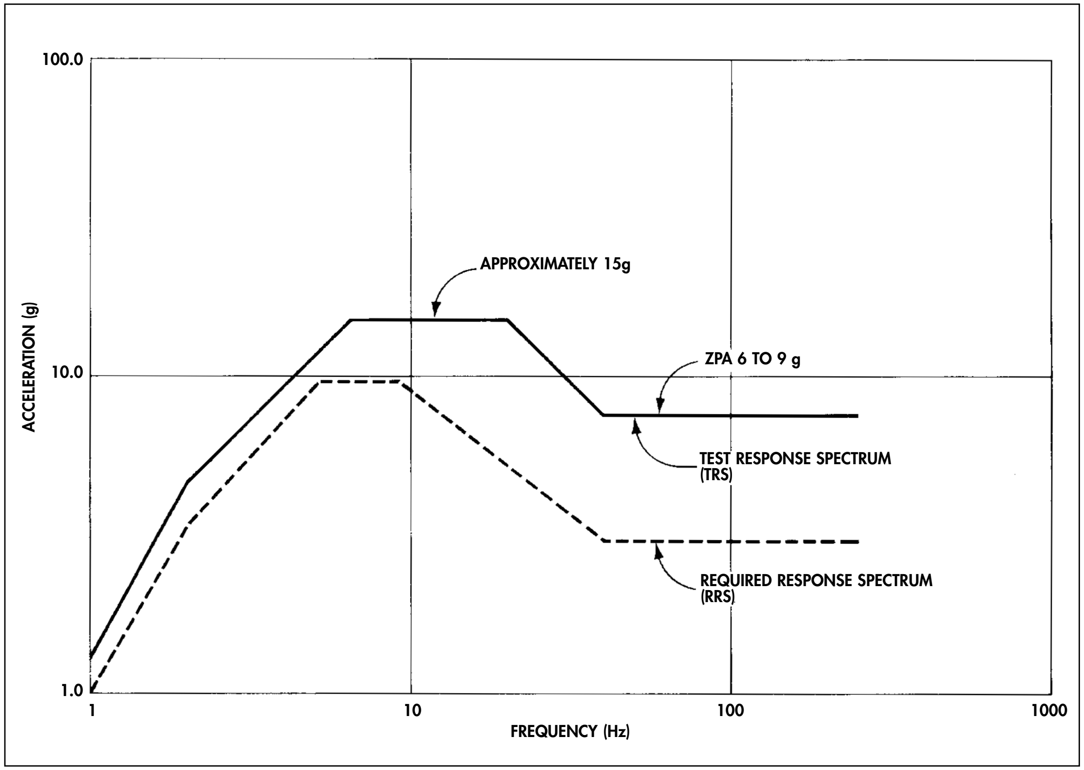

Figure 4: Seismic TRS & RRS

Next, actuator operation was demonstrated under SSE conditions using two different types of tests. While the objective under the SSE situation, is just to bring a reactor into a safe and secure shutdown condition after exposure to a single severe seismic incident, the qualification requirements for a valve actuator involve *multiple* tests to demonstrate integrity based on different types of potential valve mountings in the piping system and different directions of excitation.

Sine beat tests were performed to simulate conditions that a valve actuator may experience if the valve is installed in a flexible piping system. Random bi-axial multi-frequency tests were conducted to simulate conditions that may develop if the valve is installed near a rigid pipe support arrangement.

The multiple-frequency tests were performed with the actuator in three orientations with respect to the shake table; further, in each orientation, two tests were performed-one with horizontal and vertical motions phase-incoherent and one with the motions substantially 180° out of phase. In all tests, the A-290 actuator met criteria for safety-related valve operation. *Figure 4* shows that the Test Response Spectrum

(TRS) enveloped the Required Response Spectrum (RRS). *Figure 5* shows a typical actuator setup for seismic testing.

The second DBE simulation involved exposure of the actuator to an additional radiation dose of 10 Mrad – adding to the11.3 Mrad exposure during normal radiation aging. Following this exposure, the actuator was subjected to a DBE environmental simulation. This final test demonstrated safety-related operation of the A-290 actuator after exposure to all aging tests and other DBE simulations. The DBE environmental test is intended to simulate exposure to the severe thermal, external pressure and spray conditions that would be involved during a LOCA or MSLB.

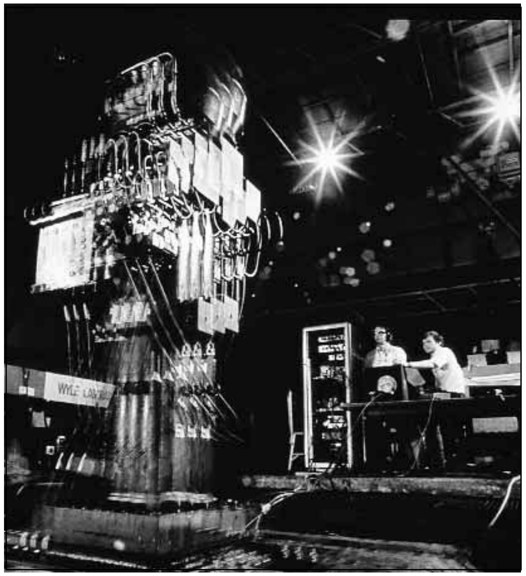

Figure 5: Actuator in Seismic test

The actuator was mounted in a pressure chamber that could be fed by steam and supplied with a water spray. The planned and actual profiles for the test are shown in *Figure 6*. In fact, while two thermal cycles are shown, there were actually three. During the first cycle, test equipment problems occurred which required the test to be aborted. Still, the actuator extended successfully after 9 minutes into the cycle and retracted successfully after returning to normal temperatures. Satisfactory safety-related operation was demonstrated a second time on the official first cycle with all test equipment performing properly. The second cycle involved a full 30-day exposure to a high initial temperature, followed by a declining temperature profile and demineralized water spray exposure. During the period, the actuator maintained gas pressure required to provide valve closing and sealing force.

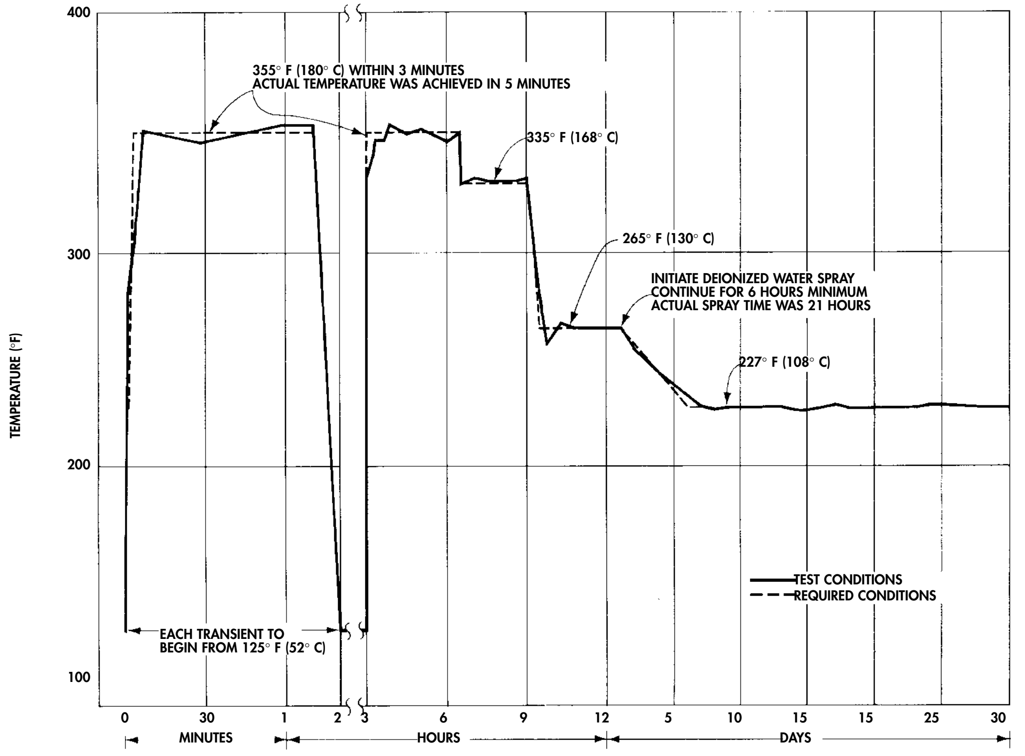

Figure 6: DBE Environmental Profiles

After the DBE environmental simulation, a final operability test was conducted. Minor external maintenance was required to permit the actuator to retract, simulating valve opening (not a safety related function). The actuator then performed successfully in a safety-related extension (simulating valve closure). Performance compared favorably with baseline test results.

Post-test inspection of the actuator components revealed no serious degradation of vital equipment which might have indicated an imminent failure. In particular, elastomeric seals exhibited only slight hardening (from temperature and/or radiation) and negligible wear.

It would be nice (but unrealistic and unbelievable) to say that there was no problems in the qualification tests. Actually, there were numerous difficulties, but none had an adverse effect on the safety-related performance of the actuator. Some of these difficulties involved expensive delays and extra testing, but they contributed to improvements in the final design of production actuators. Even if a problem is not safety-related, it can be a serious nuisance if it requires downtime for maintenance. Improvements which resulted from correction of non-safety related problems will provide greater reliability in normal service. Despite dedicated attempts to communicate all requirements to suppliers of minor components, the message did not always get through. For example, thermal aging tests revealed that purchased sight glasses for the hydraulic fluid reservoir were not really glass; plastic elements quickly deteriorated or melted, spilling the hydraulic fluid into the test pit. Where such problems developed, replacement components were exposed to aging treatments equivalent to the exposure received by the other parts of the actuator before the new parts were installed, and actuator tests were resumed.

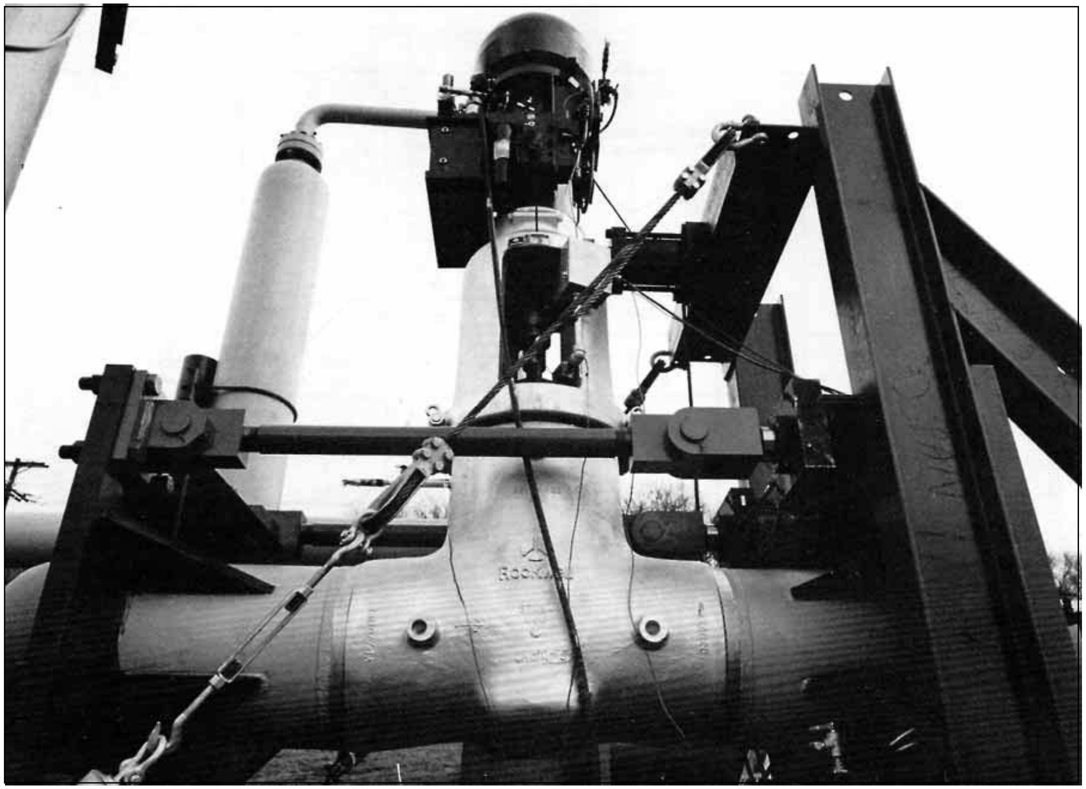

Figure 7: Size 28 MSIV in Test Station Setup

Extended Qualification of Valve/Actuator Combination

While previously described tests [4] of a size 16 Rockwell Equiwedge gate valve with the prototype A-230 actuator had provided an excellent qualification base, additional tests were designed and conducted (entirely at Rockwell expense) to provide extended qualification of the valve/actuator combination.

A size 28 production Equiwedge with a production A-290 actuator, identical to an MSIV for a customer order, was built for special tests. This valve was built into a special rig at the Flow Control Division Test Station, near Pittsburgh, and subjected to a series of tests, simulating closure under a line rupture situation while the valve was subjected to axial and bending pipe loading and loading to the superstructure (simulating seismic loads and dynamic loads from the pipe break). The valve test setup is shown in *Figure 7*. These additional tests represent just another step in the continuing Rockwell program to prove that safety-related valves will work before they are installed in customer installations.

Acknowledgement

A program of this magnitude requires contributions from many people. E. F. Schoeneweis and R. L. Clapper made particularly strong contributions at the design stage. M. E. Weller gave support in selection of hydraulic components. J. B. Gallagher provided primary guidance for the qualification program. P. A. Nye and his laboratory staff provided major support to all test phases. The author wishes to acknowledge the contributions of these and the many others who participated in this program.

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. Roger D. Norden, DEVELOPMENT OF THE ROCKWELL EDWARD EQUIWEDGE GA VALVE, Rockwell Technical Article V-Rep. 75-5
4. E. A. Bake and R. L.Clapper, QUICK CLOSING ISOLATION VALVES— THE EQUIWEDGE ALTERNATIVE, Rockwell Technical Article V-Rep. 78-4

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 worldwide 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

© 2003 Flowserve Corporation, Irving, Texas, USA. Flowserve and Edward Valves are registered trademarks of Flowserve Corporation. V-Rep 80-3 3/03 Printed in USA