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2011 TECHNICAL REPORT

Nuclear Maintenance Applications Center: Air-Operated Valve Diagnostic Testing Guide

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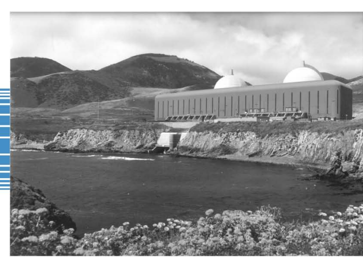

Nuclear Maintenance Applications Center: Air-Operated Valve Diagnostic Testing Guide

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Report Summary

This report provides information for personnel involved in the performance of air-operated valve (AOV) diagnostic testing, including the benefits of using diagnostics to understand valve health and to tie information into preventive maintenance programs. It provides insights for experienced personnel as well as basic information, guidance, and instructions for personnel assigned to perform, analyze, or purchase diagnostic test equipment.

Background
A diagnostic test system is a device used to verify the setup of a control valve, with the setup including the stroke length, seating force, bench set, and positioner calibration. Proper setup can improve a valve's response to changes in the demand signal from a process controller. The information that is acquired during testing can be used to confirm and verify the design basis of the control valve. Testing can also identify issues with the valve deadband, excessive friction, and stem wear.

Objectives

- To help power plant personnel understand common diagnostic systems, tests, and parameters measured
- To understand the advantages and limitations of test diagnostic systems and equipment
- To provide guidance on the selection and mounting of sensors for optimum test performance
- To provide guidance for establishing testing frequencies based on existing requirements or performance trending
- To provide an understanding of traces and plots as they relate to the design basis and troubleshooting of equipment issues

Approach
The preparers of this report conducted a detailed review of industry literature, product information, and standards to identify the various designs, applications, and maintenance practices associated with AOV diagnostic testing. Technical advisory group personnel were surveyed to determine specific vendor equipment in use, the ways in which it is being used, and any associated problems or commonly

encountered issues. Based on this information, recommendations were made on the proper selection of AOV test equipment, the AOVs that should be tested, the test that provides the best results, and how to analyze the information acquired from the test.

Results

This report presents a thorough discussion of AOV diagnostic test equipment, the principles of operation, and background information that personnel can apply when performing testing and trace analysis. Subsequent sections contain information on available tests, the expected results, and the most commonly used tests. The sections on testing experience (Section 3) and frequency of testing (Section 4) provide guidance on the use of strain gauges (for example, Crane's Easy Torque-Thrust[1] sensor and Teledyne's Quick Stem Sensor) and describe their benefits. A section on trace analysis (Section 5) provides valuable information for detecting maintenance problems. This report will help plant personnel reduce costs and the frequency of equipment unavailability as well as improve equipment reliability and performance.

Keywords

Calibration
Control valve
Diagnostic
Maintenance
Positioner
Troubleshooting

[1] Easy Torque-Thrust is a registered trademark of Crane Corporation.

Abstract

Diagnostic test equipment is used extensively in the power generation industry for calibration and design base verification of air-operated valves (AOVs). Proper AOV operation and function in the nuclear industry are essential to equipment reliability and power plant operation.

This report provides details on successful performance of valve diagnostics and how to evaluate the results. There are benefits to using valve diagnostics in understanding valve health; this report provides insight to these benefits.

This report includes a comparison of existing diagnostic test systems, common tests, and output from those tests.

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Section 1: Introduction

1.1 Background

The Electric Power Research Institute's (EPRI's) Nuclear Maintenance Applications Center (NMAC) has published multiple reports pertaining to the maintenance, engineering, and operation of air-operated valves (AOVs), with a focus on improving reliability. The scope of these reports includes the actuator, positioner, volume booster, and other accessories related to valve functionality. Practical solutions to maintenance practices and troubleshooting solutions for safe and reliable operation are offered. Specifically, these reports include the following:

- *Nuclear Maintenance Applications Center: Air-Operated Valve Maintenance Guide: Revision 2* (1016682). Includes guidance on preventive maintenance (PM) and corrective maintenance, troubleshooting, and diaphragms.
- *Valve Positioner Principles and Maintenance Guide* (1003091). Covers the control loop, calibration, condition monitoring, PM, and troubleshooting of positioners.
- *Nuclear Maintenance Applications Center: Compression Fitting Application Manual* (1016994). Provides information on industry practices related to tube-fitting installation, disassembly, and reassembly; identifies successful practices that have been shown to increase reliability and improve leak-tight performance.
- *Nuclear Maintenance Applications Center: Air-Operated Valve Evaluation Guide—Revision 1* (1022646). Provides practical methods for evaluating whether existing AOVs meet the design and functional requirements for application in nuclear power plants and suggests approaches for resolving AOV application problems.
- *Guide for Evaluating Air-Operated Valve Uncertainties and Actuator Setup Parameters* (1006555). Provides methods and equations to determine allowable ranges of setup parameters for an AOV, outlines margins for successful AOV operation, and determines the effect of uncertainties on allowable setup parameter ranges and margins.
- *PM Templates for Air Actuators and Positioners* (1018758). The PM Basis software includes templates for spring actuators, piston actuators, and positioners. The templates represent a cost-effective way to preempt the mechanisms that lead to degradation and failure.

The missing AOV program element that EPRI does not have guidance for is testing of AOVs. Diagnostic testing has become and will continue to be an essential element in many plants' AOV programs. Diagnostics can be used to validate that an AOV is capable of performing its design function, provide data to calculate as-left margins for trending the valve's performance, and aid in troubleshooting maintenance issues. Diagnostic testing is performed on many AOVs in accordance with a plant's PM template. All plant AOVs are evaluated for implementation in an AOV PM program; the requirements of this program are driven by the Joint Owners Group (JOG) document NX-1018.

1.2 Purpose

This report provides guidance on diagnostic testing of AOVs that will allow utilities to detect, identify, and correct issues across this population of valves. A properly maintained and calibrated valve will perform at optimal levels and improve efficiency and cost-effectiveness. It is believed by both NMAC and the Air-Operated Valve Users Group that the number of AOV failures could be reduced by better using diagnostics. Understanding valve condition prior to maintenance can go a long way in ensuring that the appropriate maintenance tasks are completed as needed, thereby strengthening the overall PM program.

1.3 Report Overview

The information in this report is broken up into seven sections with appendices, as follows:

- Section 1: Introduction
- Section 2: Diagnostic Systems, Tests, and Parameters Measured
- Section 3: Testing Experience
- Section 4: Testing Frequency
- Section 5: Trace Analysis
- Section 6: Case Histories
- Section 7: Bibliography
- Appendices

Each section attempts to bring the reader closer to an understanding of AOV diagnostics, the reason for it, and the benefits of adding it to a PM program. A description of each section is as follows:

- Section 1 provides an introduction to AOV diagnostics and the basis for the report.
- Section 2 provides the reader with information pertaining to equipment commercially available and common systems used in the nuclear industry. Section 2 provides an insight into the tests that are available and the information obtained from them.

- Section 3 provides insight into current issues, such as the use of strain gauges, installation of travel transducers, and proper test tubing installation. There is also discussion in reference to on-line and off-line testing and static and dynamic testing. Section 3 goes in depth about sensor selection, sensor placement, test selection, test duration, and worker qualification.
- Section 4 defines testing frequencies and the criteria used to establish them. This section describes JOG valve classifications and testing requirements in respect to valve criticality and regulatory requirements.
- Section 5 pertains to trace analysis. It describes test plots, details of the plots available, and content provided by the plot. Section 5 provides information helpful in understanding plot marking and manual marks available for each plot (that is, time base, mechanical properties, overall valve, and so on). There is information provided to describe how to manually mark plots using strain gauge thrust data to determine packing friction and seat load. Actual plots have been provided to reflect actual equipment and issues frequently encountered during AOV diagnostic testing.
- Section 6 provides actual industry case histories and lessons learned with trace plots.
- Section 7 is a bibliography for further reading on AOVs and diagnostic testing.
- Appendix A is a summary of the Key Points contained in this report, Appendix B covers literature associated with the vendor equipment mentioned within the report, Appendix C presents actuator drop test and industry leakage acceptance criteria, Appendix D gives as an example of one utility's diagnostic test procedures, and Appendix E is a overview slide presentation.

1.4 Basis for This Report

A review of the JOG NX-1018 document, which set the requirements for establishing and maintaining an AOV PM program, includes in-service diagnostic testing on nuclear plant AOVs. The criterion set forth in this document applies to all industries that use AOV controls because there are valves that have safety significance within any process system.

JOG NX-1018 provides the basis and guidance associated with the development of a nuclear industry AOV program. The intent is to specify industry AOV program requirements to provide assurance that AOVs are capable of performing their intended safety-significant (that is, risk-significant) functions. The document recommends the use of risk-informed tools in establishing the AOV categorization criteria. Specific guidance is also provided for the basic elements of an AOV program, including design, setup, testing, and maintenance. It is expected that utilities, by implementing elements within NX-1018, will focus station resources on the most critical AOVs in the plant.

Operational readiness is the ability of a valve to perform its specified functions, such as the following:

- Shutting down a reactor to the safe shutdown condition
- Maintaining the safe shutdown condition
- Mitigating the consequences of an accident

1.5 Common Valve Terms

active valve. A valve that must perform a mechanical motion during the course of accomplishing a system safety-significant function.

actuator. A device that changes the position of a control valve in response to a pneumatic or electronic input signal.

actuator, pneumatic piston. An actuator with a piston and cylinder assembly in which the movement of the piston is controlled by changes in air pressure. Pneumatic piston actuators are divided into three types of construction: double-acting (springless) actuators have the loading pressure connection ports at the top and bottom of the cylinder, spring-bias (spring) actuators are essentially double-acting actuators with a spring added, and spring-return (spring) actuators have an internal spring but only one loading pressure connection port.

actuator, spring and diaphragm. A pneumatically operated, compressible, fluid-powered (usually air-powered) device in which the fluid acts upon a flexible member—the diaphragm—to provide linear motion to the actuator stem.

actuator force. The amount (pounds or kilograms) of force that a sliding stem actuator is capable of applying to the positioning of an end-use component.

actuator lever. A lever used with rotary shaft valves to convert linear motion (thrust) into rotary motion (torque).

actuator response. The speed and/or accuracy with which an actuator responds to an input signal.

actuator stem. In sliding stem valves, an extension of the piston rod that permits convenient connection to the valve stem.

actuator torque. The rotational force applied to a rotary valve stem. It is usually discussed in terms of *breakout torque* (overcoming internal valve friction and seating or unseating a valve's closure member) and *dynamic torque* (the throttling of a rotary valve).

actuator/valve stability. A measurement of an actuator's ability to maintain the closure member in a given position.

air-operated valve (AOV) assembly. A valve and actuator combination in which the actuator uses air as a power source to provide a valve stem thrust/torque to open, close, or throttle a valve. It also includes those accessories required to allow the AOV to perform its intended safety-significant function. For example, a fail close (spring) AOV that has a safety-significant function to close will require the solenoid valve to change position to exhaust. As a minimum, the solenoid valve is an accessory that is considered part of the AOV assembly. Accessories might include solenoid valves, regulators, positioners, boosters, E/P and I/P transducers, quick exhaust valves, and lockup systems.

air spring. An actuator that is instrumented so that air pressure is applied to one side of the actuator and maintained above a minimal value throughout the stroke. By maintaining a minimum pressure, the air spring provides a constant force.

apparent bench set. The lower and upper bench values that characterize the actuator when coupled to the valve. Because the actuator and valve are coupled, valve forces can influence the pressure needed to operate the actuator. The effect that valve forces have on the apparent bench set depends on whether the forces always oppose motion (like friction) or always act in the same direction (like disk weight or pilot springs). Forces that act in one direction will cause a bias shift in the bench sets and, therefore, must be accounted for when determining the true lower bench set (or spring load).

bench set. A specification that is used to verify proper actuator operation. Bench set is expressed as the pressure range from the start of the actuator stroke to the valve's rated travel.

block valve. An isolating valve, often a butterfly valve, used to create a bypass around the control valve. A bypass is frequently created so that service can be performed on the control valve without shutting down the process.

cage. A hollow cylindrical trim element that guides the movement of a valve plug. The cage can also retain the seat ring in the valve body. The walls of the cage have openings that determine the flow characteristic of the control valve.

calibration. The act of adjusting the output of a device so that it corresponds to the value of the input of the device. In positioner calibration, zero, span, and crossover (balance) pressure are the primary calibration adjustments.

controller. A device that operates automatically to regulate a controlled variable.

control valve. A power-operated device that modulates the fluid flow rate in a process control system. It consists of a valve connected to an actuator mechanism that is capable of changing the position of a flow-controlling element in the valve in response to a signal from the controlling system.

damper. A device that regulates the flow of gas in low-pressure ducts.

deadband. The range through which an input signal can be varied upon reversal of direction without initiating an observable change in the output.

diaphragm. A flexible member capable of producing an output in force or motion in response to a pneumatic input signal.

differential pressure (DP) load. Force due to differential pressure acting on the valve disk or plug that must be overcome to operate the valve.

direct-acting actuator. An actuator in which the actuator stem extends toward the control valve in response to an increasing input signal.

direct-acting positioned. A positioner that provides increasing output pressure in response to an increasing input signal.

double-acting positioned. A positioner that has two relays; typically used with double-acting and spring-bias actuator designs.

dynamic response. The response characteristics of an element, including phase shift and dynamic attenuation, observed as the frequency of the input is varied.

dynamic torque. The torque produced in quarter-turn valves as a result of the forces produced by mass flow.

effective diaphragm area. The diaphragm area, taking into account actuator travel and deformation of the diaphragm.

elastomer. A rubberlike synthetic polymer, such as silicone rubber; the broad term for gaskets, O-rings, diaphragms, and some packing.

fail-closed. A condition in which the valve port remains closed in the event of loss of supply pressure.

fail-open. A condition in which the valve port remains open in the event of loss of supply pressure.

gate unwedging thrust. The thrust required to unwedge the gate during the opening stroke after being wedged during the closing stroke.

globe valve. A valve style with a linear motion and flow-controlling member with one or more ports. Distinguished by a globe-shaped cavity around the port region. Two types of plug guiding are recognized: cage-guided and stem- or plug-guided.

guide bushing. A bushing in a bonnet, bottom flange, or body to guide the movement of a valve plug.

high safety significance. A designation referring to the importance to plant safety. Derived by a blended process of risk ranking and expert panel evaluations.

hysteresis. The maximum difference in output value for any single input value during a calibration cycle, excluding errors due to deadband.

input. A particular process quantity or variable that has been identified as the cause of subsequent changes in the values or actions of other process values defined as outputs.

input signal. A pneumatic or electronic signal sent to a control valve.

I/P converter. A transducer that uses current for an input and pressure for an output. See *transducer*.

leakage. Pneumatic pressure losses in either the actuator or positioner resulting from defective seals, O-rings, or gaskets; also, fluid passing through a valve when the valve is in a fully closed position under stated closure forces.

leakage, seat. Fluid passing through an assembled valve when the valve is in the fully closed position under stated closure forces, with pressure differential and pressure as specified.

lower bench set. The pressure required to initiate actuator motion and compress the spring. The lower bench set represents the spring preload and is often used as an input in AOV calculations. The true lower bench set includes only the effects due to spring preload. For a fail-close valve, the lower bench set directly affects the seat load.

maintenance. All activities performed on equipment in order to maintain or restore its operational function (corrective or preventive).

maintenance, condition-directed preventive. Actions initiated as a result of equipment condition. Assessment and comparison with defined acceptance criteria; surveillance tasks, such as in-service inspection, scheduled monitoring, and trending coupled with diagnostics are also included in this group of maintenance actions.

maintenance, corrective. Activities (diagnose and repair) performed to restore the functional capabilities of failed equipment.

maintenance, periodic preventive. Scheduled activities performed on equipment to reduce the probability of failure; initiated by periodicities regardless of condition.

maintenance, predictive. Activities performed to assess the status of equipment or system degradation by the correlation of one or more parameters.

maintenance, preventive. All activities performed on equipment to avoid or reduce the probability of failure.

normally closed control valve. A valve that closes when actuator pressure is reduced to atmospheric pressure.

normally open control valve. A valve that opens when actuator pressure is reduced to atmospheric pressure.

packing. Plastic, elastomer, graphite, or other material used to seal valve shafts and stems.

passive valve. A valve that does not perform a mechanical motion during the course of accomplishing a system safety-significant function.

piston. A disk or short cylinder closely fitted in a hollow cylinder and moved back and forth by the pressure of a fluid or gas so as to transmit motion and pressure to the rod.

plug. The closure member of a globe-style control valve.

pneumatic. Pertaining to or operated by air or other gas.

positioner. A device that compares the actual actuator position with the desired position with respect to an input signal and adjusts actuator loading pressure until the desired position is attained. The desired position has a predetermined relationship to the input signal.

probabilistic safety assessment (PSA). A quantitative assessment of the risk associated with plant operation. *Probabilistic risk assessment* (PRA) is another term for PSA.

regulator, air. Regulates supply air pressure to a preset value.

relay, pneumatic. A pneumatic power amplifier in which changes in input pressure result in changes in the position of exhaust and supply valves that control a separate supply pressure.

reliability-centered maintenance. A maintenance plan based on identifying equipment or systems that have functional failures. The plan uses the failure population to develop or revise PM programs.

resolution. The minimum possible change in input required to produce a detectable change in the output when no reversal of the input takes place.

reverse-acting actuator. An actuator construction in which the actuator stem retracts away from the control valve with increasing diaphragm pressure.

rotary-shaft control valve. A valve style in which the flow closure member (full ball, partial ball, or disk) is rotated in the flow stream to modify the amount of fluid passing through the valve.

safety-related. The classification of components that are necessary to ensure the integrity of the reactor coolant pressure boundary, the capability to achieve shutdown condition, or the capability to prevent or mitigate the consequences of accidents that could result in off-site exposures comparable to guideline exposures of U.S. Code of Federal Regulations (CFR) 10CFR100.

saturation. The point in an operating range at which a change in input no longer causes an output change.

seat. That portion of the seat ring or valve body that a valve plug contacts for closure.

seat load. The contact force between the seat and the valve disk, ball, or plug. (In practice, the selection of an actuator for a given control valve is based on how much force is required to overcome static and dynamic unbalance, with an allowance made for seat load.)

setpoint. The desired value for the controlled variable. The setpoint is an input variable that can be manually or automatically set and is expressed in the same units as the controlled variable, for example, degrees Fahrenheit (degrees Celsius), standard cubic ft/h (cubic m/h), or psig (pascal).

single-acting positioned. A positioner with only one relay. Typically used with spring-return actuator designs.

sliding stem control valve. A valve construction style in which the valve closure member (plug) moves in a linear path.

span adjustment. The calibration procedure that establishes the control valve position desired when the input signal is at the maximum value of the input signal range.

split range. A technique in which one controller is used to operate to final control elements.

static test trace. Includes, at a minimum, the diaphragm or piston differential pressure for the opening and closing stroke and either the valve linear or angular position for the actuator stroked under static conditions. A static test is recorded using diagnostic software and is commonly used to determine key AOV calculation inputs.

stroking time. The time it takes an actuator to be moved between two predetermined positions (generally, valve open or valve closed).

torque. The tendency of a force to produce rotation about an axis.

total friction force. The measured running friction force during static testing. It includes all sources of friction, including valve packing friction, disk seal friction, actuator seal friction, and weight-related friction.

total friction torque. The running torque measured during static testing. It includes all sources of friction, including valve packing friction, hub seal friction, actuator seal friction, and bearing friction.

transducer. A device that accepts an input in one form (pressure, electrical current, and so on) and provides a corresponding output in another form.

travel. The movement required to take a valve plug from the closed to the rated full-open position.

trigger. A parameter setting used during live display to initiate date recording.

true bench set. The bench of the actuator when uncoupled from the valve and free from all external forces. The true lower bench set represents the spring preload.

unbalanced forces. The force or torque produced when process pressure creates more force on one side of a flow-controlling element than on the other.

upper bench set. The pressure required to complete the specified actuator travel from the fail position. The upper bench set represents the compressed spring load. The upper bench set, along with the lower bench set and actuator travel and diaphragm or pressurized piston area, can be used to calculate the spring rate. The true upper bench set includes only the fully compressed spring load. For a fail-open valve, the upper bench set directly affects the seat load.

valve body. A housing for internal parts that have inlet and outlet flow connections.

waveform. A graphical representation that the control signal imitates during the test cycle.

zero adjustment. The calibration procedure performed to establish the desired valve position when the input signal is at the minimum value of the input signal range.

1.6 Acronyms and Abbreviations

AOV	air-operated valve
BWR	boiling water reactor
dc	direct current
DP	differential pressure
E/P	voltage-to-pressure
EPRI	Electric Power Research Institute
h	hour(s)
HDRL	hysteresis, deadband, repeatability, and linearity
in.	inch(es)
in.-lb	inch-pound(s)

I/P	current-to-pressure
JOG	Joint Owners Group
kg	kilogram(s)
kPa	kilopascal(s)
lb	pound(s)
lbf	pound(s)-force
m	meter(s)
mA dc	milliampere(s) direct current
mm	millimeter(s)
MSIV	main steam isolation valve
N	newton(s)
NMAC	(EPRI) Nuclear Maintenance Applications Center
O&M	operations and maintenance
PM	preventive maintenance
psi	pounds per square inch
psig	pounds per square inch gauge
PWR	pressurized water reactor
RCM	manual relay from the control room
STARS	Strategic Teaming and Resource Sharing
TAG	technical advisory group

1.7 Key Points

Throughout this report, key information is summarized in "Key Points." Key Points are bold lettered boxes that succinctly restate information covered in detail in the surrounding text, making the key point easier to locate.

The primary intent of a Key Point is to emphasize information that will allow individuals to take action for the benefit of their plant. The information included in these Key Points was selected by NMAC personnel and the consultants and utility personnel who prepared and reviewed this guide.

The Key Points are organized according to three categories: Operation and Maintenance (O&M) Cost, Technical, and Human Performance. Each category has an identifying icon, as shown below, to draw attention to it when quickly reviewing the guide.

Key O&M Cost Point
Emphasizes information that will result in reduced purchase, operating, or maintenance costs.

Key Technical Point
Targets information that will lead to improved equipment reliability.

Key Human Performance Point
Denotes information that requires personnel action or consideration in order to prevent injury or damage or ease completion of the task.

1.8 Unit Conversions

Table 1-1 provides English and SI unit equivalents for units of measurement used in this report.

Table 1-1
Unit conversions

Property Measured	English Unit(s)	SI Unit(s)	Conversion Equation(s)
Length	inch(es) (in.)	millimeter(s) (mm)	1 in. = 25.4 mm
Pressure (thrust or torque)	pound(s) per square inch (psi); pound(s) per square inch gauge (psig); pound(s)-force (lbf/in.); inch-pound(s) (in.-lb)	pascal(s) (Pa)/ kilopascal(s) (kPa); newton/meter (N/m)	1 psi/psig = 6.89 kPa 1 lbf/in. = 1.36 N/m 1 in.-lb = 0.11 N/m
Temperature	°F	°C	°F = °C * 9/5 + 32
Weight	pound (lb)	kilogram (kg)	1 lb = 0.45 kg

Section 2: Diagnostic Systems, Tests, and Parameters Measured

2.1 Diagnostic System Benefits

Diagnostic system benefits are the long-term health of system AOV components. Gains produced through an initial calibration can easily be lost over time to normal degradation of the components. The trending abilities that come from AOV diagnostics systems play a major role in the identification, isolation, and removal of recurring issues that are induced by component degradation or maintenance. Diagnostics trending gives both immediate and long-term gains when employed and tracked. By performing and analyzing test data, AOV maintenance can be planned and scheduled; therefore, the system impact will be understood. When impending failure can be predicted, a more exact PM module can be employed to efficiently perform just-in-time maintenance. A diagnostic system is also effective at identifying a specific root cause when a plant needs a focused result and a quick turnaround on a maintenance activity.

The following sections are an attempt to identify the positive and cost-effective reasoning behind purchasing a diagnostic system and implementing an AOV test program.

2.1.1 Reduced Maintenance Expense

A diagnostic system can reduce maintenance expenses because of the following:

- Using diagnostics test results gives one the ability to minimize trips and make those trips more efficient by working on the actual problems and not just replacing parts.
- Trending test results provides data to minimize testing frequencies and establish an accurate PM repair plan.
- Focusing on PM activities will maximize valve control, reduce wear, and minimize leaking during a run cycle.
- Testing done in advance of an outage will help improve outage planning and reduce emergency parts demand.
- On-line testing can help eliminate or pinpoint a control valve as a potential cause of a loop problem, reducing unnecessary maintenance and engineering cost.

2.1.2 Reduce Unplanned Downtime Events

As in reducing maintenance expenses, diagnostic trending will give insight into potential degradation issues. Also, trending will identify weak points in the system and allow for some frequency adjustment to the PM schedule. This will ensure that necessary tasks are performed just in time, therefore preventing an unscheduled plant down-power or event.

2.1.3 Improved Process Efficiency

A diagnostic system can improve process efficiency through the following:

- Using trending concepts will help identify the cause and effect for the maintenance just performed; this will ensure that problems are resolved.
- Activities performed will have both positive and negative effects on the process. Trending will allow identification and focus items that enhance results and keep the components in service.
- Analyzing test results will identify general areas of designs that might challenge or degrade performance on an AOV, thus bringing attention to outlying components that might require engineering changes.
- Establishing and maintaining the correct seat load and packing friction will reduce the potential for leaks, which improves thermal efficiency.
- Verifying and maintaining correct valve operation facilitates proper system control and loop tuning.
- Analysis of valve response permits physical modifications to the valve and air supply to better match the response to the process requirements.
- When used as a calibration device, the proper setup and calibration are ensured. A printout of this information provides documentation of this setup.
- Using the system in conjunction with a training program permits easy visualization of such things as bench set and packing friction, which helps improve overall maintenance performance.

2.1.4 Improved Safety

Valves will operate as designed, which allows systems to maintain control, mitigate issues, and remain on-line during power runbacks. Maintaining a valve maintenance program will minimize leaks in the primary system; this will lower the contamination level, thus lowering the overall radiation exposure.

2.2 Diagnostic Systems Currently on the Market

The manufacturers of AOV diagnostic test systems support a variety of attachments and sensors; some use their own, and others use equipment on the market. The primary systems that are purchased in the U.S. nuclear industry are as follows:

- Emerson FlowScanner[2]
- Crane Nuclear Viper[3]
- Crane Nuclear VOTES[4] Infinity
- AREVA UltraCheck
- Teledyne QuikLook
- Westinghouse AirCEt[5]

2.3 Common Diagnostic Tests and Descriptions

There are multiple tests and parameters measured that can be performed regardless of the diagnostic system used. However, the most commonly used tests include the ramp, step response, and static point. The following common diagnostic test options are listed in the order of frequency:

- Ramp
- Step response
- Static point
- Step sensitivity
- Step resolution
- Frequency response
- User-defined test
- Live data acquisition

The following sections describe these tests in more detail. The intent of this section is to cover the common tests found and not to include every test for each system. The various trade names for common diagnostic systems are given along with an explanation of the parameter measured. Table 2-1 has a representation for each waveform for the defined test. A *waveform* is defined as a graphical representation that the control signal imitates during the test cycle. With the exception of the ramp and sometimes step response test, all of the tests are typically used solely for trending purposes.

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[2] FlowScanner is a registered trademark of Emerson Electric Co.

[3] Viper is a registered trademark of Crane Corporation.

[4] VOTES is a registered trademark of Crane Corporation.

[5] AirCEt is a registered trademark of Westinghouse.

Table 2-1
Comparison of diagnostic system tests and parameters measured

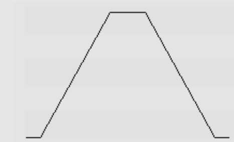
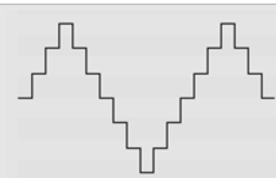
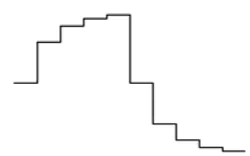
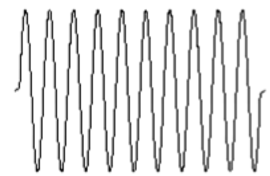
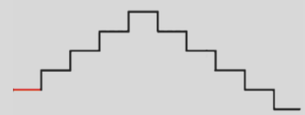
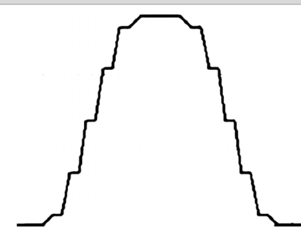
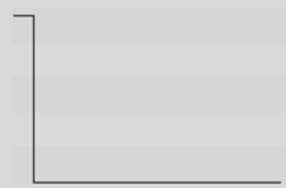
Test Type and Relevant Report Section	Diagnostic System			Typical Waveform	Parameter Measured
	Crane	Fisher	Teledyne		
2.3.1 Ramp	Baseline	Dynamic scan	Slow ramp		Overall valve performance and calibration
2.3.2 Step Response	Step response	Step change	Step open/ step close		Stroking speed and valve dynamic response
2.3.3 Static Point	Hysteresis, deadband, repeatability, and linearity (HDRL) error	Static point	HDRL		HDRL error
2.3.4 Step Sensitivity	Step sensitivity	Stepped ramp	Sensitivity		Sensitivity to step changes of progressively decreasing magnitudes in the same direction
2.3.5 Step Resolution	Step resolution	Step study	Resolution and response		Positioning resolution about a setpoint with small input changes and inclusive of deadband

Table 2-1 (continued)
Comparison of diagnostic system tests and parameters measure

Test Type and Relevant Report Section	Diagnostic System			Typical Waveform	Parameter Measured
	Crane	Fisher	Teledyne		
2.3.6 Frequency Response	Frequency response	Sine wave	Frequency response		Frequency response to certain sinusoidal input signals
2.3.7 User-Defined Test	Manual	Step study	Custom		
2.3.8 Live Data Acquisition	Live display	Monitor mode	Manual		
2.3.9 Other Test	Deadband				Quasi-static deadband error
	Static calibration				Response to certain specified step changes mimicking a three-step or five-step calibration
			Drop test		Leak rate test for actuator

2.3.1 Ramp

The ramp test is the primary screening test designed to assess the overall health of a valve. This test supplies the majority of information required to evaluate a valve's mechanical properties and calibration of the equipment. This test is most often used to verify valve setup. On new or reconditioned valve assemblies, it is possible to establish or reestablish a performance benchmark that subsequent tests can be compared to. Any change can reveal problems, such as wear or damage to the valve and/or its instruments. These traces provide a baseline that represents real valve operation.

2.3.2 Step Response

This test is used to measure a valve's response to sudden changes in signal and the stroking time of the valve. This test is used to check the delay of movement and the amount of time needed to reach the intended target established by the control signal. The valve response is measured against a control signal that shows the valve response to a step change.

2.3.3 Static Point Test

This test is designed to measure valve HDRL error. This test steps the control signal, then pauses and records the valve travel. Data are recorded for both the up and down strokes.

2.3.4 Step Sensitivity

Step sensitivity is a general-purpose test designed to assess the valve sensitivity to signal step changes of progressively decreasing or increasing magnitudes in the same direction.

2.3.5 Step Resolution

Step resolution is a general-purpose test used to check the valve's ability to react to small changes in signal magnitude around a setpoint. This test includes a series of small steps changing in size; it is used to check valve resolution and response.

2.3.6 Frequency Response

Frequency response is a general-purpose test designed to assess the valve's frequency response to certain sinusoidal input signals. The test uses a sinusoidal test signal of constant amplitude at various frequencies. In general, this test is infrequently performed.

2.3.7 User-Defined

The intent of this test is to acquire data while stroking a valve from a user-defined custom waveform. The user can create an unlimited number of custom profiles based on the system requirements and data needed for analysis.

2.3.8 Live Data Acquisition

Live data acquisition is a mode that allows recording data of a valve when the user does not have control of the valve. This is used for troubleshooting valve performance through long-term monitoring or by setting an event-based trigger to toggle data recording.

2.3.9 Other Tests

There are a few other diagnostic tests that are available to the end user, but they are generally specific to a certain manufacturer. They include the deadband, static calibration, and drop test (see Table 2-1 to identify the vendor for each test). The drop test is generally performed during all AOV maintenance, but only one vendor has an actual defined drop test. These tests are discussed in more detail in this section.

2.3.9.1 Deadband

A deadband test begins at a defined input signal before sending a series of very small input signal changes, followed by a hold period until the valve moves. After the valve moves, it presumably has taken up mechanical play. The series of small input signal changes is then reversed until the valve moves a perceptible distance in the other direction. Deadband is the signal change from the point of reversal to the point of movement in the decreasing direction.

2.3.9.2 Static Calibration

A static calibration test is designed to mimic a manual three-step or five-step calibration. Static calibration is used when the dynamic effects of a ramp test skew the data away from what would be achieved in static (non-varying) conditions. Dynamic effects most often influence the results on very large actuators or otherwise slowly moving valves. The test measures actuator pressures and valve travel after movement stops, when an mA signal and I/P signal are held static at the calibration points.

2.3.9.3 Drop Test

The intent of a drop test is to record the actuator pressure in response to removal of the control signal after the actuator is isolated. Generally, this test is used each time maintenance is performed on an actuator. Currently, this system is offered with only one diagnostic manufacturer. However, similar information can be collected using a manual test or live display found with other systems. Typically, this drop test is performed while the technician monitors the value on the display in calibration mode; there is no information recorded on the system.

2.4 Digital Components and On-Line Monitoring

Off-line testing can be performed with analog or digital positioners installed on an AOV and with any of the standalone AOV diagnostic test systems described in Section 2.2. When a digital positioner is installed, the use of an external I/P for testing is eliminated.

On-line and partial stroke tests pertain mainly to digital positioners. Several nuclear plants in the United States have installed digital feedwater control systems—some have only digital positioners, and others could have also installed digital feedwater level controllers. The digital feedwater software can initiate a test from the system mainframe or a laptop computer in the field. Smart positioners use a communication bus structure that allows for communications to be imposed on the control signal to the positioner. Table 2-2 lists the manufacturers that support on-line testing and the communication structure used. The overriding signal allows for communication to the positioner without disruption to the ongoing controls of the positioner.

Table 2-2
Digital valve positioner manufacturers

Manufacturer	Model	Communication Protocol	On-Line Diagnostics	Pneumatic Signal Generation Scheme
ABB	TZID	HART[6]	Yes	I/P—three-way valve
Control Components, Inc.	QuickTrak[7]	HART	Yes	Motor-operated spool valve
Dresser Masoneilan	FVP 110	Fieldbus[8]	Yes	I/P—pneumatic relay
Dresser Masoneilan	SVI II AP	HART	Yes	I/P—pneumatic relay
Fisher	DVC6000	HART	Yes	I/P—pneumatic relay
Fisher	DVC6000f	Fieldbus	Yes	I/P—pneumatic relay
Flowserve	Logix 500	HART	Yes	Piezo valve—pneumatic amplifier
Flowserve	PMV D20	HART	Yes	Piezo valve—pneumatic amplifier
Siemens	SIPART PS2	HART, PROFIBUS, Fieldbus	Yes	Pneumatic block actuator—pneumatic block
Siemens	SITRAN VP3000	HART	Yes	Pneumatic block actuator—pneumatic block

[6] HART is a registered trademark of the HART Communication Foundation.

[7] QuickTrak is a registered trademark of Control Components, Inc.

[8] Fieldbus is a registered trademark of Fieldbus Foundation.

The benefits of smart positioners and control system software, such as ValveLink,[9] include the following:

- There are in-service diagnostics for monitoring the health of the valve assembly and customized diagnostics for advanced troubleshooting.
- There are continuous analysis of the valve assembly and passive gathering of data without disturbing or interrupting the control valve while it is in process.
- In-service monitoring helps detect problems with air leakage, valve assembly friction and deadband, instrument air quality, loose connections, supply pressure restriction, and valve assembly calibration.
- When a problem is identified, the diagnostic provides a general description of and information about the severity of the problem, a probable cause, and recommended action.
- In-service diagnostics for troubleshooting allow custom diagnostics to be set up to collect data at a high-frequency collection rate and present the data in a graphical format.
- There is a capability to initiate a partial stroke test of the final control element without requiring a process shutdown. The plant can run a partial stroke test to prove that the valve will respond on demand. Store partial stroke test results for future comparison and study. The test can also be initiated by shorting the auxiliary terminal in the field with a push button located at the device or remotely from the valve.
- Performing out-of-service diagnostics, such as valve signature, dynamic error band, and step response, can assist in the identification of emerging valve problems quickly and accurately, without the installation of additional test equipment.

2.4.1 Final Control Element Diagnostics

According to the EPRI report *Nuclear Maintenance Applications Center: Valve Positioner Principles and Maintenance Guide (Updated to Include Digital Valve Positioners)* (1022989), the following three categories of diagnostics are available:

- Off-line diagnostics physically moves the control valve and requires that the valve be isolated from the process.
- On-line diagnostics is performed while the valve is in service and responding to the control system and does not interfere with the control valve response to control system demands.
- Partial stroke testing physically moves the valve while the valve is in service responding to control system demands, but it does not interfere with the control valve response to control system demands.

These categories are explained in more detail in the following sections.

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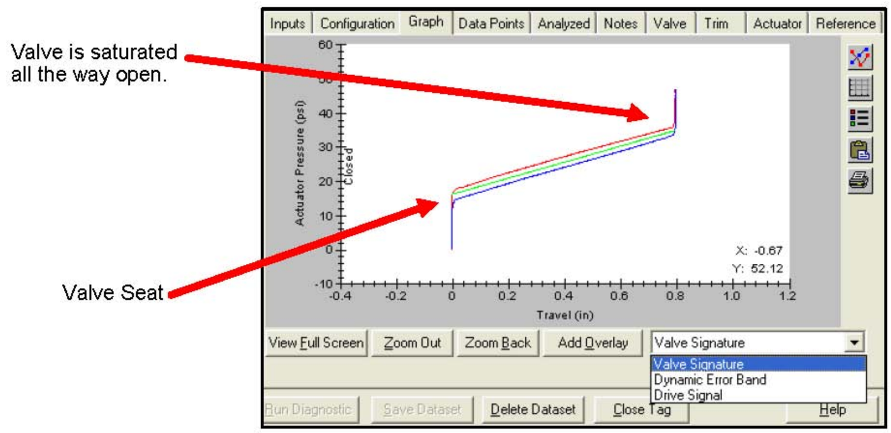
[9] ValveLink is a registered trademark of Fisher.

2.4.2 Off-Line Diagnostics

Off-line diagnostics dynamically strokes the valve while performing diagnostic tests, such as valve signature, dynamic error band, drive signal data, and step response test, as follows:

- The valve signature plots actuator pressure versus valve travel and calculates friction, seat load, spring rate, and many other variables (see Figure 2-1). It is used to determine valve and actuator mechanical condition and can identify issues such as worn seat, worn/bent stem, insufficient air supply, and insufficient frictional forces.



Example of a Valve Signature and analyzed data with a spring and diaphragm actuator

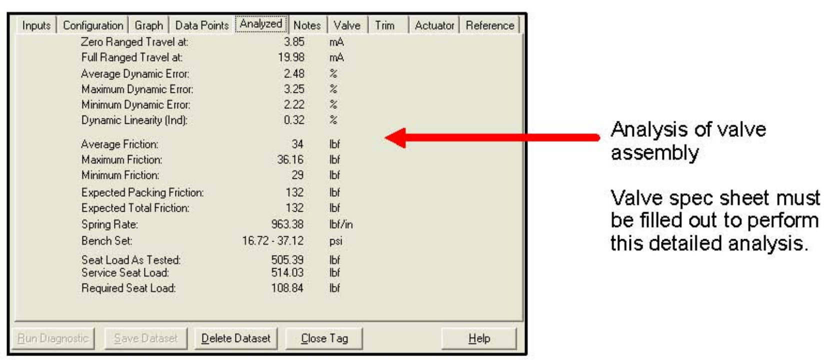


Figure 2-1
Valve signature diagnostic test
Illustration provided courtesy of Emerson Process Management, Fisher

- The dynamic error band plots valve travel versus input setpoint and calculates minimum, maximum, and average dynamic error and dynamic linearity. It provides a snapshot of the performance of the entire final control element, including the positioner.
- The drive signal plots the input setpoint in percent of ranged travel versus the drive signal in percent of maximum drive signal current and provides a measure of how hard the instrument is working while trying to position a valve. The normal drive signal ranges from 55% to 85% of maximum. High

drive signals mean that the positioner is working very hard to position the valve correctly, and they can be an indication of a sticking valve, an I/P that is starting to plug, or an I/P calibration shift.

- The step response plots valve travel versus the time it takes to move through the specific steps, and it checks the response of the entire final control element. It provides an indication of the effectiveness of the tuning of the final control element control loop.

2.4.3 On-Line Diagnostics

On-line diagnostics is a series of final control element diagnostic tests that can be run while the valve is in service. It is based on the sensors mounted in the digital valve positioner that monitor the following parameters:

- Input current from the controller
- Supply pressure to the positioner
- Output pressure to the actuator
- Valve position
- Positioner temperature
- Drive signal and drive current of the internal I/P transducer
- Booster relay position (based on the pneumatic amplifier using a booster relay)

Using the data collected from these positioner sensors, the following diagnostic tests can be performed.

2.4.3.1 Profile Test

The profile diagnostic test gathers and stores information selected by the utility, much as an extremely fast electronic strip chart would do. This information can be used to help troubleshoot problems. For example, the sequence of events during a control valve transient can be tracked and analyzed. The profile test allows the utility to select from the following variables:

- Travel
- Travel setpoint
- Drive signal
- Actuator pressure 1
- Actuator pressure 2
- Supply pressure
- Input current
- Internal relay positions
- Travel deviation

2.4.3.2 I/P and Relay Integrity Test

The I/P and relay integrity diagnostic test evaluates the physical condition of the I/P and booster relay components of the positioner. The diagnostic parameters monitored are as follows:

- Booster relay hall effect sensor position
- Travel
- Travel feedback position
- Drive signal

The I/P and relay integrity diagnostic test can detect the following issues:

- I/P beginning to plug
- I/P O-ring failure
- Booster relay diaphragm failure
- Booster relay jammed
- Supply pressure low
- I/P calibration shift
- Valve stuck
- Feedback damaged
- Air supply line blocked
- Actuator crossover pressure wrong

2.4.3.3 Supply Pressure Test

The supply pressure diagnostic test evaluates the physical condition of the I/P and booster relay components of the positioner. The diagnostic parameters monitored are a follows:

- Travel
- Travel setpoint
- Supply pressure

The supply pressure diagnostic test can detect the following issues:

- Low supply pressure
- High supply pressure
- System pressure drop
- Pressure sensor out of calibration
- Incorrect bench set specified

2.4.3.4 Relay Adjustment Test

The relay adjustment diagnostic test evaluates the booster relay adjustment when the positioner is used on double-acting piston actuators and sets the pneumatic crossover pressure point of the actuator. The diagnostic parameters monitored are as follows:

- Travel setpoint
- Actuator pressure 1
- Actuator pressure 2
- Supply pressure

The relay adjustment diagnostic test can detect the following issues:

- Booster relay jammed
- Booster relay crossover misadjusted
- Crossover pressure low
- Crossover pressure high
- Port 1 relay diaphragm failure
- Port 2 relay diaphragm failure
- External leaks
- Fail assist spring weakening or broken

2.4.3.5 Travel Deviation Test

The travel deviation diagnostic test evaluates the reasons that a valve assembly is deviating from the setpoint. The diagnostic parameters monitored are as follows:

- Travel
- Travel setpoint
- Actuator pressure

The travel deviation diagnostic test can detect the following issues:

- Travel calibration shift
- I/P or booster relay fault
- Supply pressure low
- Blocked instrument supply air line
- Valve stuck
- Interlock active
- External leaks

2.4.3.6 Air Mass Flow Test

The air mass flow diagnostic test calculates the total air received and used by the positioner. It calculates the flow rate from the instrument air supply header and the output to the actuator. For double-acting actuators, it can identify the positive and negative flow rates to each side of the piston. The diagnostic parameters monitored are as follows:

- Relay hall effect sensor position
- Supply pressure
- Actuator pressure 1
- Actuator pressure 2

The air mass flow diagnostic test can detect the following issues:

- Kinked, cracked, or loose tubing
- Piston actuator O-ring failure
- Actuator diaphragm leaks
- Incorrect regulator setting
- Filter regulator plugging

2.4.4 Partial Stroke Test

The purpose of the partial stroke test is to ensure that the valve assembly will move upon demand. A valve signature type of test is performed while the valve is in service and operational. The valve is partially stroked while the input signal is still continually monitored. If a demand arises, the test is aborted, and the valve moves to its commanded position.

The partial stroke valve travel is configurable between minimum and maximum travel limits (typically, between 1% and 30%). The standard test is typically a 10% stroke test. The stroke speed is configurable between minimum and maximum speed limits (typically, between 0.06% per second and 1% per second). The typical default value is 0.25% per second. Data from the last partial stroke test is stored in the positioner memory for retrieval by the software.

A partial stroke test can be initiated in numerous ways, such as the following:

- It can be scheduled by the positioner as an automatic partial stroke test. The test is scheduled to be performed periodically, based on the number of hours in operation.
- It can be initiated through a remote push button switch installed in the field near the valve and wired into the auxiliary terminal.
- A field communicator can be connected to the positioner input terminals. The test is configured and performed by following the menu prompts.
- A software terminal can be used to configure and perform the test by following the menu prompts.

Section 3: Testing Experience

This section presents information that pertains to AOV diagnostic testing, such as travel transducer installation, the proper use of tubing, and typical problems encountered. The use and advantages of strain gauges for the purpose of providing thrust and torque data are covered in detail. Sensor selection and placement are described along with test time requirements and worker qualification.

3.1 On-Line and Off-Line Testing

Key Technical Point
It is a good practice to allow the data acquisition system to warm up 10–20 minutes prior to performing any diagnostic test. Consult the manufacturer for specifics on the proper warmup period for each system.

Whether testing is performed on-line or off-line is typically decided by accessibility and the impact of risk on unit operations. Many safety-related systems will have windows of availability, but maintenance activities can challenge the available timeframe. Testing of a valve can typically be accomplished in these windows, provided that extensive planning is completed and all affected parties are aware of the potential impacts and outcomes.

The other question is the one of physical access. For those plants that have multiple trains of various systems, it might be possible to take one train off-line to perform testing. This is sometimes a challenge because of lack of access due to radiation levels during operation. These types of questions are individual to the plant design and the amount of risk with altering operating configuration that the plants are willing to take on. The advantage comes from moving more routine tasks to the on-line window, resulting in fewer items in an outage to manage.

Regardless of on-line or off-line testing, it is a good practice to allow the data acquisition system to warm up 10–20 minutes prior to performing any diagnostic test. Consult the manufacturer for specifics on the proper warmup period for each system.

3.2 Static and Dynamic System Testing

Static and dynamic testing can be defined as off-line and on-line, respectively. Static testing is performed off-line with the system drained at atmospheric pressure. Dynamic testing is performed with the system in service. Sections 3.2.1 and 3.2.2 define the purpose of static and dynamic testing in greater detail.

3.2.1 Static System Testing

An AOV static test is the simplest and most common test performed on an AOV using digital data-recording equipment. In a static test, the actuator is typically coupled to the valve, and the AOV is stroked while there is no flow, line pressure, or differential pressure (DP) in the pipe. Measurements, including the actuator pressure and stem position as a minimum, are recorded during the stroke. The information that can be obtained and analyzed from the test depends on which data measurements are recorded, but, typically, some information about the actuator output thrust (or torque) as well as some aspects of the valve's required thrust are obtained. Also, indications of valve problems or degradation might be revealed by the data.

3.2.2 Dynamic System Testing

AOV dynamic testing is typically the more difficult AOV test to perform because it requires the most extensive set of instrumentation to be meaningful; also, it requires coordination of system operation with the testing. In a dynamic test, the AOV is stroked while there is flow and DP in the pipe. Stem thrust (or torque) measurements are recorded and can be interpreted to determine the thrust (or torque) required to overcome the loads caused by fluid flow. Further, valve problems that are revealed only by flow-induced loads (such as damage to load-bearing surfaces) might be observed in the data. To be most meaningful, data measurements should include the fluid conditions in the pipe (for example, pressure, temperature, DP, and flow). Test conditions should be evaluated to ensure that sufficient DP load can be generated to provide meaningful results.

3.3 Tubing Diameter

Key Technical Point
Air supply, tubing diameter, and length are important elements of the results and accuracy of the diagnostic tests. When performing diagnostics, mimic the existing tubing configuration as much as possible to minimize the introduction of false errors.

Air supply, tubing diameter, and length are important elements of the results and accuracy of the diagnostic tests. When performing diagnostics, mimic the existing tubing configuration as much as possible to minimize the introduction of false errors. Variance in tube diameter and excessive length from the installed system can change the amount of air volume required to perform the test. This effect can be seen more significantly on larger actuators.

3.4 Actuator Pressure Drop Test

A drop test is used to identify air leakage in the actuator. This is accomplished by locking full supply pressure in the actuator and shutting off the supply signal. Pressure is monitored at the actuator, and readings are typically taken after 1 minute and monitored for an additional 4 minutes.

Based on a survey of plants in the Strategic Teaming and Resource Sharing (STARS) Utility Service Alliance, as a maximum leakage criterion, a drop of 1–2 psi per minute (6.9–13.8 kPa per minute) from the established supply pressure is common. Each plant or utility has established an acceptance criterion of its own; each compares to the criterion previously described. Data from the STARS survey are provided in Appendix C.

Key Technical Point
Based on a survey of plants in the Strategic Teaming and Resource Sharing (STARS) Utility Service Alliance, as a maximum leakage criterion, a drop of 1–2 psi per minute (6.9–13.8 kPa per minute) from the established supply pressure is common. Each plant or utility has established an acceptance criterion of its own; each compares to the criterion previously described.

Key Technical Point
If an actuator fails the drop test, maintenance can be performed prior to final testing. Any actuator air leakage will be evaluated to determine if maintenance is required. Typically, an actuator with less than 2-psi-per-minute (13.8-kPa-per minute) air leakage at full rated pressure can remain in use, and maintenance can be scheduled for the next PM cycle. However, any air leakage should be reviewed by engineering or the responsible program

If an actuator fails the drop test, maintenance can be performed prior to final testing. Any actuator air leakage will be evaluated to determine if maintenance is required. Typically, an actuator with less than 2-psi-per-minute (13.8-kPa-per-minute) air leakage at full rated pressure can remain in use, and maintenance can be scheduled for the next PM cycle. However, any air leakage should be reviewed by engineering or the responsible program owner.

For double-acting piston actuators, the test pressure is typically set at the maximum expected piston DP.

3.5 Advantages and Limitations of Strain Gauges in Data Collection

Strain gauges add a new dimension to acquisition of diagnostic data. They provide data directly related to changes in stem geometry (diameter for thrust, deflection for torque) due to load or the lack of load. Often, strain gauge information is used solely for indication of seat contact. Typical results can also be compared to the calculated force values derived from the air pressure times the effective diaphragm area. The addition of these direct reading components is seen by many as an advantage in AOV programs.

One challenge for all strain gauge applications can be maintaining qualified personnel who are proficient in the installation of the gauges. Another challenge can be the accuracy of the strain gauges on the very small stem diameters (low force) used in AOV applications; however, it should be noted that strain gauge accuracy is almost always better than inaccuracy due to changing diaphragm effective areas.

As previously noted, an advantage of using a strain gauge can immediately be seen in verifying seat contact within the valve (see Figure 3-1). The strain on the stem shows a spike on the end where the load is applied through the stem, proving that the plug is taking the force in the valve.

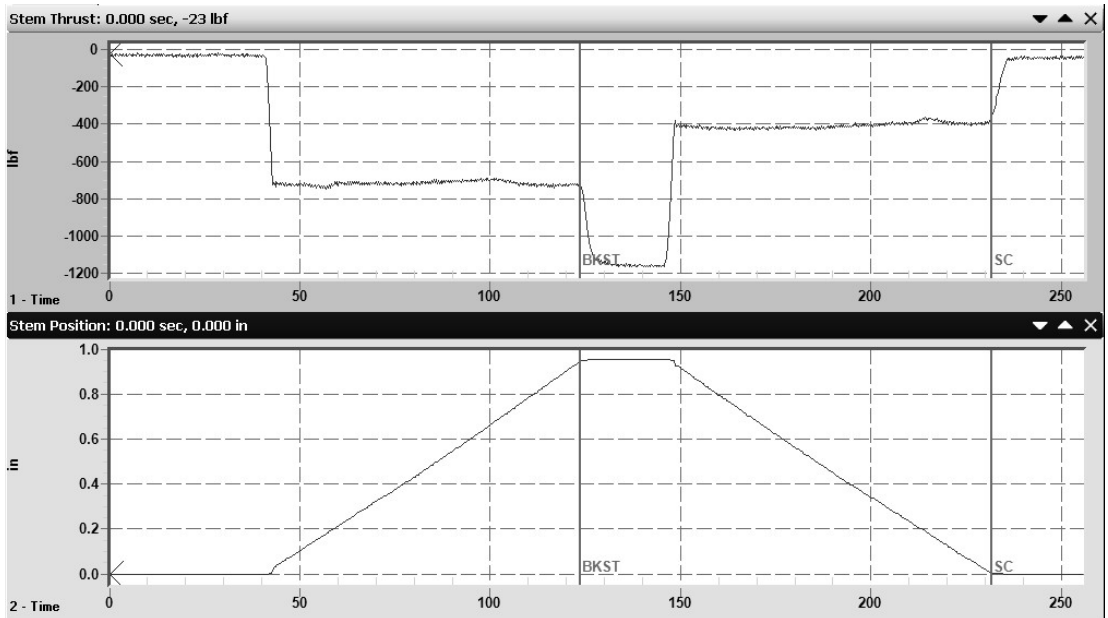


Figure 3-1
Stem thrust marking showing backseat contact in the open direction and seat contact in the closed direction (Valve travel is shown for clarity.)
Used with permission from Crane Nuclear

Key Technical Point
An advantage of using a strain gauge can immediately be seen in verifying seat contact within the valve.

Quarter-turn link and lever actuators are mathematically difficult to analyze using air pressure and displacement. This is because of the changing moment arm as the link and level travel through the valve stroke. For these cases, the valve can be analyzed by plotting the torque vs. travel (see Figure 3-2).

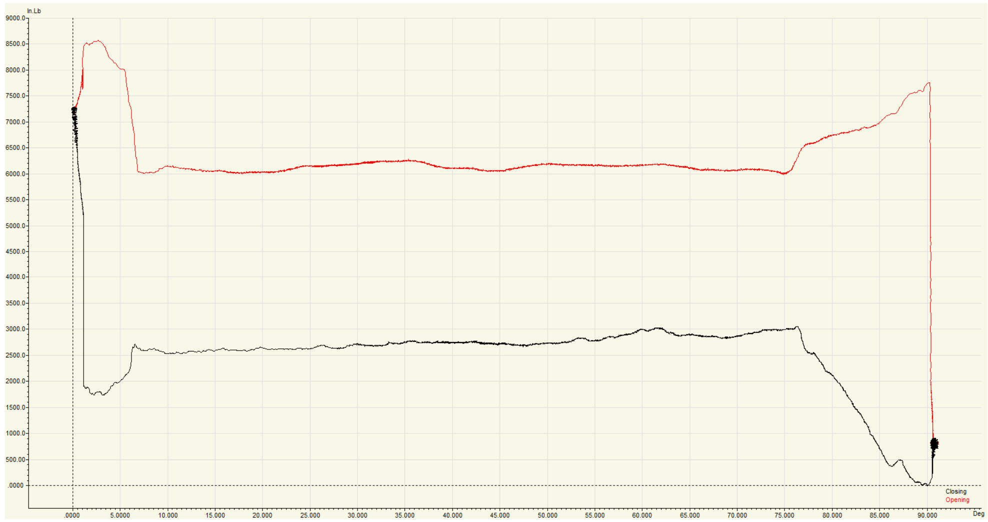


Figure 3-2
Example trace of a segmented ball valve with a double-acting spring-return Scotch yoke piston operator (From this trace, it is possible to determine the strain gauge zero, running torque, seating, and unseating.)
Courtesy of First Energy Nuclear Operating Company (FENOC)

3.6 Test Connections

Figure 3-3 represents a typical control valve test setup for various pressure and travel transducers and parameters measured. A typical on-off valve would contain a solenoid valve in place of the I/P and positioner. A description of the schematic is as follows:

1. **Control pressure:** a 30-psig or 50-psig (207-kPa or 345-kPa) transducer is typically used to monitor control pressure. Depending on the positioner operating range, the I/P transducer will output a pressure in the range of 3–15 psig (21–103 kPa), 3–27 psig (21–186 kPa), or 6–30 psig (41–207 kPa). The pressure transducer channel is designed to monitor the signal.
2. **Supply pressure:** a sufficiently rated transducer is used to monitor supply pressure. Because supply pressures can range by more than 100 psig (689 kPa), it is important to select the correct transducer for the application. An optional transducer may also be placed upstream of the regulator(s) if desired.
3. **Actuator pressure**: a sufficiently rated transducer is used to monitor diaphragm pressure. For dual-acting piston actuators, there will be sensors installed to monitor pressure above and below the piston.
4. **Electrical control signal:** the current or voltage signals feeding the I/P. This electrical signal can be connected to the input of the I/P replacing the normal plant signal or monitored.
5. **Valve position:** a position transducer is used to monitor the valve position.

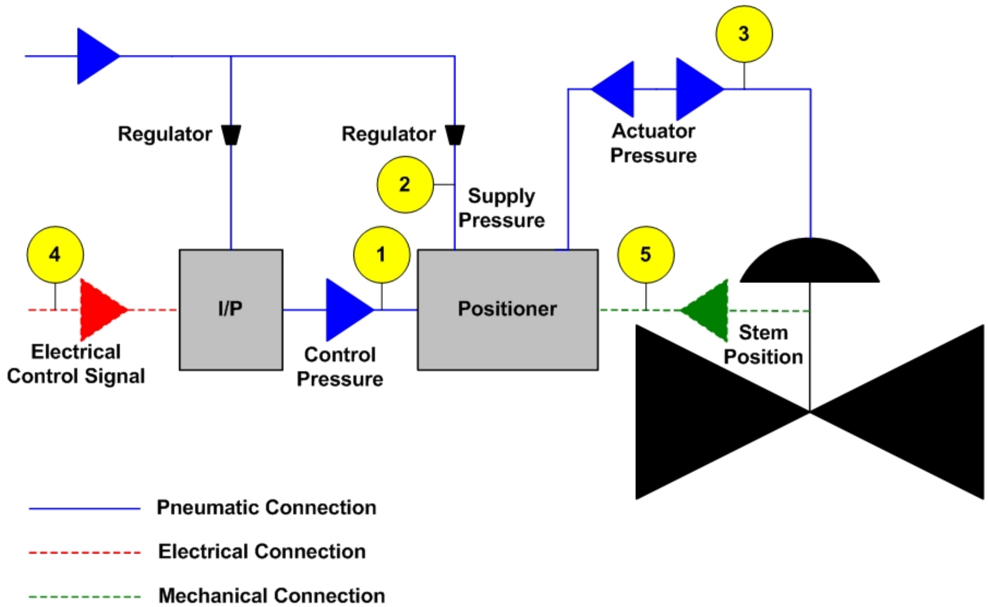


Figure 3-3
A typical control valve test setup

Key Human Performance Point
Consistent location of sensors is of prime importance for the trending of valve performance. Quick disconnects or designated testing connections will provide efficiency and consistency from test to test.

3.7 Selecting and Mounting Sensors

The type of test and system components will determine the number and type of sensors needed during testing. Consistent location of sensors is of prime importance for the trending of valve performance. Quick disconnects or designated testing connections will provide efficiency and consistency from test to test.

Key Human Performance Point
All of the commonly used items will provide sufficient information, but the skill and knowledge level of the installer will challenge the quality of data obtained.

On components where no test connections are installed, it is ideal to locate the sensor as near to the end usage as practical. For example, locating a diaphragm pressure transducer nearest to the diaphragm rather than on the positioner is best. The effects of tubing length plus any components that could be restrictions (such as booster relays or solenoids) will be reduced if located closest to the end usage. Again, consistent test locations provide test results that are easily compared and trended. Sensor selection for the stem force application is varied, and selection is an end user preference that takes into consideration the space, the time available for installation, and the local qualifications and training on each sensor type. All of the commonly used items will provide sufficient information, but the skill and knowledge level of the installer will challenge the quality of data obtained.

There are various sensors used during testing of AOV diagnostics. The most prevalent include the following:

- Pressure transducers (Section 3.7.1)
- Travel transducers (Section 3.7.2)
- Control signal transducers (Section 3.7.3)
- Strain gauges (Section 3.7.4)

These are covered in more detail in the following sections.

3.7.1 Pressure Transducers

Pressure transducers used in AOV diagnostics are made by a variety of manufacturers. The typical ranges include 30 psi (206.8 kPa), 50 psi (344.7 kPa), and 100 psi (689.5 kPa). The sensor ranges provided with the systems are similar for each vendor. Some vendors may supply transducers labeled with colored tape around the sensor to designate which channel it is associated with. Table 3-1 is a typical transducer and channel configuration setup using pressure transducers.

Table 3-1
Typical system pressure channel configuration

Channel	Air	Color Code	Range
1	Auxiliary	Purple	0–100 psig
2	Auxiliary	Brown	0–50 psig
3	Actuator 2 (or auxiliary)	Orange	0–100 psig
4	Supply	Red	0–100 psig
5	Control (instrument)	Green	0–30 psig
6	Diaphragm (actuator, output)	Blue	0–100 psig

Notes:

- Channel numbers may vary by vendor, and some manufacturers require a certain channel order hierarchy.
- Color codes may differ by vendor.
- Pressure ranges may differ by vendor, such as the use of 30-psi (206.8-kPa), 60-psi (413.7-kPa), and 120-psi (827.4-kPa) sensors.

Test connections will minimize time in the field, thereby reducing radiation exposure and costs while improving consistency between tests. Each time a permanently installed fitting is removed from an AOV for testing, there is a risk of galling the fitting or damaging the tubing upon restoration, and the use of permanent test connections minimizes these risks. The largest drawback to installing test fittings on safety-related valves is the engineering cost of performing a design change. In the case of safety-related AOVs, many factors are waived to determine if a design change will provide the return on investment needed to justify the cost. In areas of high radiation dose rates, the reduced exposure will justify the cost.

Key O&M Cost Point
Test connections will minimize time in the field, thereby reducing radiation exposure and costs while improving consistency between tests.

An example of typical installation and configuration of test fittings is in the publication defined in Appendix B, Section B.3.

Figures 3-4 and 3-5 show a typical transducer and channel configuration. The spring and diaphragm actuator shown in Figure 3-4 has a pressure sensor connected to Actuator 1 input, whereas Actuator 2 input is vented. For the piston actuator shown in Figure 3-5, Actuator 2 input will have a sensor connected to the bottom of the piston.

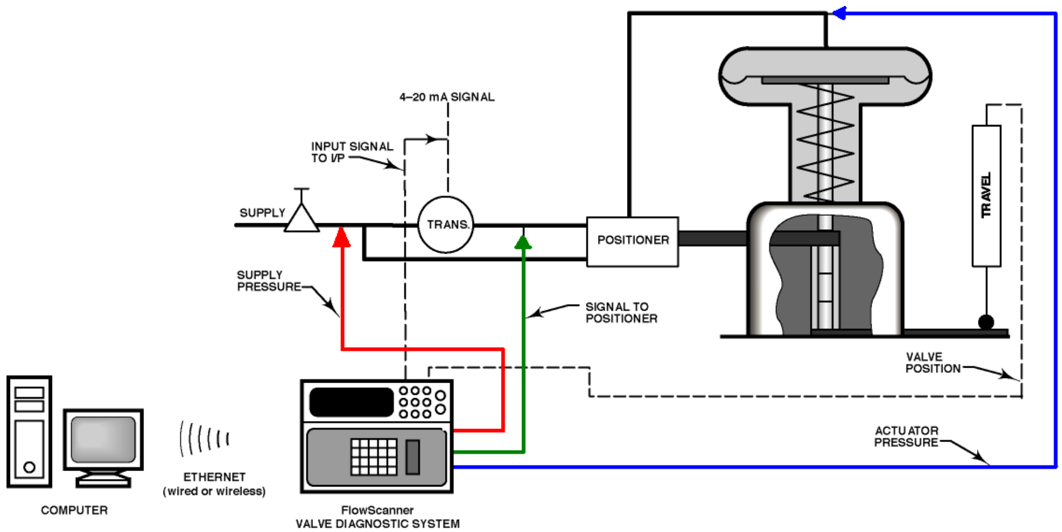


Figure 3-4
Typical test connections for a spring and diaphragm actuator
Illustration provided courtesy of Emerson Process Management, Fisher

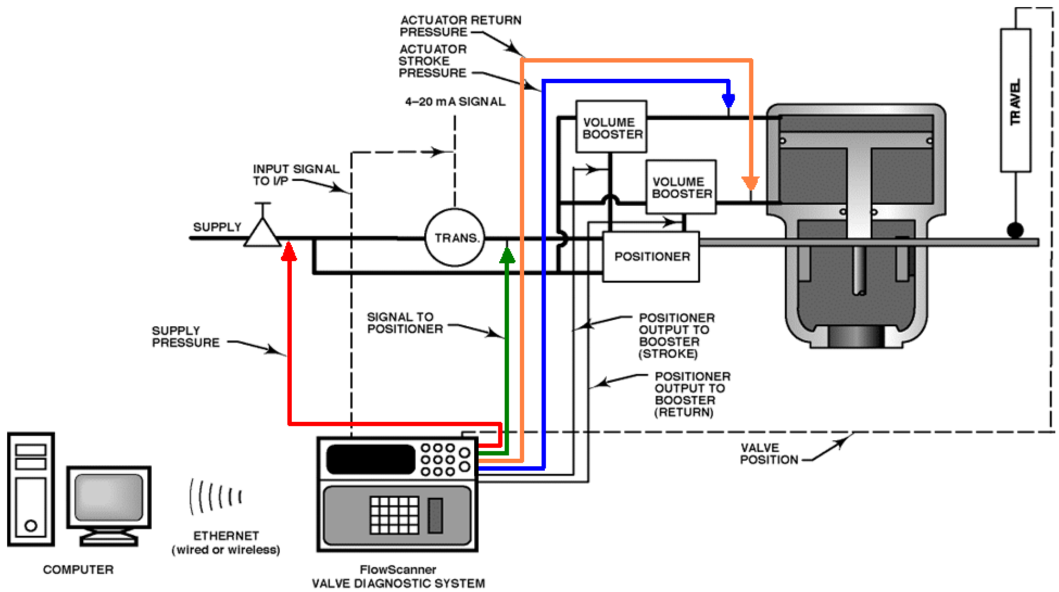


Figure 3-5
Typical test connections for a piston actuator (with boosters)
Illustration provided courtesy of Emerson Process Management, Fisher

3.7.2 Travel Transducers

There are typically two types of travel or displacement transducers used—one for linear stem motion and one for rotary stem motion. Both are covered in the following sections.

3.7.2.1 Linear Transducer

Key Technical Point
Mounting from the actuator to the stem is highly recommended and will give indication of the stretch of the yoke legs when the valve is under full load.

The linear displacement transducers (see Figure 3-6) are typically supplied with a travel length of 10 in. (254 mm) or 30 in. (762 mm). Linear transducers can be mounted on the component by a variety of means, two of which are (1) an extension bar and accompanying C-clamp vise and (2) a magnetic base. Mounting from the actuator to the stem is highly recommended and will give indication of the stretch of the yoke legs when the valve is under full load. This shows up as the slope of the trace from seat contact to full load. To reduce the amount of measurement error, when the linear transducer is mounted, the string should be verified to be straight up and down in two planes.

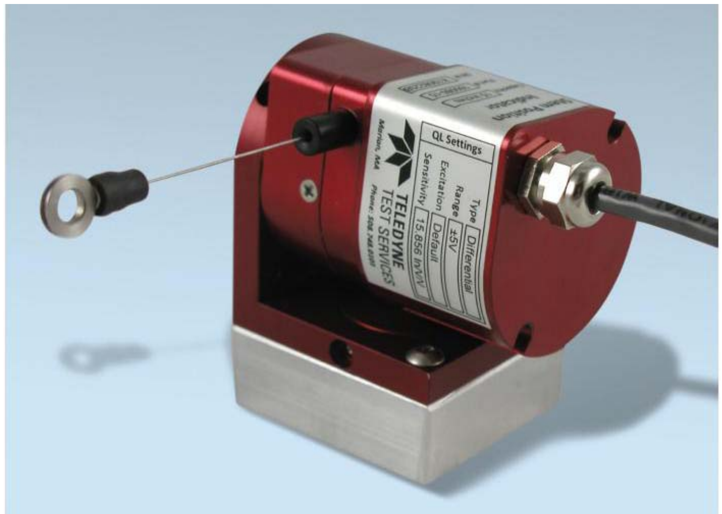


Figure 3-6
Teledyne test services stem position indicator
Used with permission from Teledyne

Key Technical Point
Regardless of the method chosen, consistency is the key requirement for trending purposes.

The alternative is to mount the transducer from the stem with the other end of the transducer mounted on the valve bonnet or a structural steel member (the least preferred method). This method will give a squared seating profile and will not show the stretch of the actuator legs. Regardless of the method chosen, consistency is the key requirement for trending purposes.

For other actuators, such as the Copes-Vulcan fail-close actuators, the user may need to validate the position of the transducer to obtain optimum results. The fail-open actuators can be mounted either on the bonnet or the actuator.

After mounting, the transducer cable is extended from the transducer and hooked onto a stem connector. The two types of stem connectors are those that screw into the stem coupling (mostly seen on Fisher valves) and a vise grip device with an extending T-arm. Multiple connection possibilities are required in order to accommodate the various types of valve/actuator combinations.

Additionally, Teledyne and Crane offer a rotary shaft adapter for the linear transducers (see Figures 3-7 and 3-8). The shaft adapter uses a linear transducer, which makes the transition of monitoring travel in degrees of rotation simple. For each stem size, the diameter is always the same, and the diameter of the adapter is used in place of the shaft diameter. Rotor installation can be performed without the shaft adapter, but the user must apply the correct stem diameter used for monitoring the rotary action.

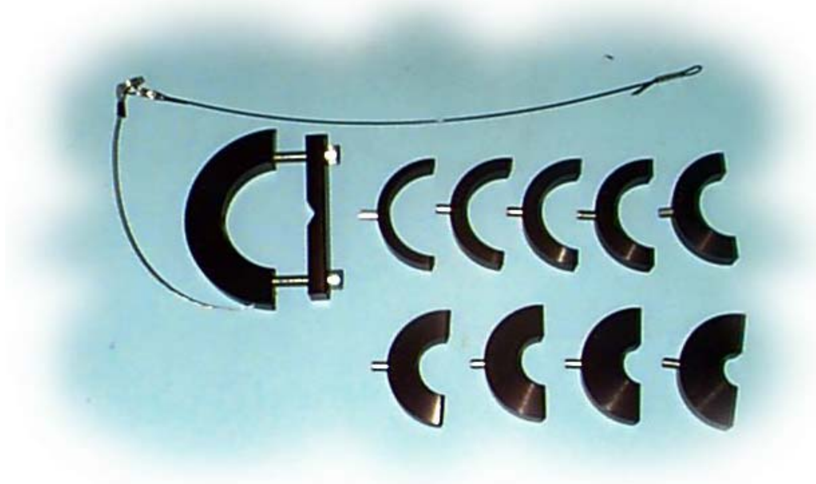


Figure 3-7
Crane's rotary adapter kit
Used with permission from Crane Nuclear

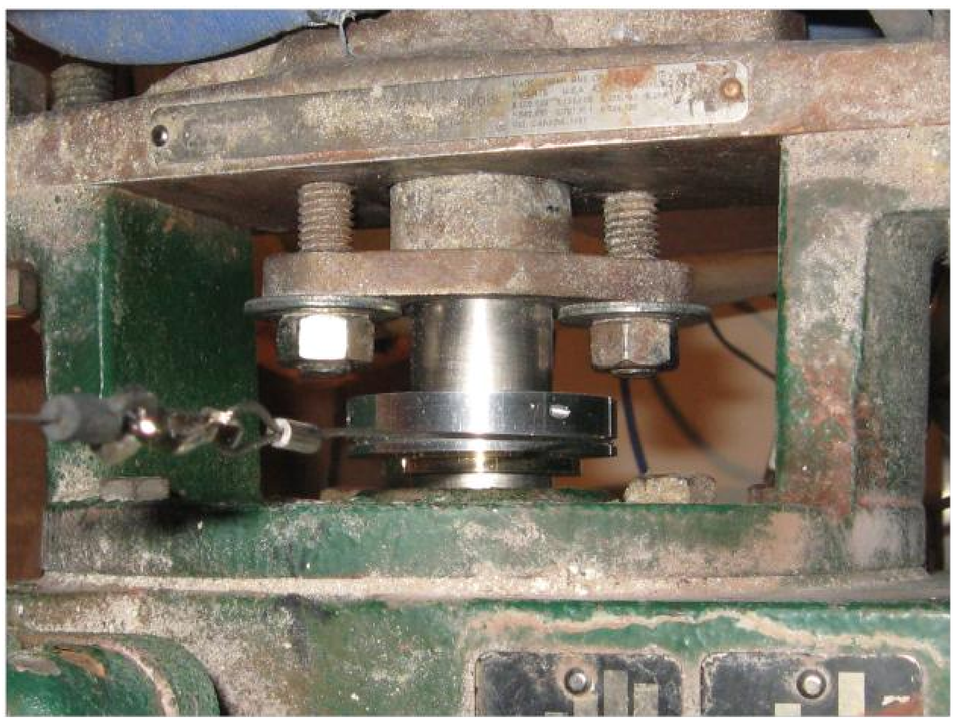


Figure 3-8
Stem position indicator with optional rotary shaft adapter
Used with permission from Teledyne

The displacement setup for a rotary valve with linear motion linkage is the same as explained for a linear transducer. The transducer cable is extended and hooked onto an actuator stem.

3.7.2.2 Rotary Transducer

The typical rotary displacement transducers are Celesco. The system displays the output in degrees. The transducer is typically mounted on the actuator by means of two magnetic bases, as shown in Figure 3-9.

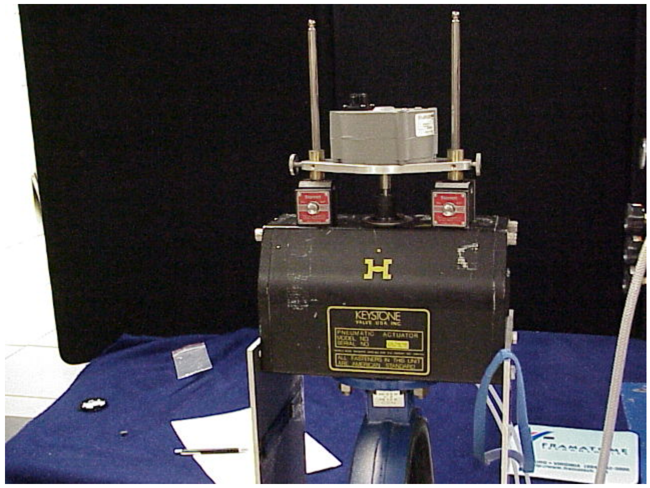


Figure 3-9
Rotary displacement transducer test setup
Used with permission from AREVA N.P.

Position the rotary transducer on the actuator so that the rubber stopper comes in contact with the rotary travel indicator. Obtaining access to the rotating indicator may require removal of a cover plate. Securely connect the transducer to the actuator using the magnetic mounts.

3.7.3 Control Signal Transducer

The control systems are designed to initiate a current or direct current (dc) voltage signal to drive installed or test I/P-E/P controllers. The output signal to the transducer can be configured to a ramp, step, or instantaneous response, depending on the test performed.

Key Technical Point
To maintain a high degree of accuracy and repeatability, the test I/P should be used in the same position as it was calibrated. Additionally, most vendors require the I/P to be in the stable and upright position.

The preferred method would be to use the installed I/P transducer. If the plant I/P cannot be accessed or is not available, a test transducer will be needed. These test transducers can be external modules that receive their signal from the system. The test transducers are typically Fairchild I/Ps (see Figure 3-10); typical ranges are 3–15 psi (20.7–103.4 kPa), 6–30 psi (41.4–206.8 kPa), and 0–120 psi (0–827.4 kPa).

To maintain a high degree of accuracy and repeatability, the test I/P should be used in the same position as it was calibrated. Additionally, most vendors require the I/P to be in the stable and upright position.

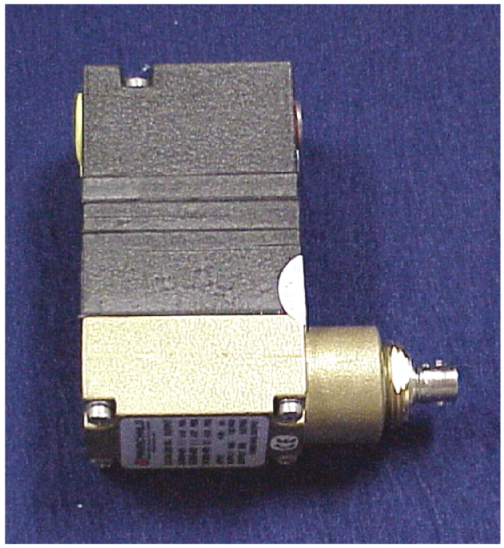


Figure 3-10
Fairchild I/P controller
Used with permission from AREVA N.P.

3.7.4 Strain Gauges (Torque-Thrust Sensors)

There are several types of torque and thrust sensors available, depending on the system that is purchased.

3.7.4.1 Portable, Clamp-On Strain Gauges

Key Technical Point
Clamp-on strain gauges are also sensitive to impact loads, and great care must be taken to ensure the health of the clamp-on transducer. Additionally, clamp-on gauges can be challenged by valves that have very short stroke times and a noticeable impact load upon stroking. The rapid change in acceleration can cause clamp slippage on the valve stem.

Clamp-on strain gauges were developed for use on motor-operated valves when installation of permanently bonded strain gauges was not possible due to interferences. The challenge to using a clamp-on strain gauge on an AOV is obstructions during the full stroke of the valve. Clamp-on strain gauges are also sensitive to impact loads, and great care must be taken to ensure the health of the clamp-on transducer. Additionally, clamp-on gauges can be challenged by valves that have very short stroke times and a noticeable impact load upon stroking. The rapid change in acceleration can cause clamp slippage on the valve stem.

One of the sensors typically used is the nuC[10] Stem Force Sensor from Crane Nuclear, a portable, stem-mounted sensor (see Figure 3-11) that measures thrust on rising stem valves. The nuC sensor is smaller, more stable, and more accurate than the older Crane (Liberty) C-Clamp.

[10] nuC is a registered trademark of Crane Corporation.

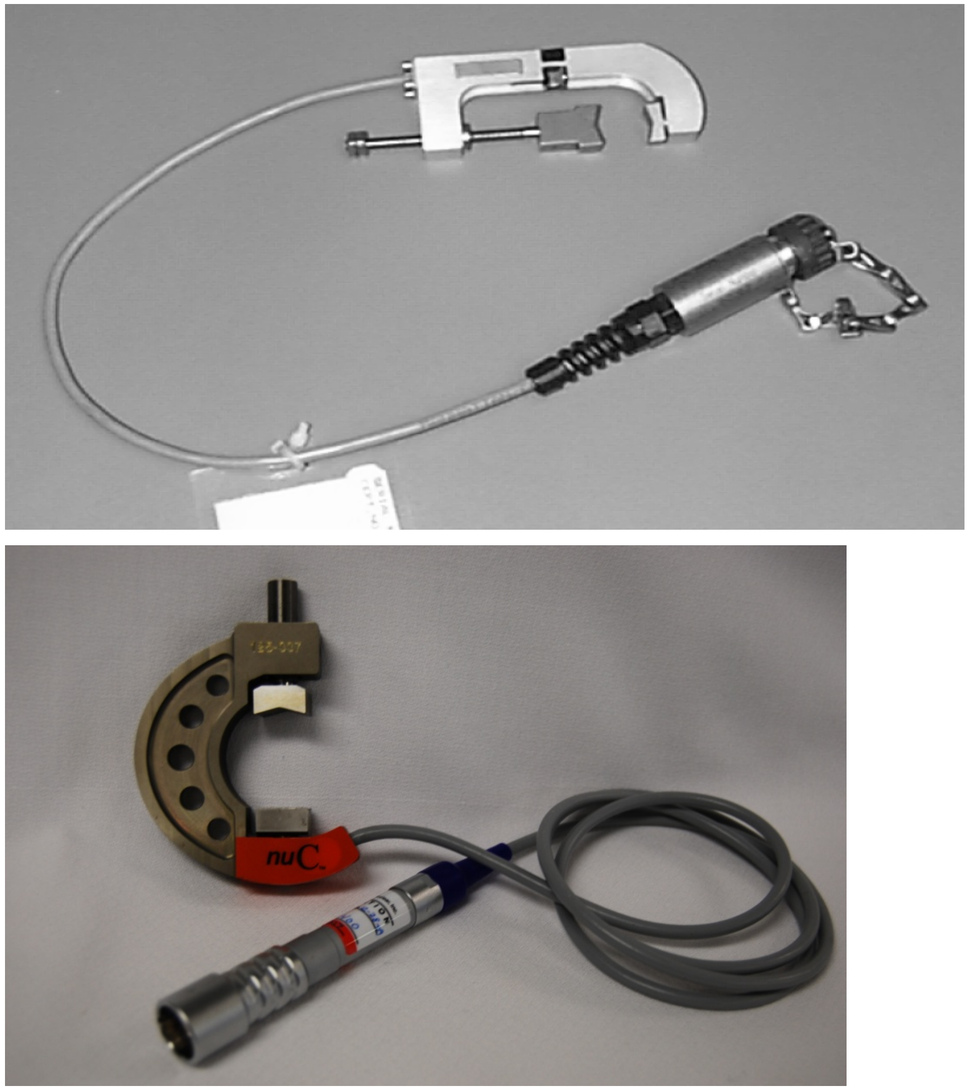


Figure 3-11
The Crane Nuclear C-Clamp (top) and nuC (bottom) sensors
Used with permission from Crane Nuclear

Crane Nuclear's C-Clamp, D-Clamp, Mini, and Micro C-Clamp product lines are strain-gauge-type diametric expansion sensors that are temporarily applied to the valve stem (see Figure 3-11). Most fit inside the yoke and around the valve stem. The temperature limit for standard calibrators is 150°F (66°C), but high-temperature units are available. The purpose of these devices is to provide direct thrust measurement on the valve by sensing the diametric change of the stem. The calibrated sensor's deflection sensitivity is converted by computer to a force sensitivity value using the material properties of the stem, the stem diameter, and the stem thread dimensions as applicable.

Table 3-2
Diameter ranges for stem clamps
Used with permission from Crane Nuclear

Stem Clamp	Stem Diameter Range (in.)	Minimum Required Height (in.)	Temperature Range (°F)	Stem Diameter Range (mm)	Minimum Required Height (mm)	Temperature Range (°C)
Crane nuC 075	0.25–0.75	0.6	≤ 170°F	6.4–19	15	≤76°C
Crane nuC 125	0.75–1.25	0.6	≤170°F	19–32	15	≤76°C
Crane nuC 175	1.25–1.75	0.6	≤170°F	32–45	15	≤76°C
Crane nuC 225	1.75–2.25	0.6	≤170°F	45–57	15	≤76°C
Crane Micro C-Clamp (VVC-100)	0.25–0.625	0.43	≤150°F	6–16	11	≤65°C
Crane Mini C-Clamp (MCC-100)	0.5–1.125	0.43	≤150°F	12–29	11	≤65°C
Crane Extended Mini C-Clamp (EMC-125)	0.5–1.25	0.43	≤150°F	12–32	11	≤65°C
Crane High Temp Extended Mini C-Clamp (EMC-125H1)	0.5–1.25	0.43	≤450°F	12–32	11	≤232°C
Crane Standard C-Clamp (CCL-100)	1–1.875	0.63	≤150°F	25–48	16	≤65°C
Crane Extended C-Clamp (ECC-225)	1–2.25	0.63	≤150°F	25–57	16	≤65°C
Crane High-Temperature Extended C-Clamp (ECC-225H1)	1–2.1875	0.63	≤450°F	25–56	16	≤232°C
Crane Standard D-Clamp (DCC-350)	1.125–3.5	1.00	≤150°F	29–89	25	≤65°C
Crane Narrow D-Clamp (DCC-3131) (3/4 in. [19 mm] narrower than DCC-350)	1.125–3.125	1.00	≤150°F	29–79	25	≤65°C
Crane Extended D-Clamp (DCC-5501)	3–5.5	1.00	≤150°F	75–140	25	≤65°C

If using the Crane C-Clamp, connect the clamp to the valve stem. In rare cases when only qualitative information is desired and access to the valve stem is restricted, one can connect the clamp to the actuator stem.

3.7.4.2 Bonded Strain Gauges

When possible, it is suggested to use a permanently mounted (bonded) strain gauge, such as Teledyne's Quick Stem Sensor (QSS), Crane's Easy Torque-Thrust[11] (ETT), or other direct-bonded strain gauges (see Figure 3-12). Direct-bonded strain gauges are strongly recommended to validate torque generation in quarter-turn applications because of the uncertainty with quarter-turn actuators. If using the QSS, ETT, or UltraCheck[12] strain sensor (USS), install it according to vendor instructions.

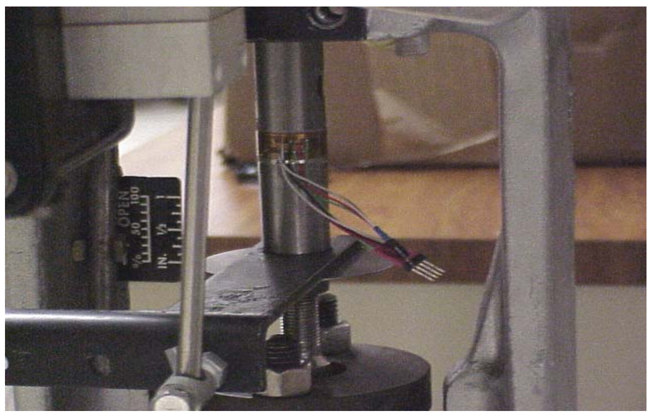


Figure 3-12
Teledyne QSS Sensor
Used with permission from Teledyne

There is a varied selection of devices for directly measuring torque and force. Each diagnostic system supports specific devices; contact the manufacturer of the diagnostic test equipment for details. Table 3-3 presents typical strain gauge selections by various vendors.

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[11] Easy Torque-Thrust is a registered trademark of Crane Corporation.

[12] UltraCheck is a registered trademark of AREVA.

Table 3-3
Diameter ranges for bonded strain gauges

Bonded Strain Gauge	Stem Diameter Minimum to Maximum (in.)	Temperature Limits
Crane ETT-250	0.750–2.500	250°F
Crane ETT-600	0.750–6.000	250°F
Teledyne QSS	0.375–8.00	300°F
Teledyne high-temperature QSS	0.375–8.00	450°F

The following is a list with definitions of the different sensors that are typically used:

- **Crane ETT sensor**. ETT sensors are developed by Crane Nuclear. The sensor mounts on the valve stem and captures stem thrust plus torque data in the open and closed direction for the entire length of the stroke.
- **Teledyne QSS.** Teledyne Test Services (TTS) offers a sensor that is applied to a valve stem using a layer of adhesive (see Figure 3-12). Strain gauges, Wheatstone bridge circuitry, and pre-wired connectors are included in the one-piece transducer. The transducer can be used with or without calibration, depending on accuracy requirements. For greater accuracy, the transducer is calibrated *in situ* for torque and thrust using QuikLook.
- **UltraCheck Diagnostics USS**. In 2005, the UltraCheck Diagnostics Group developed the UCK Strain Sensor (USS). The 2005 model comes in various sizes to accommodate many different sizes of valve stems. The USS is used as a quantitative indication of direct stem force. The USS is installed in a thread-free, no-transition-zone area of the stem. The accuracy of the USS's output is dependent on the stem characteristics (that is, Young's Modulus of Elasticity, Poisson's Ratio, the inner stem diameter, the outer stem diameter, and the gauge factor).
- **Teledyne SmartStem**.[13] The TTS SmartStem measures stem thrust and/or torque using bonded resistance strain gauges directly mounted to the valve stem. These are direct replacements of the valve stems supplied by the valve manufacturers.

Key Technical Point
Test duration has a direct impact on the ability of a component to accurately show a response to a given signal change. Test durations need to be consistent for similar valve configurations to allow for trending of test results.

3.8 Determining Optimal Test Duration

A test must be timed appropriately so that the measured pressures accurately reflect the intended profile. Test duration has a direct impact on the ability of a component to accurately show a response to a given signal change. Test durations need to be consistent for similar valve configurations to allow for trending of test results. Accessories, such as boosters and high-output positioners, could allow shorter test times.

[13] SmartStem is a registered trademark of Teledyne.

For plants that do not use published default times, the test duration must be determined for the application and provide reasonable approximation to stabilized values. A default method has been used and is highlighted in Section 3.8.1.

3.8.1 Running a Ramp Test

The purpose of the slow ramp is to allow the valve to approach its steady-state condition as it is moving along dynamically. It also eliminates or greatly reduces pressure drops and venturi effects in the air tubing and test tees, thus enabling accurate pressure readings. Many factors, such as actuator size (volume) and the presence of high-capacity positioners and volume boosters, affect the ramp time required for an appropriate test. Consequently, it is very important to ensure that the ramp rate will provide a minimized dynamic error similar to static air-flow conditions. Figure 3-13 shows the consequences of an incorrect test duration.

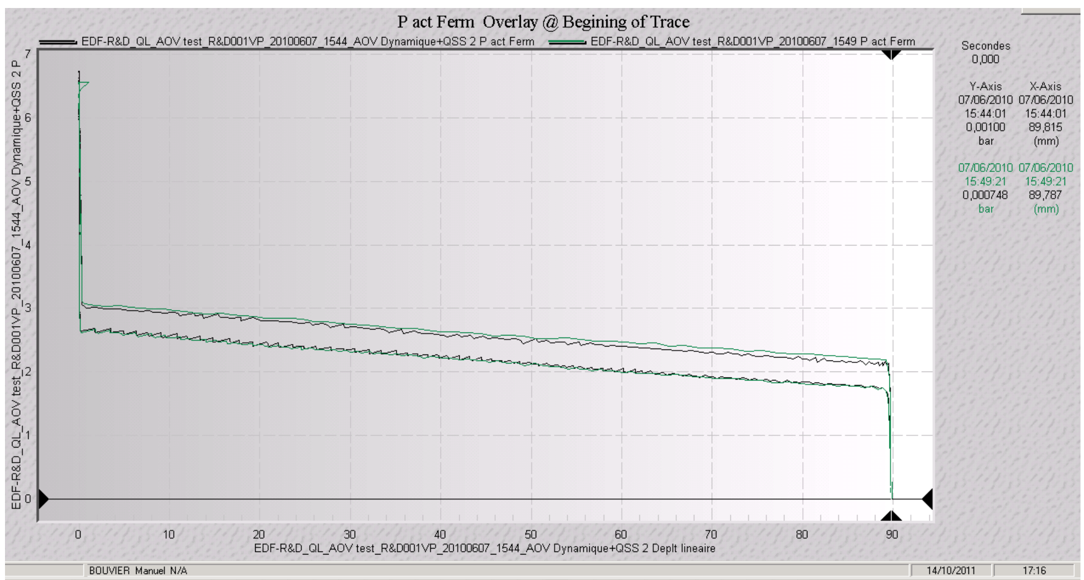


Figure 3-13
Example of an on/off valve and the effect of incorrect test duration (The green line is the suggested speed; the black line is the lowest ramp. Notice the high level of friction on the stem packing.)
Used with permission from EDF

Key Human Performance Point
Qualification of plant and supplemental workers is an important part of obtaining valid data.

3.9 Worker Qualification

Worker qualification is a varied point throughout the industry. Each station establishes their individual level of qualification. Qualification of plant and supplemental workers is an important part of obtaining valid data.

EPRI has taken on a process to establish qualification standardized task evaluations (STEs) to cover diagnostic testing. These are developed by EPRI following the Institute of Nuclear Power Operations guidelines for the Systematic Approach to Training. EPRI has developed practical demonstrations and knowledge-based, diagnostic tests that are available to members for testing of personnel. These standard formats allow for a consistent testing program that will quickly identify the proficient performer.

Key O&M Cost Point
The EPRI STE is a cost-effective way to validate knowledge and qualify individuals. Using this process means that the equivalent that must be written in the training program will have to be performed only once. The EPRI STE process will ensure that all personnel are trained and qualified to the same standard.

Use of the EPRI STE process is not common through the industry. This is a cost-effective way to validate knowledge and qualify individuals. Using this process means that the equivalent that must be written in the training program will have to be performed only once. The EPRI STE process will ensure that all personnel are trained and qualified to the same standard. Most training programs in plants that are EPRI members will accept this qualification. Acceptance of the qualification assures the plant that any qualification that comes from another location will be based on the same standard. Cost savings from this type of evolution has been measured in the tens of thousands of dollars for each activity.

3.10 Trending

Trending of valve performance is done through the comparison desired parameters over time. The selected parameters typically include travel, bench set, friction, seat load, and air pressure. Once specific component data sheets are developed or the values are identified in a calculation, these become the standards that a valve is set to during maintenance and compared to as a result of testing. For example, every valve has a rated length of travel. This would be the standard, and a station would set a value for the acceptable deviation. This same practice would apply to all trended parameters. This method will show how a valve has maintained over an operating period and validate that the component is set up properly at the end of a maintenance period.

An alternative method is to compare current component performance to a previous test using the test trace overlay method described in Section 5.5.8. Criteria should then be established that covers how to handle any deviations from the standard.

Key Technical Point
Acceptance criteria should be established for all valves that will be part of the diagnostic test programs. This could take the form of a plus or minus tolerance to a specific parameter or the meeting of conditions specified in a unique component calculation. The values typically include travel, bench set, friction, seat load, and air pressure.

3.11 Acceptance Criteria

Acceptance criteria should be established for all valves that will be part of the diagnostic test programs. This could take the form of a plus or minus tolerance to a specific parameter or the meeting of conditions specified in a unique component calculation. The values typically include travel, bench set, friction, seat load, and air pressure. Information to determine these values might be according to some of the following typical examples:

- **Travel**: a specific distance to give a required flow rate. This will be based on specific system conditions. Rated travel of the component.
- **Seat load**: this might be required to obtain a specific level of leakage criteria.
- **Friction minimum/maximum**: the minimum may be to establish a minimum amount of load to ensure proper sealing. The maximum may be to ensure that friction does not compromise seat loading.
- **Bench set**: values corresponding to force required to obtain seat load.
- **Air pressure**: sufficient pressure to accomplish a full travel or seat loading condition.

Section 4: Testing Frequency

Key Technical Point
Establishing testing frequency is a result of historical tests and results. The intent is to establish a time interval that is minimally intrusive to the maintenance environment and yet sufficient to predict impending failure or degradation and enable the plant to make repairs.

Key O&M Cost Point
To reduce the impact on diagnostic testing resources during an outage, many plants are making use of system unavailability time to perform diagnostic tests on-line. This requires a proficient team on diagnostics such that impact to the window of opportunity is not encountered by a team that is not efficient in their diagnostic practices.

The testing frequency is established based on historical tests and results. The intent is to establish a time interval that is minimally intrusive to the maintenance environment and yet sufficient to predict impending failure or degradation and enable the plant to make repairs. Ideally, this would be a test in one cycle to determine repairs to be performed during the next. The most effective approach is to use this as a predictive tool on a viable operation.

4.1 Review of JOG Valve Classifications

AOVs are tested based on testing requirements determined by the site AOV PM program. AOVs are screened for inclusion or exclusion from the JOG AOV program. Those included in the program are placed in two categories (Categories 1 and 2) based on their contribution to safe plant operation and/or accident mitigation. Category 1 includes AOVs that are active and have high safety significance. Category 2 includes AOVs that are safety-related and active but do not have high safety significance as well as AOVs determined by an expert panel to be within the Category 2 scope.

4.2 Diagnostic Testing in Relation to Valve Criticality

Valve testing was first looked at under the JOG program as the support for establishing the functionality and verification of the design basis inputs for Category 1 valves. Testing frequency was established at every three cycles or six years—whichever is longer—until sufficient data could be obtained to determine a more appropriate interval. This was a starting ground. This became a method to derive additional data to enhance the periodic cycling programs that were required by other programs. Data would validate the forces available against the design requirements to ensure an available actuator margin.

To reduce the impact on diagnostic testing resources during an outage, many plants are making use of system unavailability time to perform diagnostic tests on-line. This requires a proficient team on diagnostics such that impact to the window of opportunity is not encountered by a team that is not efficient in their diagnostic practices. This also requires confident maintenance and PM procedures to ensure that all tasks are accomplished within the appropriate windows of opportunity.

Category 2 valves did not require testing, unless there was an issue identified in the design basis review that could be solved by testing. This population was initially designed as including a "safety-related and active valve that did not have high safety significance." Many populations have also included "money valves" or "valves having a high impact on unit efficiency." This population has brought the most notoriety to the AOV programs because its impact has affected unit operation by several megawatts, which translates to millions of dollars. This is where trending and periodic maintenance have the most impact. These valves will constantly have the effects of time-related degradation, and, through trending, we have brought these conditions to light. This has successfully restored megawatts to the grid and dollars to each utility's bottom line. The counter of this is that without the judicious following of trend analysis and PM programs, these megawatts will again be lost to the heat sinks as will the associated financial gains.

Key O&M Cost Point
Trending data will forecast when maintenance will be required. By taking this forecasting approach, plants can put themselves in control to budget repairs and determine a priority of the valves requiring maintenance. This allows informed decisions to be made during the outage scope validation meetings.

Periodic testing of these valves really depends on the usage and impact of the individual components. Many of the plants have gone to a breakdown of those with positioners will be tested on a cyclic interval such as those in the Heater drain strings. This also becomes more critical when you go to the boiling water reactor (BWR) designs vice the pressurized water reactor (PWR) designs. The lack of accessibility drives the cost and the overall impact of maintenance very high for the BWR. In fact, most will test these highly important valves every cycle in areas of inaccessibility during plant operation. Calibration of the components can be performed during these visits, and health of the component can be determined. Trending data will forecast when maintenance will be required. By taking this forecasting approach, plants can put themselves in control to budget repairs and determine a priority of the valves requiring maintenance. This allows informed decisions to be made during the outage scope validation meetings. Ensuring system operability for the entire cycle is the point of this maintenance. When the component is normally inaccessible, effective maintenance and PM procedures are musts.

4.3 Regulatory Requirements

Currently, the only document specifying actions in regard to AOVs is the U.S. Nuclear Regulatory Commission (NRC) Regulatory Issue Summary (RIS) 2000-003, "Resolution to Generic Safety Issue 158: Performance of Power-Operated Valves Under Design Basis Conditions." The NRC does follow AOV reliability and its effect on plant operations.

The RIS does make the statement that although the JOG program has limitations, the industrywide implementation of the program would achieve a level of consistency that would provide increased confidence in the design basis capabilities of high-risk-significant AOVs in nuclear power plants. Furthermore, the NRC stated that they will continue to work with industry groups to ensure that safety-related POVs are capable of performing their specified functions under design basis conditions. The attributes to be considered for a successful power-operated valve program and long-term periodic verification are also explained in the RIS.

Section 5: Trace Analysis

Diagnostic trace analysis is a comparison of the design requirements for the component to the actual condition, identification of the deltas, and a determination of the results and actions to be taken. First, you need to know what the requirements are for the specific component. These are best used if they are compiled into a source document that identifies all limitations. These are the tasks that need to be completed prior to the testing period so that they are ready for comparison when the test results are handed in. Methodology varies from site to site, but many work to have a unique document that lists the component, its attributes, and its requirements. Also included in the data sheet are typical and unique requirements, such as stroke time, unique failure positions, and special tests for auxiliary devices, such as lockouts or trip valves that operate at a specific pressure. By consolidating all of this information into one location, you have a much better chance for success in analyzing the test results.

5.1 Test Plot Formats

Test plots will come in two different formats. The first type is an X-Y plot, where a specific set of information is plotted against another specific set. These are also called *cross-plot graphs*. The second type is a time plot where all data will be plotted versus a Y-axis of time. This will allow a comparison of all values at any one point in time. Both have their advantages, and it all depends on one's experience as to which is preferred.

5.1.1 X-Y Plots (Cross Plots)

Realize that test results typically come in four arrangements. The names vary among vendors, but they typically provide the same information. The results of a ramp-type test are as follows:

- Valve/actuator plot
- Positioner plot
- I/P plot
- Control loop plot

These plot types are further defined in the following sections.

5.1.1.1 Valve/Actuator Plot

The valve/actuator plot or net valve plot will typically show the results of the diaphragm pressure plotted on the Y-axis versus the displacement on the X-axis (see Figure 5-1). Figure 5-1 shows the relationship of pressure to open and close the valve at any one position along the stroke. This is also the typical plot used to show friction, which will display as half of the difference between the opening and closing strokes. These lines should be even and parallel during a good valve stroke and represent even friction throughout the stroke. As any frictional force increases or decreases, this is shown by greater widths between the opening and closing strokes at a given location. If this occurs only at a given location, you have identified an anomaly that will require an answer.

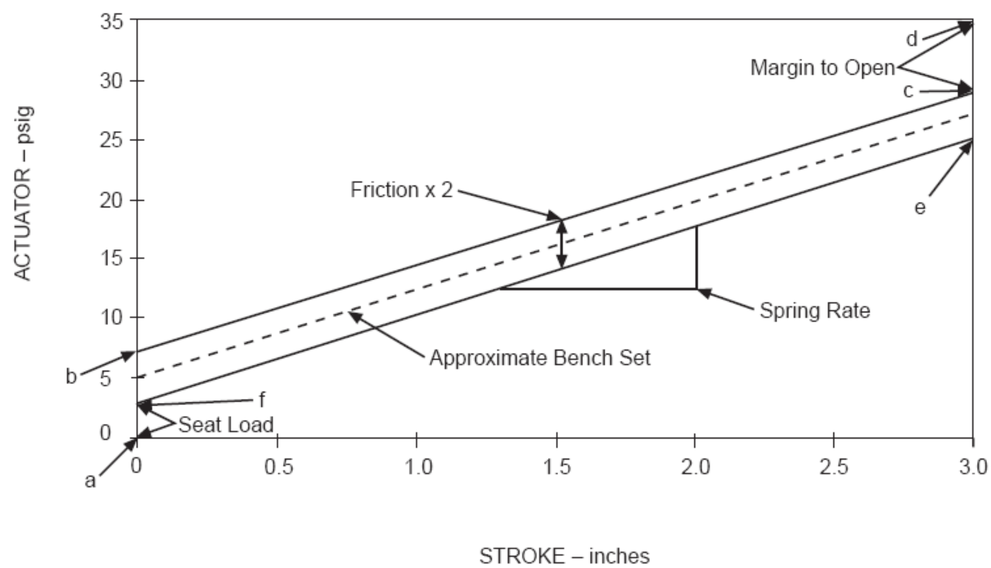


Figure 5-1
Mechanical properties of a valve
Used with permission from Duke Energy

5.1.1.2 Positioner Plot

The positioner plot should look similar to a valve stroke plot, except that the Y-axis will represent the instrument signal into the positioner. This plot shows the relationship between signal and position. The main validation point is that the operations all fall within the minimum and maximum signals to be used, typically, 3–15 psi (20.7–103.4 kPa).

5.1.1.3 I/P Plot or E/P Plot

This plot displays the relationship of the control signal current generated by the diagnostic unit (typically, 4–20 mA) to the signal sent to the positioner (for example, 3–15 psi [20.7–103.4 kPa]) (see Figure 5-2). Again, any anomalies in the straight-line plots need to be addressed.

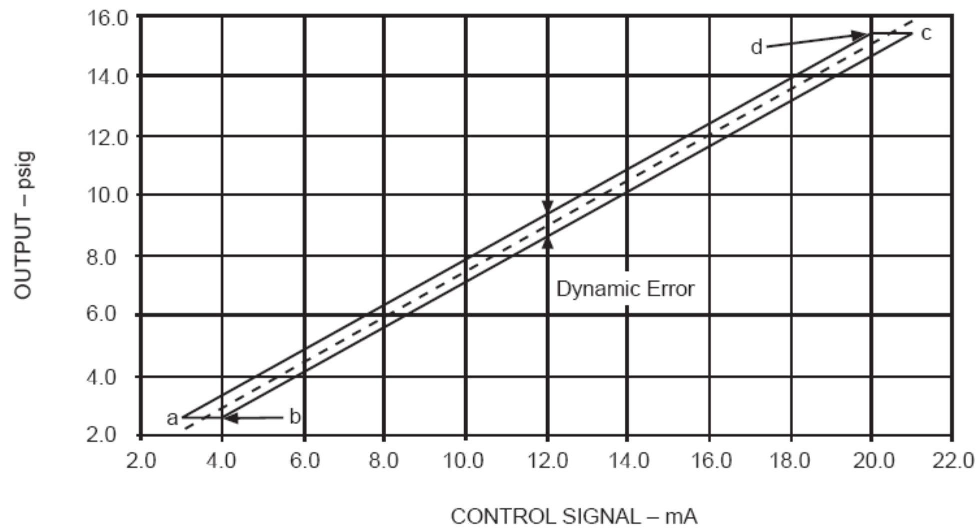


Figure 5-2
Typical calibration of an I/P transducer
Used with permission from Duke Energy

The valve/actuator plot, positioner plot, and I/P and E/P plots all address a specific boundary of the component to determine component health. The valve actuator plot is limited to the valve and actuator operation. The positioner plot addresses only the health of the positioner.

5.1.1.4 Control Loop Plot

The control loop plot addresses the operation of the loop and final control element operation. The plot is typically a 4-mA to 20-mA signal versus travel. This plot indicates whether the expected response from a given signal is obtained. The appearance should mimic the valve actuator plot, but will have a different axis.

5.1.2 Time Plots

The time-based plot displays parameters individually on the Y-axis and plots the time of the test on the X-axis. This type of representation allows for verification of cause-and-effect relationships occurring in the proper order or with the correct delay. The time-based plot is designed for analysis of step-open-close profiles. This plot is used to calculate the 90% response time of various components in the valve control circuit (that is, solenoid valves, positioners, I/P, E/P, volume boosters, and so forth). The theory is to send a 100% change in input signal instantaneously to the valve and measure the time required for each component to reach 90% of its rated response.

Key Technical Point
The overlay option allows the user to view two (or more) sets of cross-plot data on the same screen. This option is particularly useful for graphically depicting changes in a valve's performance over time or as adjustments are made to the performance.

5.1.3 Custom Plots: Overlay

The overlay option allows the user to view two (or more) sets of cross-plot data on the same screen. This option is particularly useful for graphically depicting changes in a valve's performance over time or as adjustments are made to the performance.

5.2 Analysis Preview Marking

In this section, marks are described and defined. The marks listed are typical and will vary based on the data acquisition system that is in use. Marks are used to set points on a plot; these points are used by the system to perform calculations for the desired outcome. There are many reasons that a mark is incorrectly selected by the system. During the analysis phase of a diagnostic test, the user should evaluate marks made by the system; in most cases, they will be acceptable.

5.2.1 Marks

Marks are generated automatically but might require manual placement because of abnormalities in the plot. Typical data presentations that use marks are the time-based plot, the mechanical properties plot, the overall plot, the I/P or E/P calibration plot, and the positioner calibration plot. The plots and marks associated with each plot are listed and described in the following sections.

5.2.2 Time-Based Plot Marks

The time-based plot is designed for analysis of step-open-close profiles. This plot is used to calculate the 90% response time of various components in the valve control circuit (that is, solenoid valves, positioners, I/P, E/P, volume boosters, and so on). The idea is to send a 100% change in input signal instantaneously to the valve and measure the time required for each component to reach 90% of its rated response. Typical markers are as follows:

- **Start of step open:** the start of the step open input control signal; could be the milliampere signal to the I/P or positioner or the pressure signal to the positioner if a transducer is not an accessory.
- **Opening pressure signal:** the opening pressure signal coming from the transducer is marked at 90% of rated pressure or any other location as appropriate.
- **Opening stroke:** the opening stroke of the valve trace is marked at either 90% of rated travel or maximum travel as appropriate.
- **Start of closing:** the start of the closing input control signal could be the milliampere signal to the I/P or positioner or the pressure signal to the positioner if a transducer is not an accessory.
- **Closing pressure signal:** the closing pressure signal coming from the transducer is marked at either 10% of rated pressure or any other location as appropriate.

- **Closing stroke:** the closing stroke of the valve trace is marked at either the fully closed position or 10% of rated travel.
- **Maximum plant supply:** this mark should be used to note the maximum indicated plant supply or regulated pressure that is supplying the positioner.
- **Lowest plant supply:** this mark should be used to mark the lowest indicated plant supply or regulated pressure that is supplying the positioner.

5.2.3 Mechanical Properties Plot Marks

The mechanical properties plot is useful in determining mechanical parameters associated with the valve and actuator operation. For example, values for total friction, spring rate, seating force, and bench set can be determined from this plot. Typical markers are as follows:

- **Minimum/maximum actuator pressure (full closed):** the minimum or maximum actuator pressure with a full closed signal going to the valve.
- **Unseating pressure:** the pressure at which the valve comes out of its seat.
- **Start of opening pilot pressure:** the beginning of the linear stroke of the pilot valve during an opening cycle.
- **Pilot full open:** the point at which the pilot reaches its full open position during an opening cycle.
- **Start of opening main plug press:** the beginning of the linear stroke of the main valve plug during an opening cycle.
- **Main plug full open:** the point at which the main plug reaches its full open position during the opening cycle.
- **Overpressure:** the minimum or maximum pressure that the actuator goes in order to have the valve reach its open stop.
- **Start of closing main plug press:** the beginning of the linear stroke of the main valve plug during a closing cycle.
- **Main plug seats:** the point at which the main plug reaches its closed position during the closing cycle.
- **Start closing pilot press:** the beginning of the linear stroke of the pilot valve during a closing cycle.
- **Pilot plug seats:** the point at which the pilot plug just reaches its closed position during the closing cycle.

5.2.4 Cross-Plot Marks (Control Loop Plots)

This plot is a cross-plot of the input control signal to the I/P or E/P transducer (the X-axis) and the stroke of the valve (the Y-axis). This plot shows the overall calibration and operation of the valve as a complete unit, combining the errors of the transducer and positioner. The cross-plot marks are as follows:

- **Lowest increasing:** the lowest location on the increasing trace where data appear to be running true.
- **Highest increasing**: the highest location on the increasing trace where data appear to be running true.
- **Highest decreasing (maximum open)**: the highest location on the decreasing trace just at or after the valve starts its linear movement. This point will be used to designate the maximum open position.
- **Lowest decreasing:** the lowest location on the decreasing trace just before the valve stops its linear movement.
- **Increasing signal (valve open):** the location on the increasing trace where the input control signal reaches its rated signal to open the valve.
- **Decreasing signal (valve closed):** the location on the decreasing trace where the input control signal reaches its rated signal to close the valve.

5.2.5 I/P or E/P Calibration Plot Marks

This plot is a cross-plot of the input control signal to the transducer (X-axis) and the control pressure output by the transducer (Y-axis). The I/P or E/P calibration plot marks are as follows:

- **Lowest increasing signal:** the lowest location on the increasing signal where data appear to be running true.
- **Highest increasing signal:** the highest location on the increasing signal just before the input signal stops increasing.
- **Highest decreasing signal:** the highest location on the decreasing signal where data appear to be running true.
- **Lowest decreasing signal:** the lowest location on the decreasing signal just before the input signal stops decreasing.

Figures 5-3 and 5-4 are examples of typical parameters that might be marked on a plot.

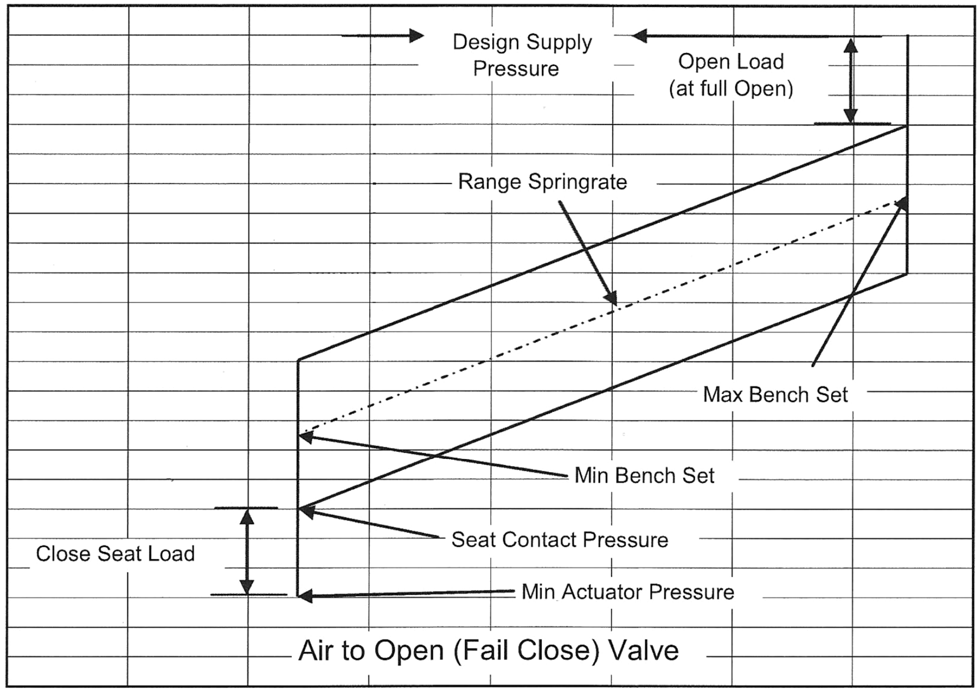


Figure 5-3
Marking air to open (fail close) valve

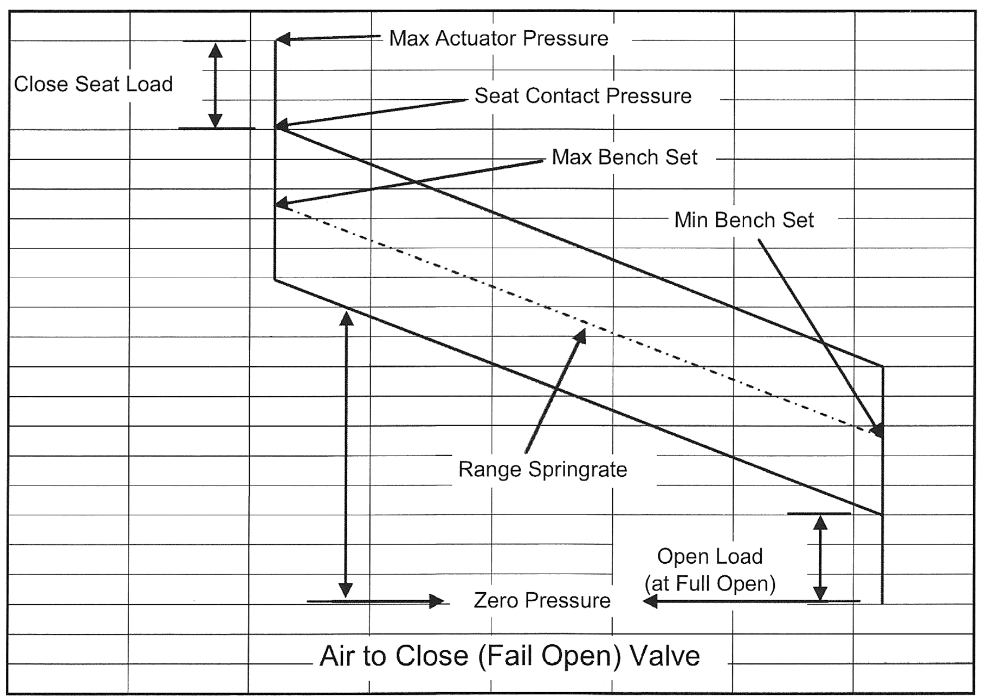


Figure 5-4
Marking air to close (fail open) valve

5.3 Measured Packing Friction Load Using Thrust Data

Using Figure 5-5, one can obtain packing friction by measuring from the middle of the closed running load plateau (Point 9 to Point 2) to the middle of the open running load plateau (Point 5b to Point 6) and dividing by two.

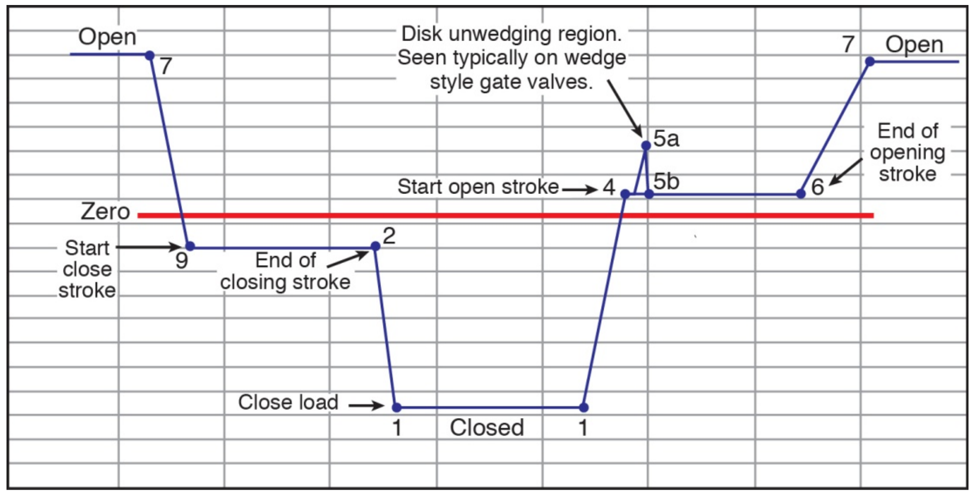


Figure 5-5
Marking packing friction load using thrust data

If running load plateaus are skewed and irregular, a more accurate average running load can be obtained by measuring from the zero to the closed running load plateau (Point 9 to Point 2 or Point 5b to Point 6 in Figure 5-5).

Compare the running load value to the maximum and minimum expected running loads from the AOV setup sheet. No determination of operability is made based on these values; the comparison is simply a check of the packing condition.

5.4 Measured Seat Load Using Thrust Data

Using Figure 5-6, one can obtain measured closing seat load (lb [kg]) by measuring from Point 2 (the point of hard seat contact) and Point 1 (force at full close). Obtain measured backseat load (lb [kg]) by measuring from Point 6 (the point of backseat contact) and Point 7 (force at full open). Compare the measured seat load values to the required seat load from the AOV setup sheet. For active and JOG AOV program valves, this indicates the available margin of the actuator.

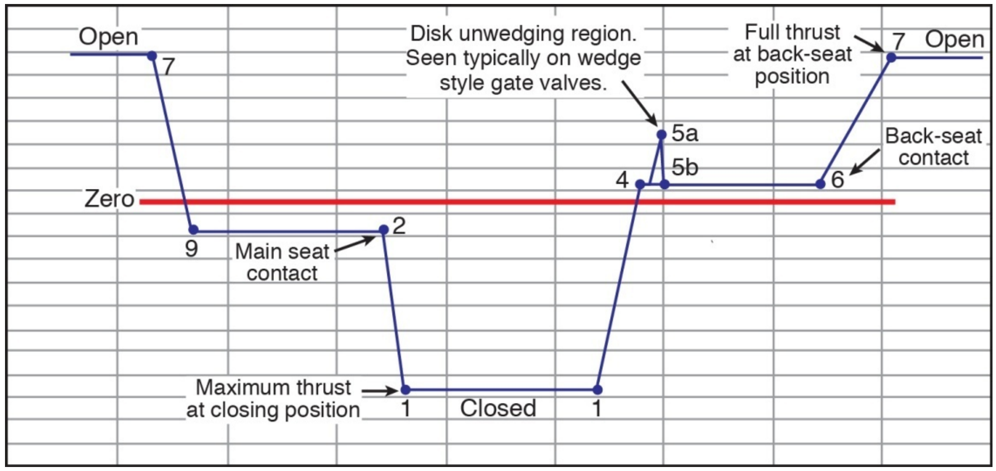


Figure 5-6
Marking seat load using thrust data

5.5 Data Analysis with Example Signatures

The information presented in this section pertains to setting up the data acquisition system for a test to be performed. Also covered are calculations and methods used to determine many of the parameters provided. Plots and graphs are presented to reflect many of the profiles available. These graphs show good and bad traces using various vendor accessories.

5.5.1 Nametag Information

Nametag information is required for any test system; the data are input into the system and used for calculations performed by the system. The information necessary to complete nametag data can be found in several sources, such as the following:

- AOV data sheets
- Vendor manuals
- Vendor drawings
- Valve setpoint data sheets
- Vendor catalog information
- For Fisher valves: valve serial card (need the serial number for valve) (bill of materials)
- AOV testing data sheets (once completed)
- Valve nameplate data

5.5.2 Control Loop Plot

The control loop plot shows the overall calibration of the valve and the type of cam installed in the positioner. This graph is plotted as travel versus signal. The travel is on the Y-axis, and the signal (I/P input in mA dc) is the X-axis. *Total Valve* also shows the total hysteresis and deadband in the valve. The graph should have a "hockey stick" on each end showing that the mechanical stops where contacted at each end. The overall gain of the valve from the input to output is also found on the Total Valve graph. If the graph is not smooth, there is a problem somewhere. The problem can be isolated using other available graphs.

It must be noted that these evaluations are of a specific arrangement of components. The specific arrangement and the locations of sensors could change the exact look of this plot.

Figures 5-7 through 5-13 are examples of control loop plots.

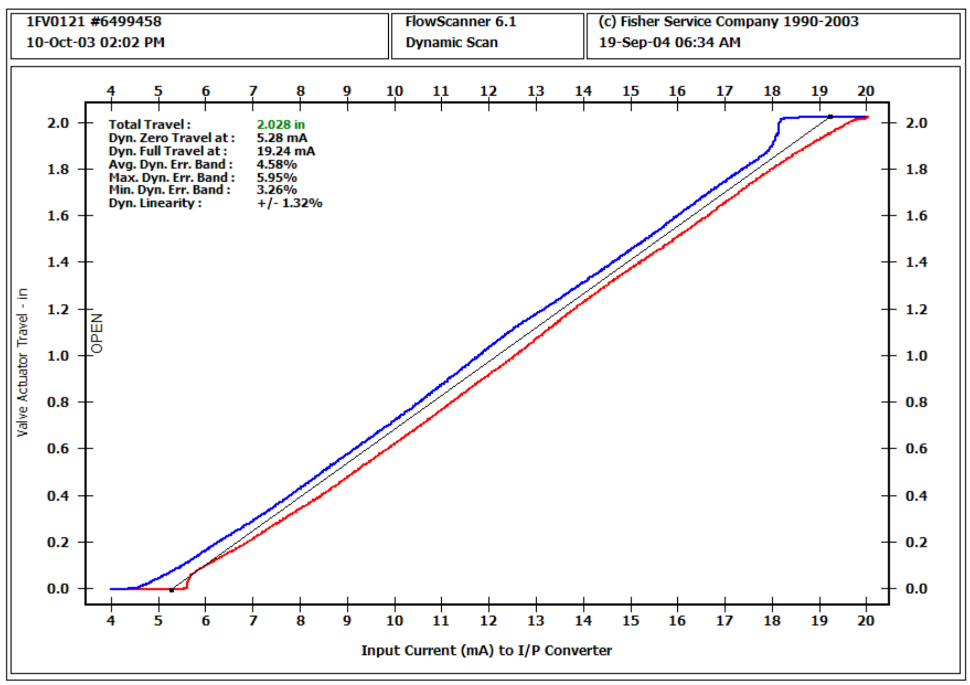


Figure 5-7
Bailey AV1 positioner (linear cam) with pilot valve arrangement showing higher dynamic error band (Valve movement begins at 5.6 mA dc, and the valve seats at 19.8 mA dc.)
Used with permission from Southern Company

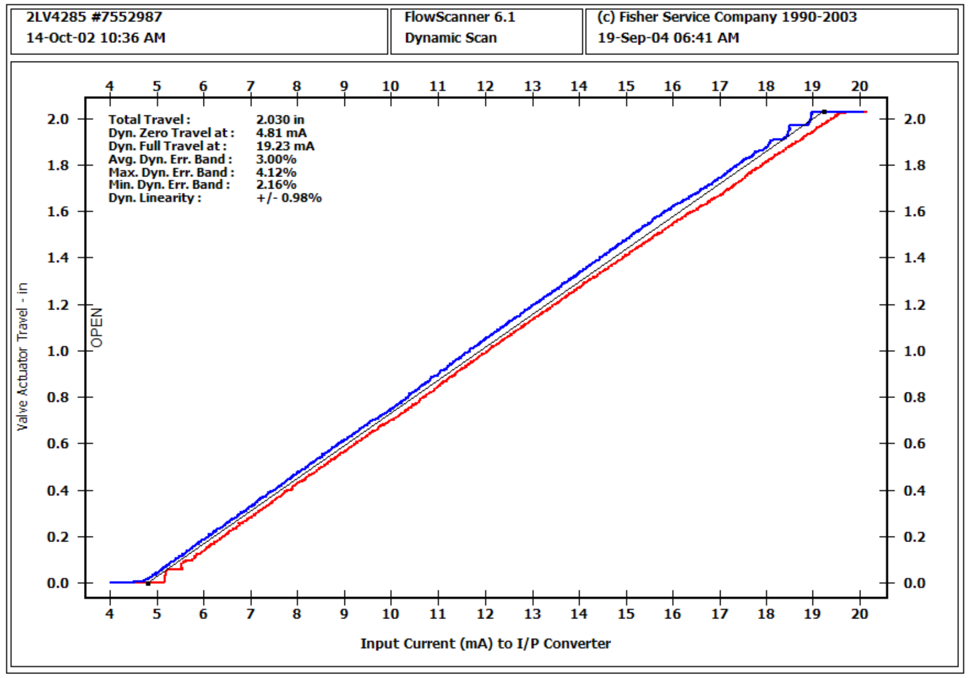


Figure 5-8
Fisher positioner (linear cam) with flapper and nozzle arrangement showing lower dynamic error band
Used with permission from Southern Company

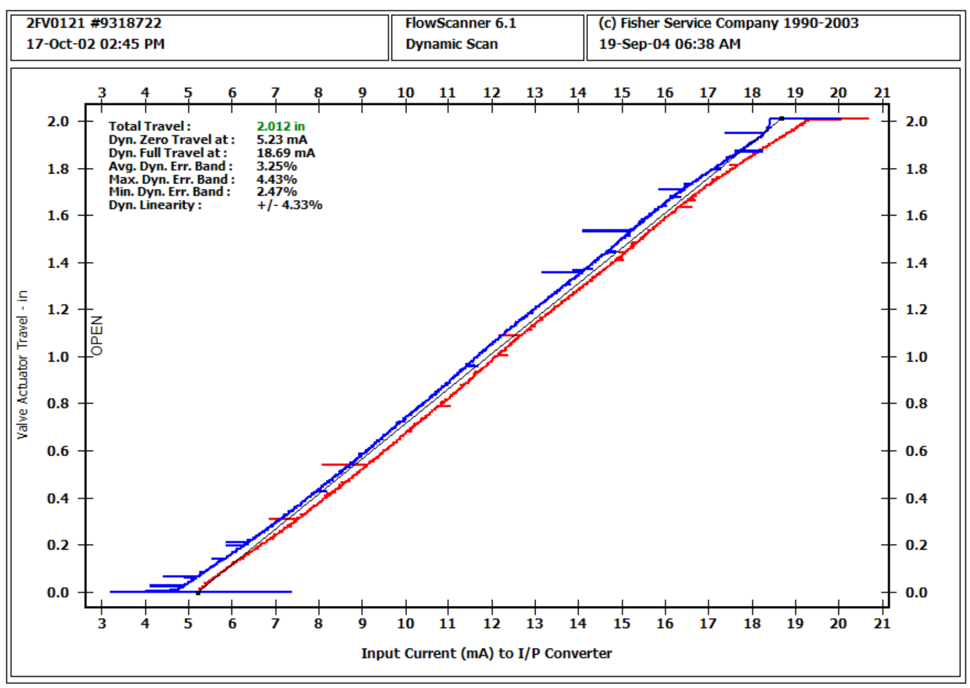


Figure 5-9
Current signal tails from a Masoneilan 7000 I/P transducer
Used with permission from Southern Company

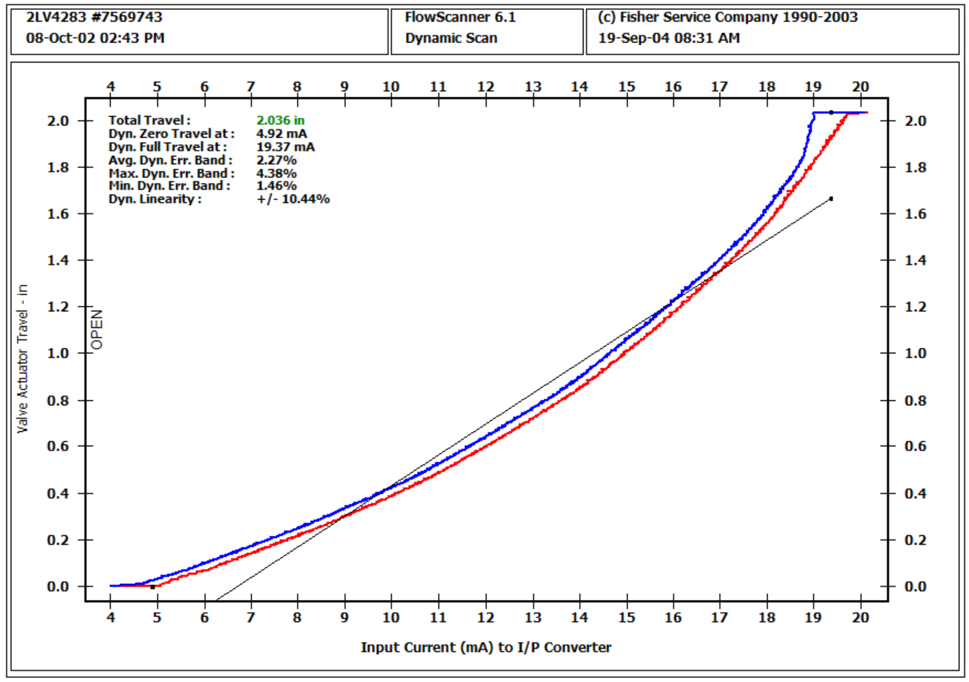


Figure 5-10
Positioner with nonlinear cam (Notice that the best-fit linear line is not in the center of the graph.)
Used with permission from Southern Company

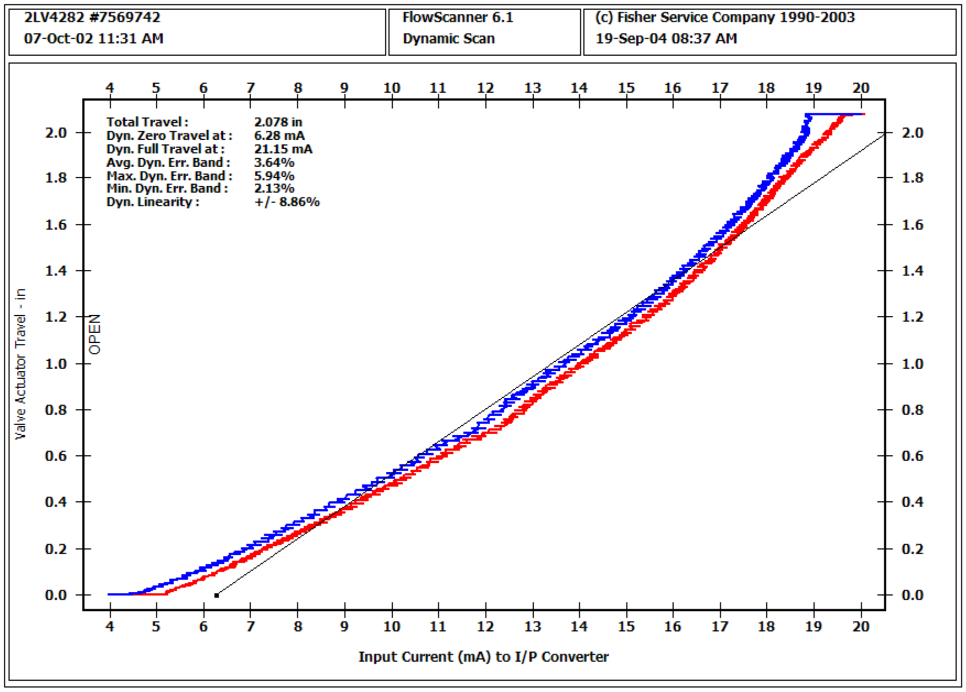


Figure 5-11
Isolations in opening and closing strokes (Notice the bump at 12 mA dc input and 0.7 in. [17.8 mm] valve travel, which is probably due to cam or cam roller wear or wear in the feedback arm.)
Used with permission from Southern Company

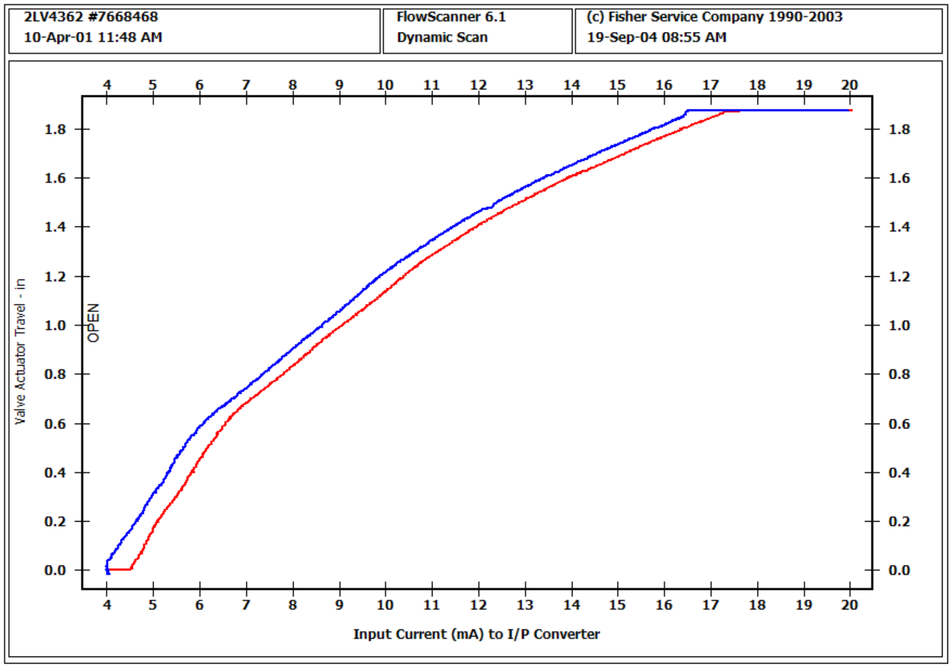


Figure 5-12
Accessories out of calibration identified by the missing hockey stick shape at both ends (The bump and flat spot in the graph could be due to a flat spot on the cam, a groove in the cam roller, and the bump likely from a notch in the feedback arm.) Used with permission from Southern Company

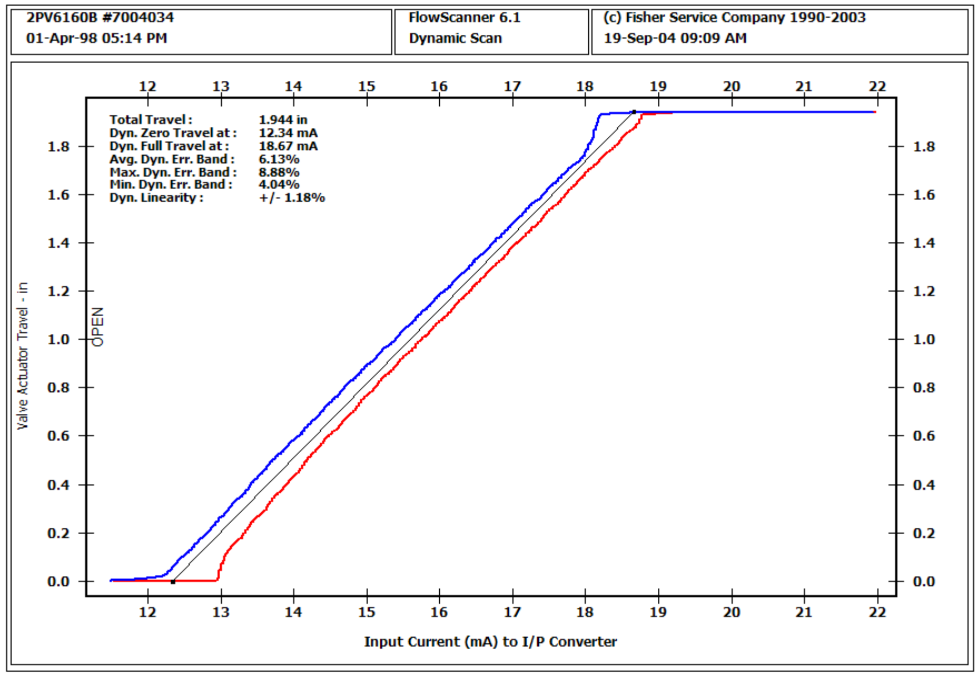


Figure 5-13
Slit ranged positioner (Notice the current on the opening and closing strokes.)
Used with permission from Southern Company

5.5.3 The I/P Graph

The I/P plot of a dynamic scan shows the calibration and performance of the I/P and can help isolate performance problems related to the I/P or the positioner. Because I/P performance depends on the volume of air it must deliver, the performance generally looks worse if no positioner is used (it typically shows a wider separation between the I/O and down stroke). This is because the I/P must supply the total volume needed by the actuator. This graph plots the output pressure of the I/P as a function of the control signal. This plot is typical of an I/P when used with a positioner.

The I/P trace is used to verify the calibration of the I/P transducer and identify any air leaks in the I/P or tubing and connections on the output of the I/P transducer. The dynamic error band for an I/P transducer is typically very small—less than 1%. If an air leak is present, the graph will show a flat spot. The more air that is present, the lower the pressure at which the flat spot will occur on the I/P graph. For example, a small air leak might occur at an output greater than 15 psi (103.4 kPa) for an I/P output of 3–15 psi (20.7–103.4 kPa) output of the I/P. As the amount of the air leaking increases, the flat spot would occur at a lower pressure, for example, 12 psi (82.7 kPa) on the I/P output. If the I/P has a tight shutoff feature, the zero and span might not be calculated properly because the output pressure drops to zero when the tight shutoff value is reached. To analyze these I/Ps, the cursors should be moved to the operating band of the I/P.

Figures 5-14 through 5-18 are examples of I/P graphs.

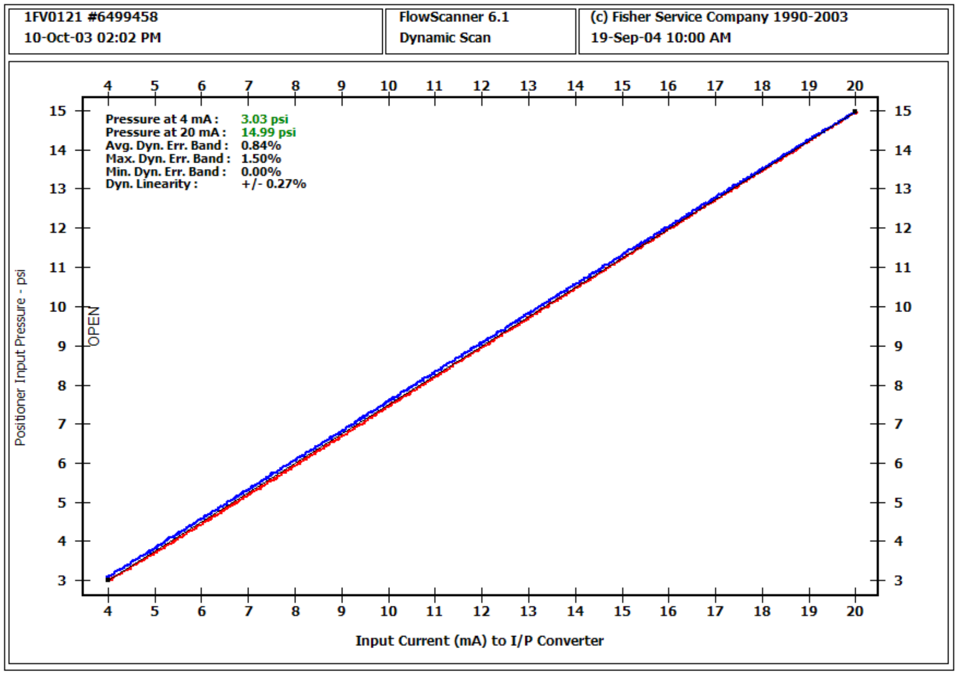


Figure 5-14
I/P transducer connected to a positioner
Used with permission from Southern Company

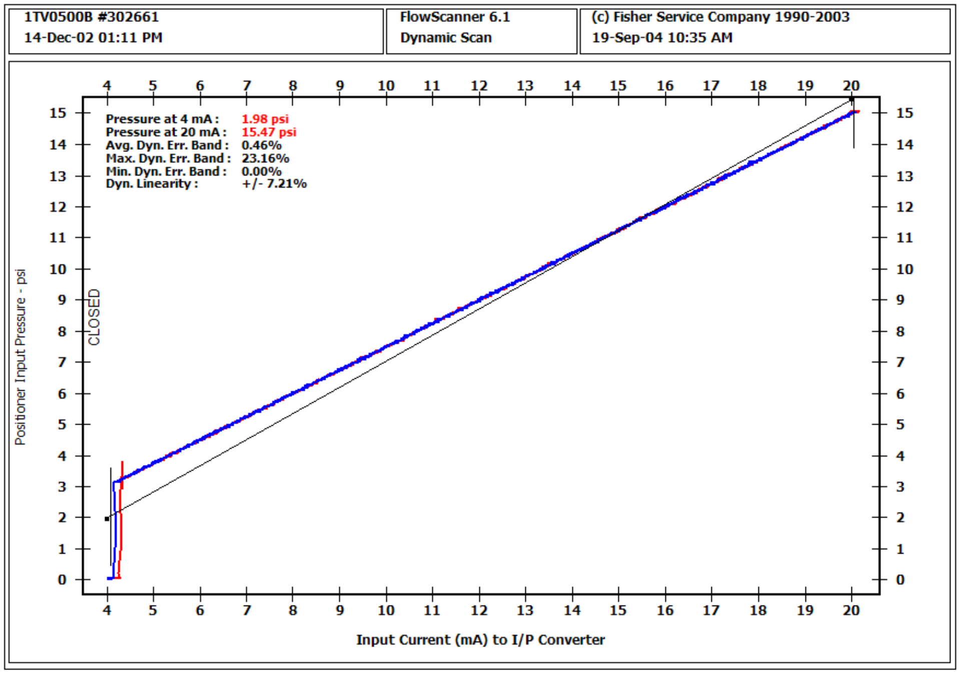


Figure 5-15
I/P transducer with the tight shutoff feature (The best-fit linear line is not in the center of the graph, and the zero and span points of the I/P transducer appear to be out of calibration.)
Used with permission from Southern Company

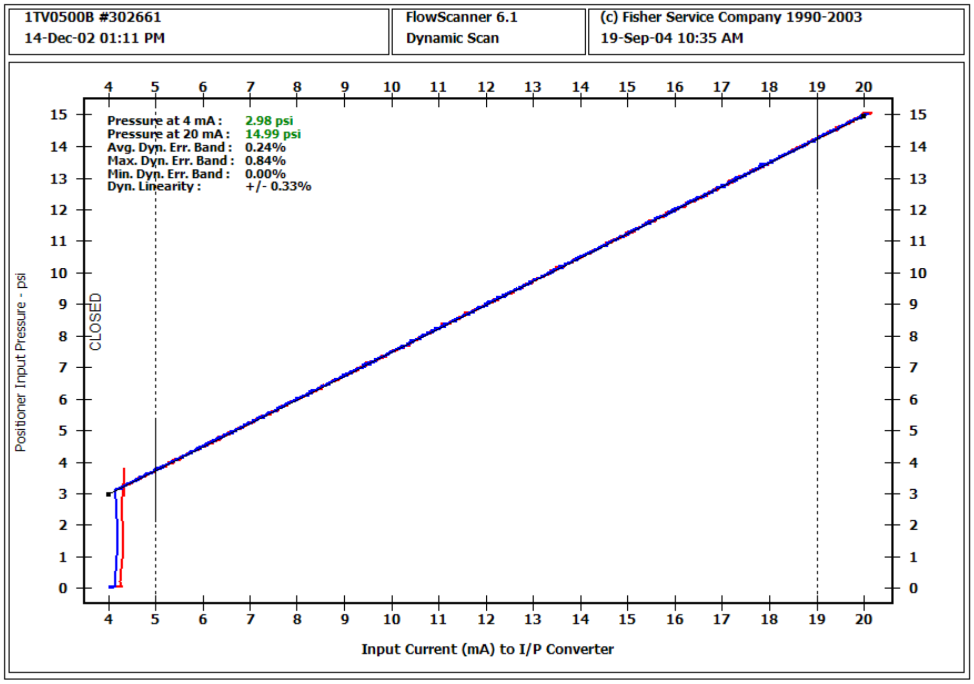


Figure 5-16
I/P transducer with tight shutoff feature and cursors moved back to 5 mA dc and 19 mA dc points with the graph reanalyzed
Used with permission from Southern Company

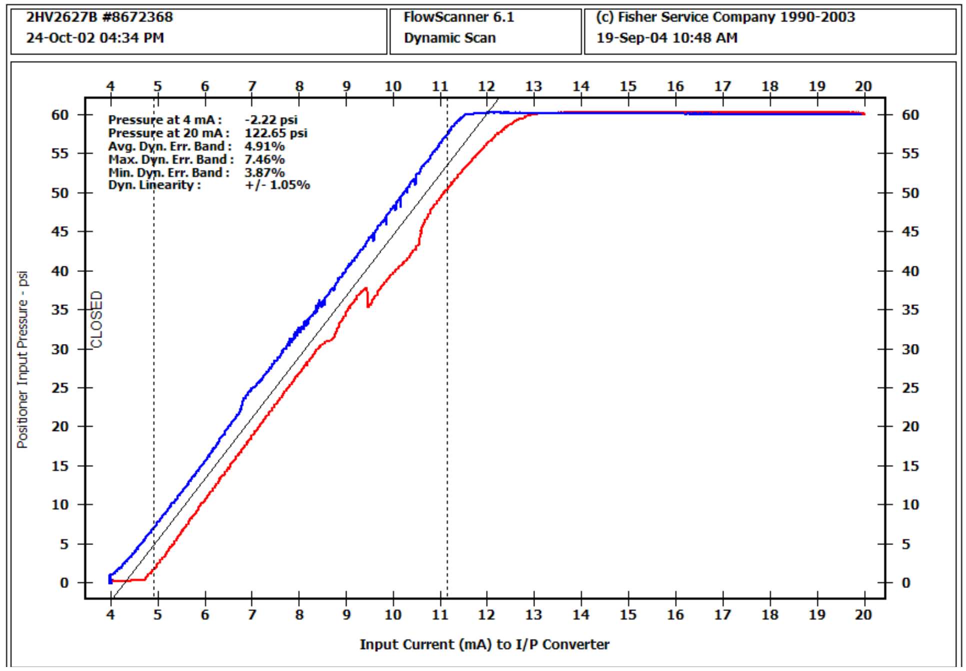


Figure 5-17
Dynamic error band of an I/P used to test a valve without a positioner (The dynamic error is greater than normal.)
Used with permission from Southern Company

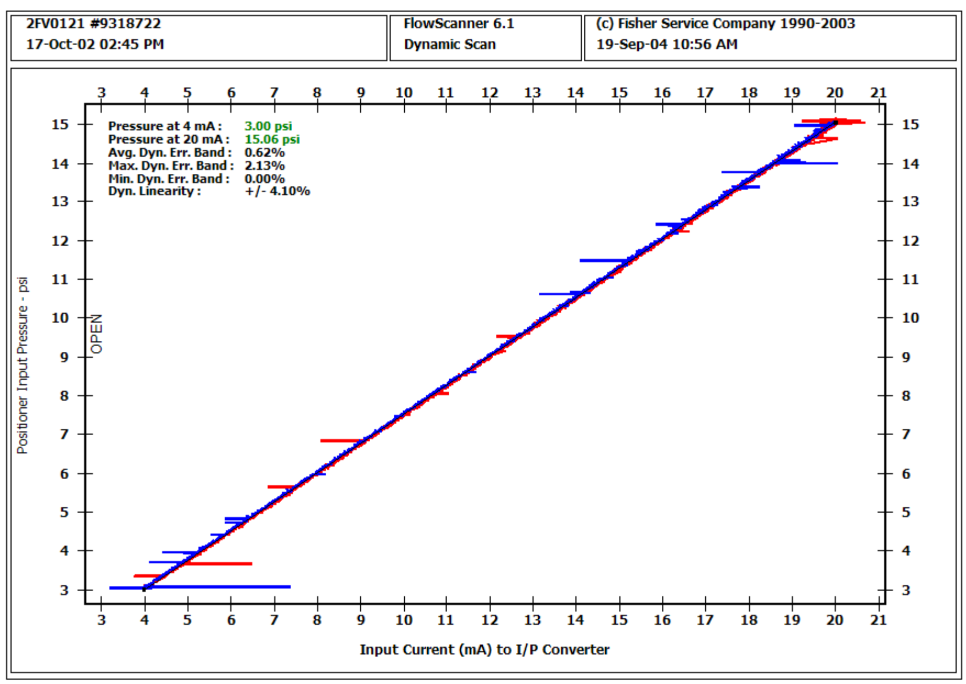


Figure 5-18
I/P graph of Masoneilan 7000 with pulsing output due to use of a redex valve
Used with permission from Southern Company

Tails occur in the current input signal in Figure 5-18; however, the output pressure is not pulsing. Most of the new type I/P transducers also require a current above a certain amount before the I/P will start working. If the signal to the I/P is ramped from below the turn-on current, the I/P transducer will cause a spike in the output signal, which causes the other graphs to look like a problem exists. For this reason, when using these types of I/Ps, the dynamic scan should be started at a point where the I/P transducer has an output.

5.5.4 Positioner Graph

The positioner graph (see Figure 5-19 for an example) shows the performance of the positioner. The positioner graph does not show the static end points marked prior to the start of the dynamic scan test. This graph also shows the relationship of the cam installed to the input signal. Any problems with the cam, cam roller, or feedback arm will also be seen on this graph. This graph, combined with the versus-time plot of supply pressure, positioner output, and I/P output pressure, will verify that the positioner is operating properly. The positioner graph plots the I/P output pressure or positioner input signal versus travel; this graph resembles the total valve graph.

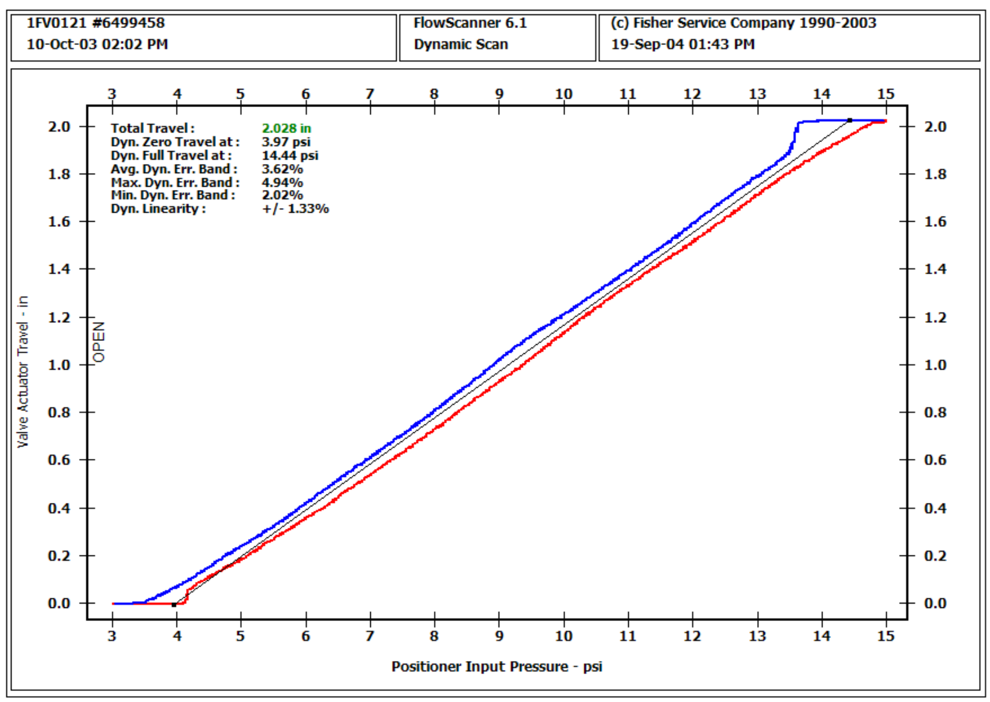


Figure 5-19
A positioner graph
Used with permission from Southern Company

5.5.5 Valve/Actuator Performance Graph

The valve graph shows the mechanical condition of the valve and plots the pressure into actuator versus valve travel. This is the graph in which the friction load, spring rate, valve travel, seat load, and bench set are calculated. This graph should also have "hockey sticks" at each end of travel showing that two mechanical stops are contacted. On a typical valve, at one end of the valve travel, the actuator top stop is contacted; on the other end, the valve seat is contacted. The friction calculated during the analysis on this graph is the total of the valve and actuator friction.

The net pressure versus travel graph will automatically calculate the seat load based on the pressure change between the end of the closing stroke (which could be either end of the graph, depending on whether zero signal is open or closed) and the pressure at a point near where the plug contacts the seat. It draws a small circle around the two pressure points it uses. This works well for most valves and tests, but sometimes test data are such that you believe the points it automatically picks could be improved. You can override the automatic selection of pressures by moving the top and bottom cursors to the pressures that you think it should have selected before you analyze the graph. If either the top or bottom cursor is moved in from the edge of the graph before analyzing, the seat load calculation will be based on the pressure difference between the two cursors.

Sometimes, the ending pressure is directly at the bottom of the screen, and you can leave the bottom cursor in place. However, it must be moved to the lowest actual pressure if that is not the bottom screen position. The top cursor will always have to be moved down.

The dynamic scan test does not perform an actual leak test. Zooming in on the seating action shows how the plug wedges into the seat ring and gives an indication of the trim condition. The stair-step appearance of the plug moving into the seat is actually caused by the digital resolution of the travel sensor. If it had infinite resolution, a smooth trace would be shown. New seats tend to have a sharper break in the curve as the plug contacts the seat. This profile degrades into a more gradual curve with wear.

During the analysis on the valve graph, the following should be verified:

- The opening and closing are linear, except for valves with linkages (typically, rotary valves).
- The valve graph is smooth, without humps or bumps that are not typical for the type of valve being tested.
- The valve stem does not show evidence of stem wear, as indicated by an hourglass-shaped graph.
- The best-fit linear line is in the center of the graph. If not, the cursors might need to be repositioned to center the best-fit line.

- The valve friction is within limits. If the friction is low, the packing should be adjusted to bring the friction within limits. In some cases, a valve repack or valve rebuild on rotary valves might be necessary.
- The points chosen are appropriate and correct.
- The valve travel should be verified to be within limits. If not, the travel should be adjusted.
- The valve does not show signs of seat degradation. One way to look for degradation is to compare with past test data and data from like valves.

Figures 5-20 through 5-32 are examples of valve/actuator performance graphs.

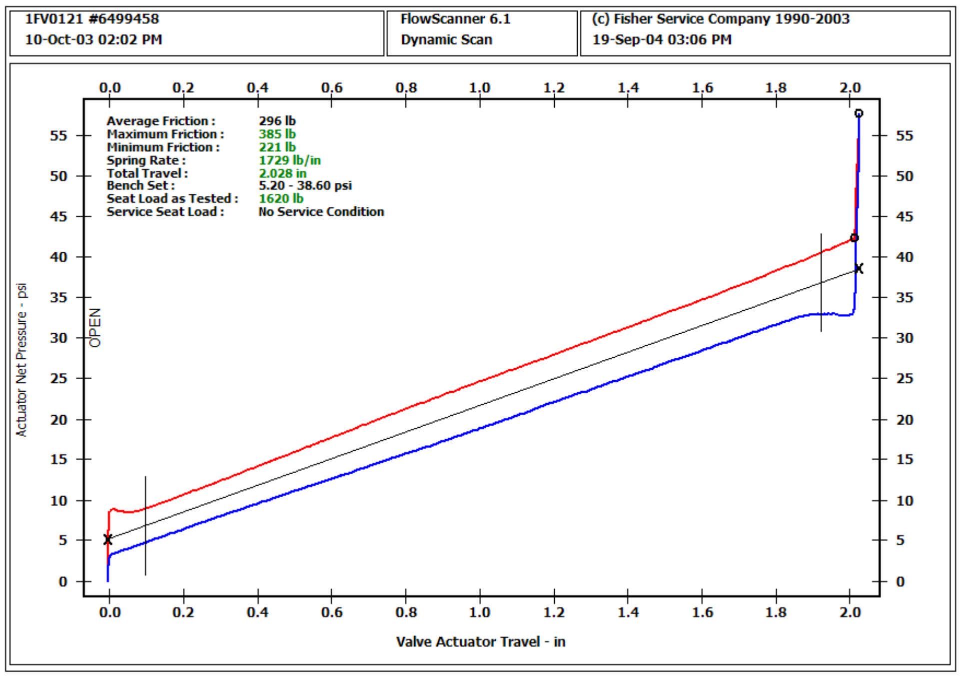


Figure 5-20
A sliding stem globe valve (The black lines [the analysis area] at the 10% and 90% [or 5% and 95% markers] show the area that the bench set, spring rate, and valve friction will be analyzed within.)
Used with permission from Southern Company

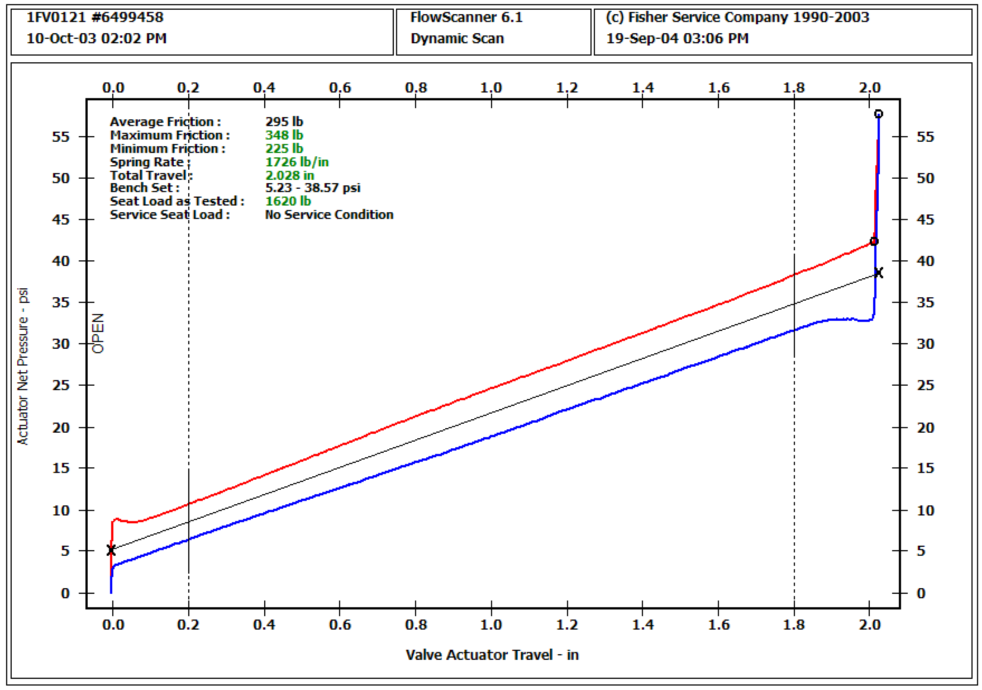


Figure 5-21
A sliding stem globe valve with repositioned cursors (Notice that the maximum friction was lowered from 385 lb [174.6 kg] to 348 lb [157.9 kg]. This was accomplished by mark selection and by not including the larger area at the beginning of closed travel, which was mainly due to air movement.)
Used with permission from Southern Company

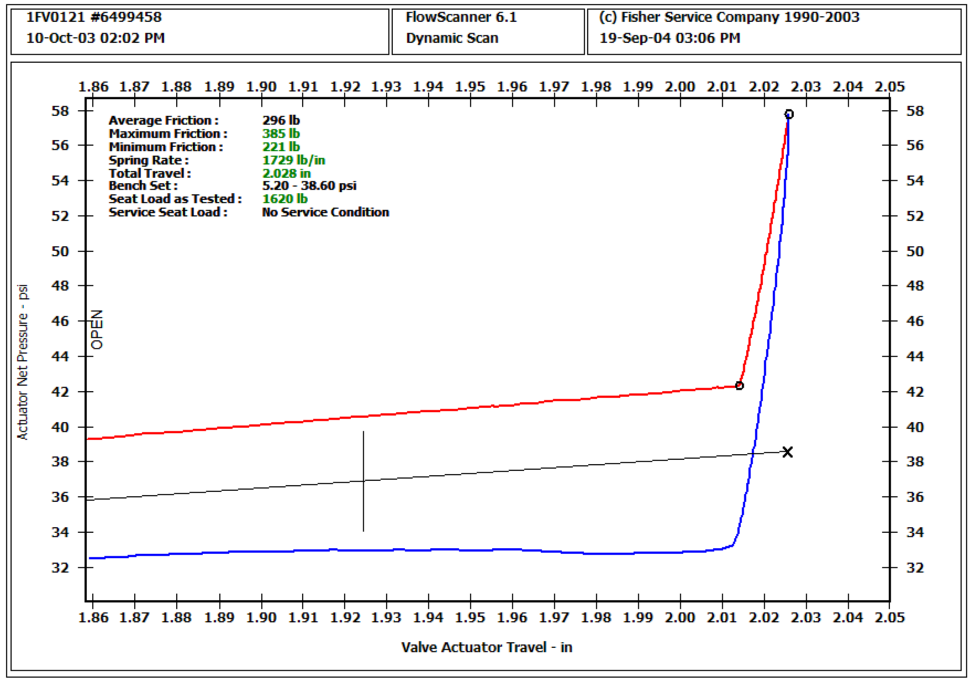


Figure 5-22
A sliding stem globe valve with valve seating points verified
Used with permission from Southern Company

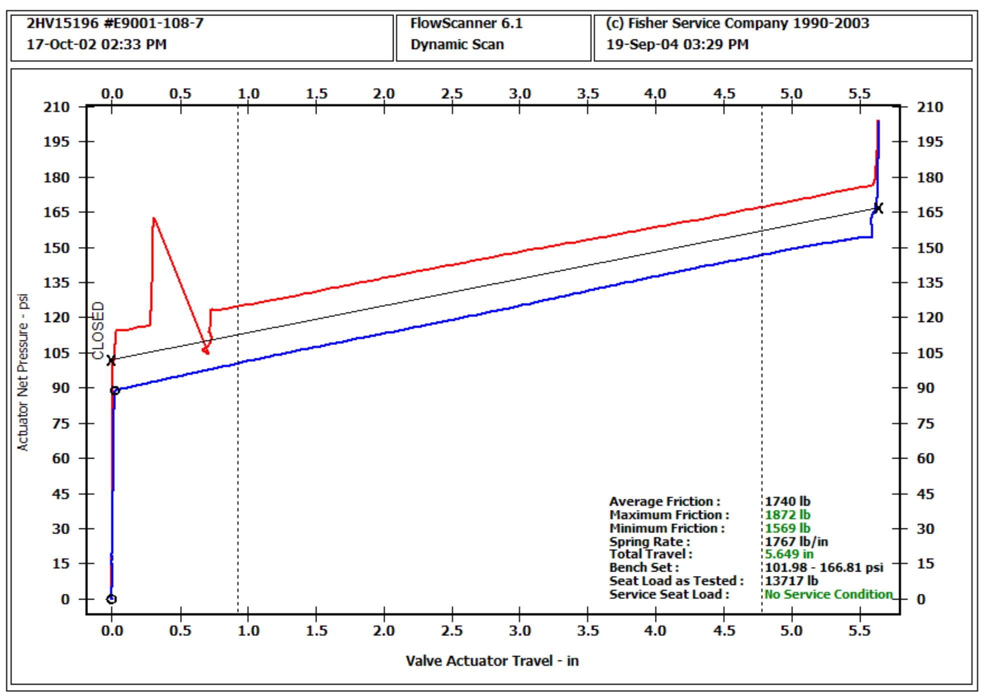


Figure 5-23
A gate valve showing unwedging from the valve seat
Used with permission from Southern Company

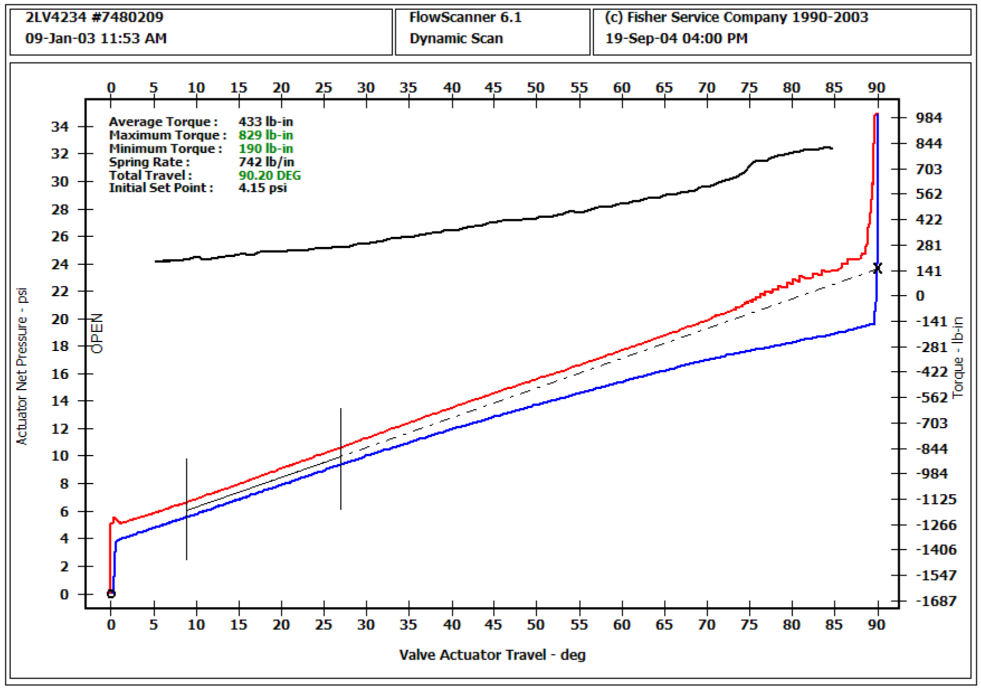


Figure 5-24
A rotary V-ball valve with an overlaid friction plot
Used with permission from Southern Company

Figure 5-25 is the graph for a rotary valve with T-rings with a Scotch yoke actuator; notice that the torque curve is almost constant in the middle portion of the graph, even though the DP is greater in the middle section of the graph. This is because the mechanical advantage of the Scotch yoke is less in the middle than at the ends. Also, note the indicated valve movement with low friction at the opening and closing ends of the graphs—this is due to the gap in the linkage of the Scotch yoke when the direction is changed. The spike in the graph is caused by the butterfly popping out of the T-ring.

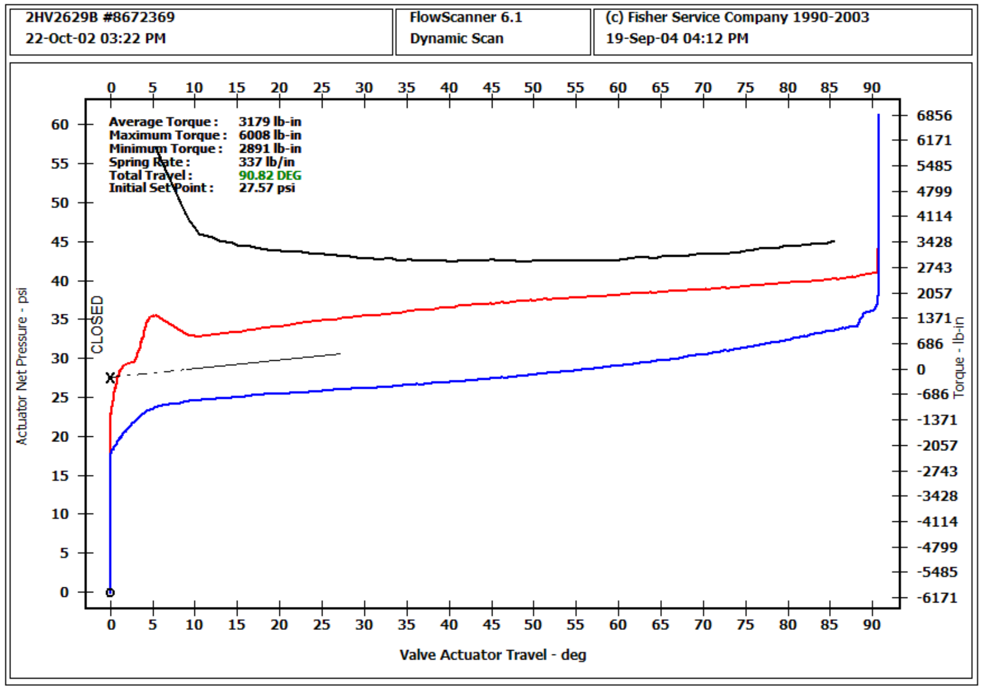


Figure 5-25
Rotary valve with T-rings and Scotch yoke actuator
Used with permission from Southern Company

Figures 5-26 and 5-27 are the graphs of a butterfly valve that was not set up correctly, and the valve is rotating through the seat liner. One thing to remember is that, in most cases, the stops for air-operated rotary valves are in the actuator. Unless the valve and actuator are coupled with the valve removed from the line, the setup is difficult to verify, and valve leakage is likely.

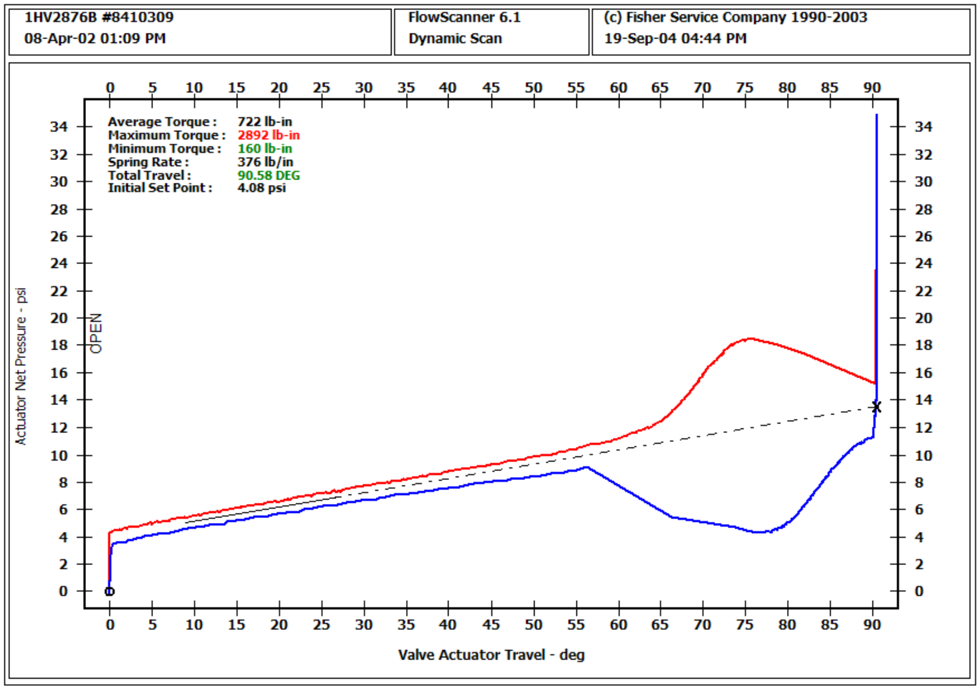


Figure 5-26
A butterfly valve rotating through the seat liner
Used with permission from Southern Company

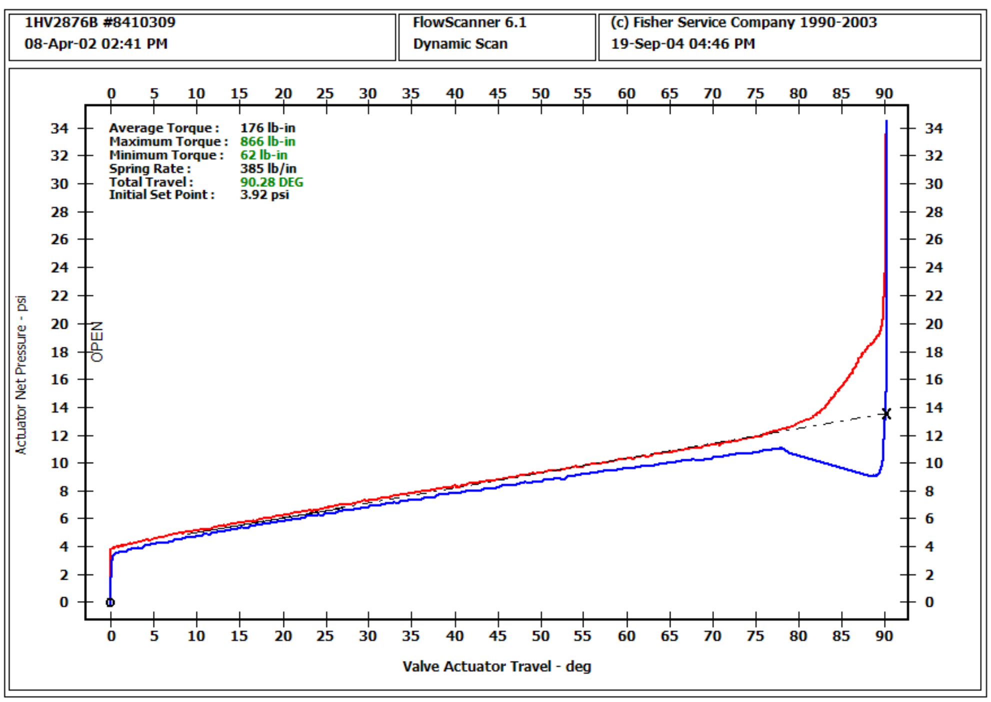


Figure 5-27
The same graph as in Figure 5-26 with the shaft realigned
Used with permission from Southern Company

The packing sticking is shown by the saw tooth type of wave form in Figures 5-28 and 5-29. The pressure is lowered until a point where the valve stem breaks free and travels past the intended area. Plotting the data points shows several data points in one spot; then, when the valve stem starts moving, very few data points are recorded.

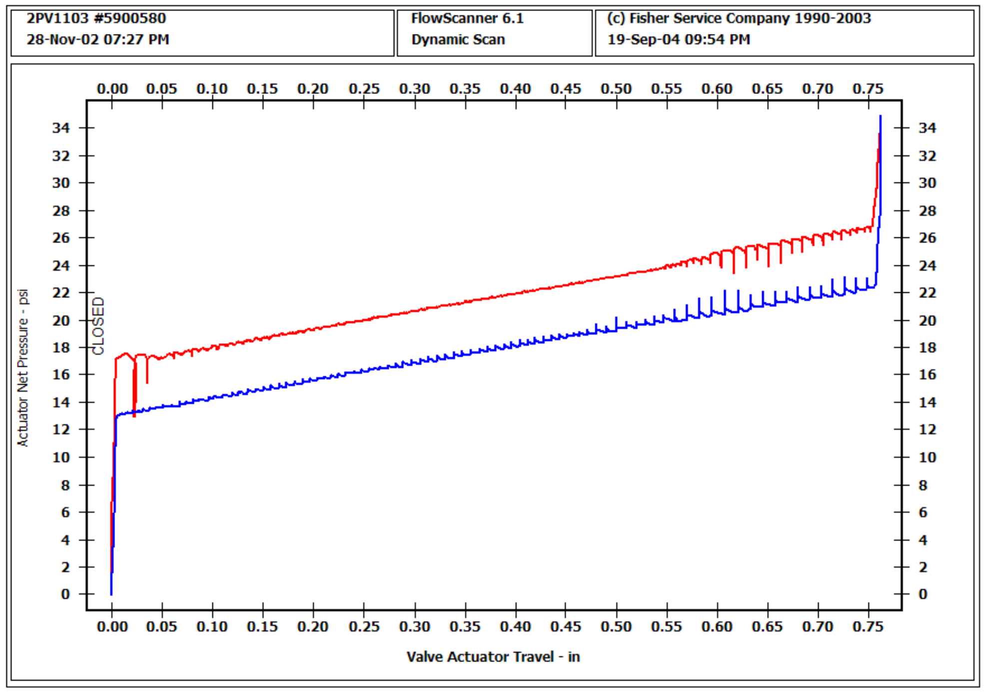


Figure 5-28
Example of packing sticking
Used with permission from Southern Company

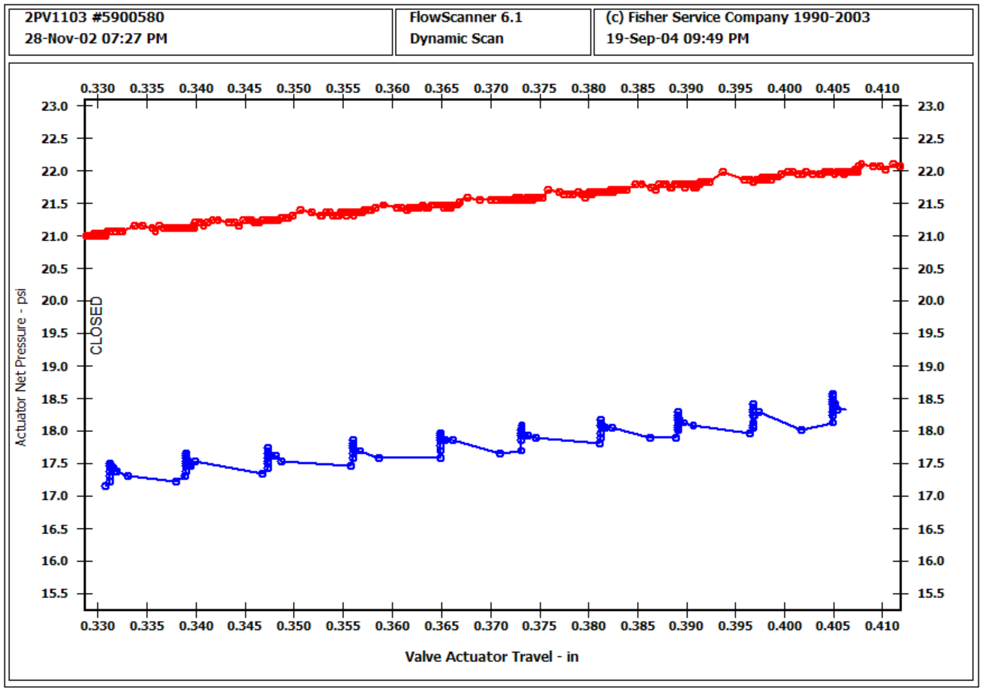


Figure 5-29
A close-up of packing sticking shown by saw tooth type of wave form
Used with permission from Southern Company

In Figure 5-30, it looks like the packing is sticking; however, this problem is caused by a degraded booster or relay in the positioner.

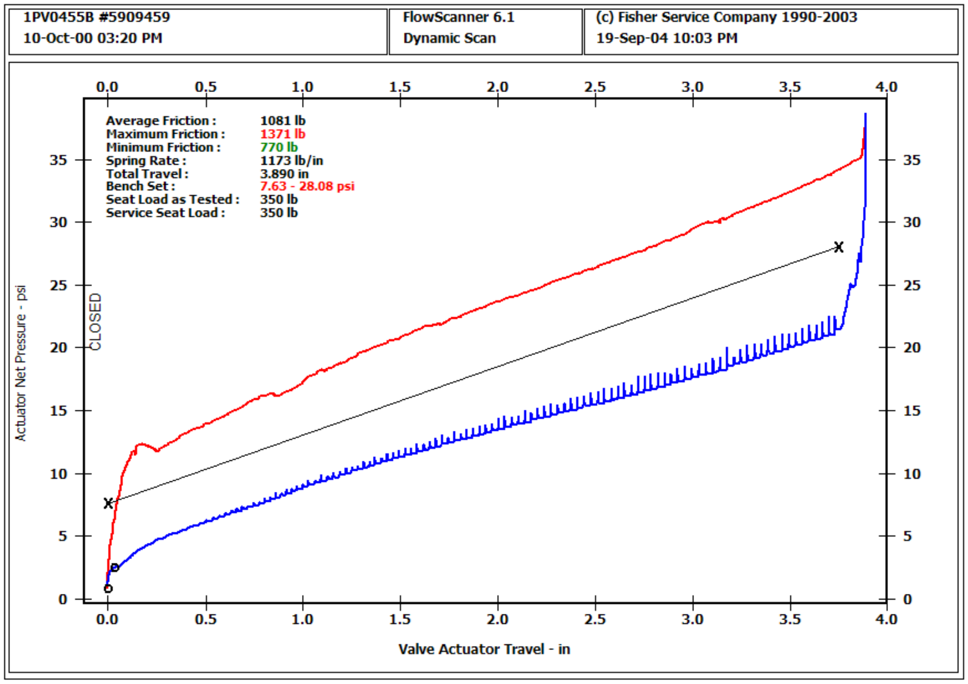


Figure 5-30
A degraded booster or relay
Used with permission from Southern Company

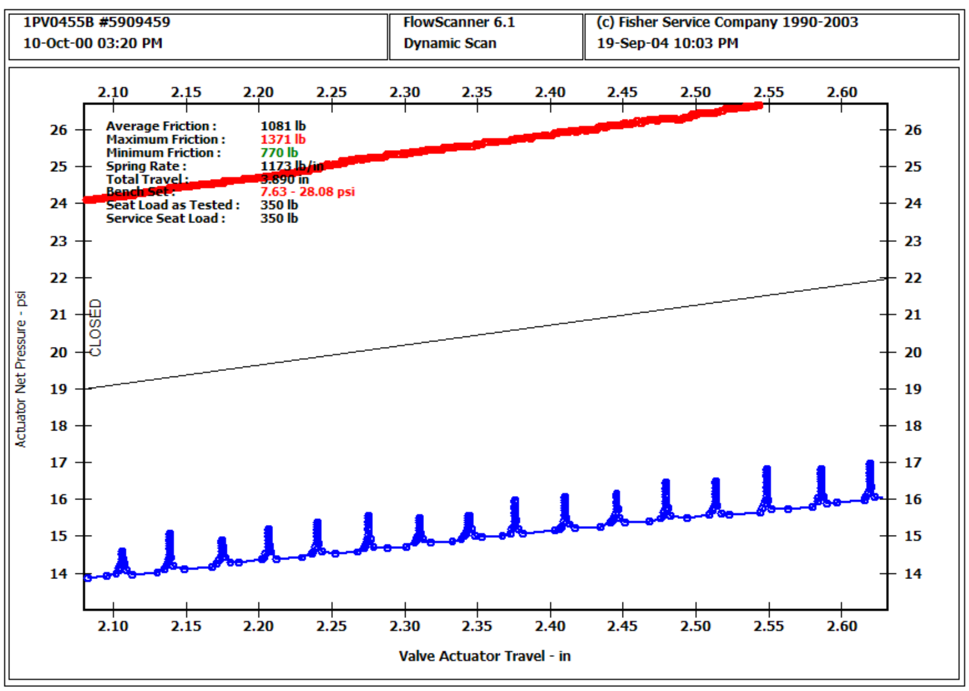


Figure 5-31
A close-up of Figure 5-30 showing a rounded sticking area instead of saw tooth and a defective booster
Used with permission from Southern Company

Figure 5-32 represents a worn valve stem. Notice how the trace forms an hourglass shape due to the variance at the beginning and end of the stroke.

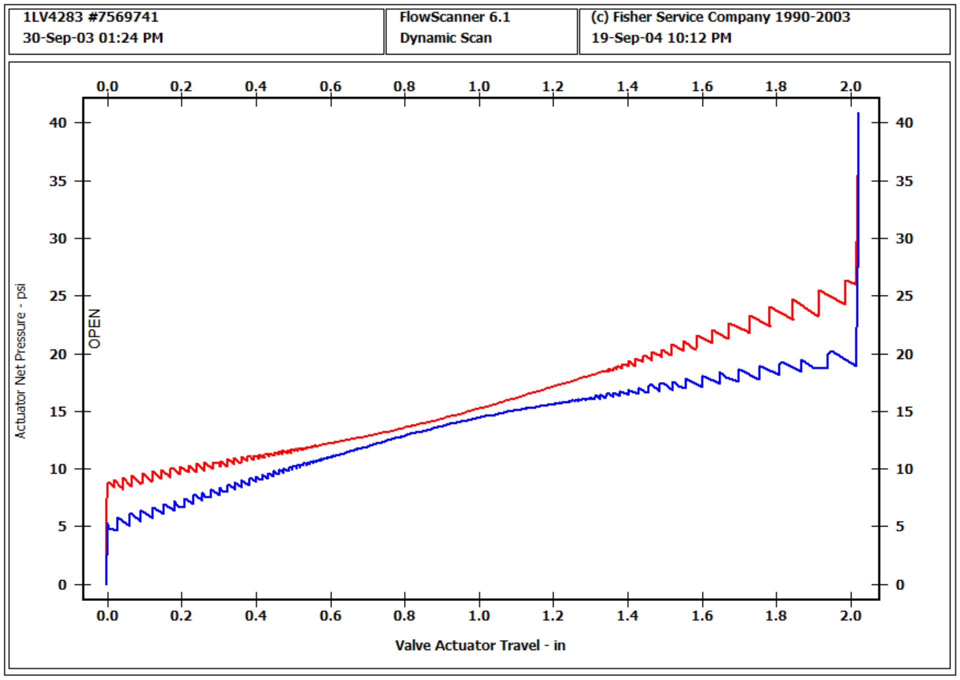


Figure 5-32
A worn valve stem with hourglass shape
Used with permission from Southern Company

5.5.6 Versus-Time Graph (Time-Based Graph)

The versus-time graph is useful in troubleshooting valve and actuator problems as well as verifying proper positioner calibration, regulator setting and operation, and valve stroke times.

On double-acting actuators with positioners, the versus-time graph can be used to verify that the relays are working properly in the positioner and to help identify air leaks.

When a step test is performed, the valve stroke time can be measured on the versus-time graph. Figures 5-33 through 5-38 are examples of versus-time graphs.

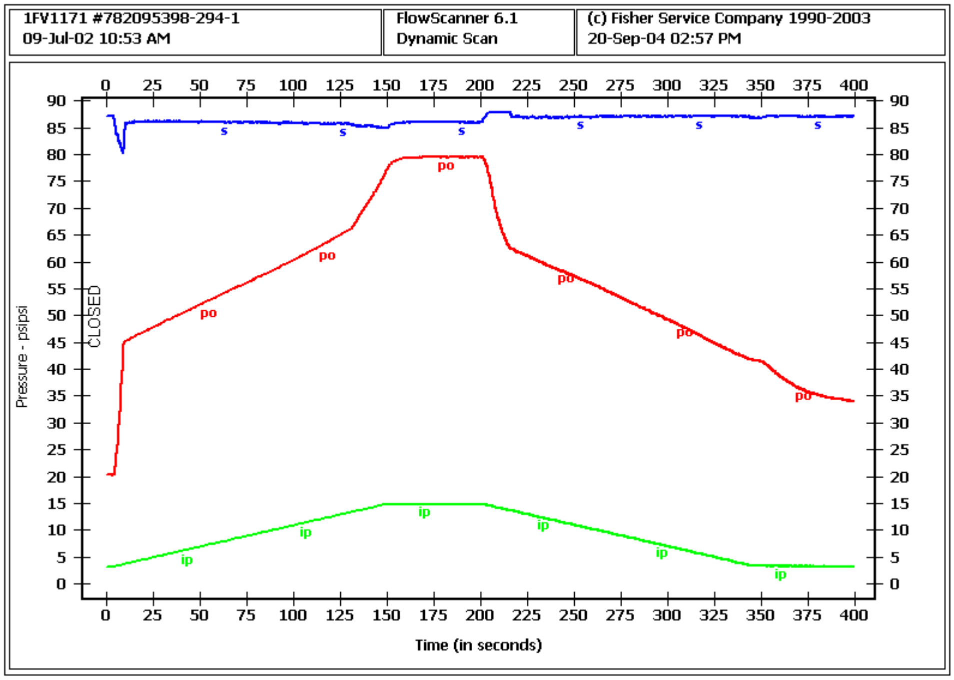


Figure 5-33
A positioner out of calibration (Notice that the positioner output pressure does not load all of the way up to the supply pressure, and the pressure at the zero signal ends does not unload to about 0 psi [0 kPa].)
Used with permission of Southern Company

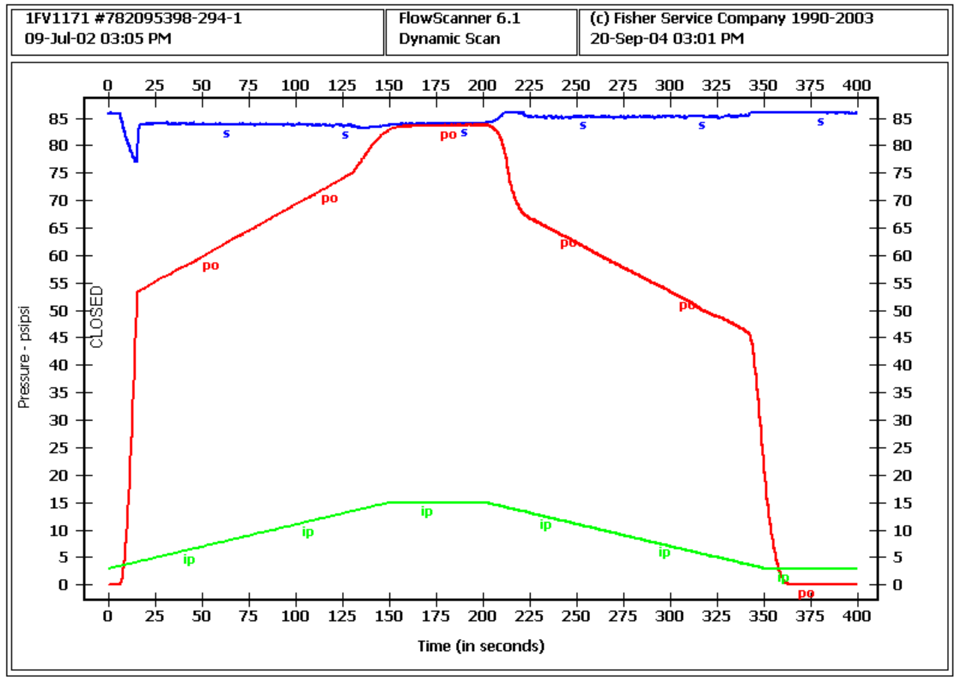


Figure 5-34
As-left graph with the positioner calibrated
Used with permission of Southern Company

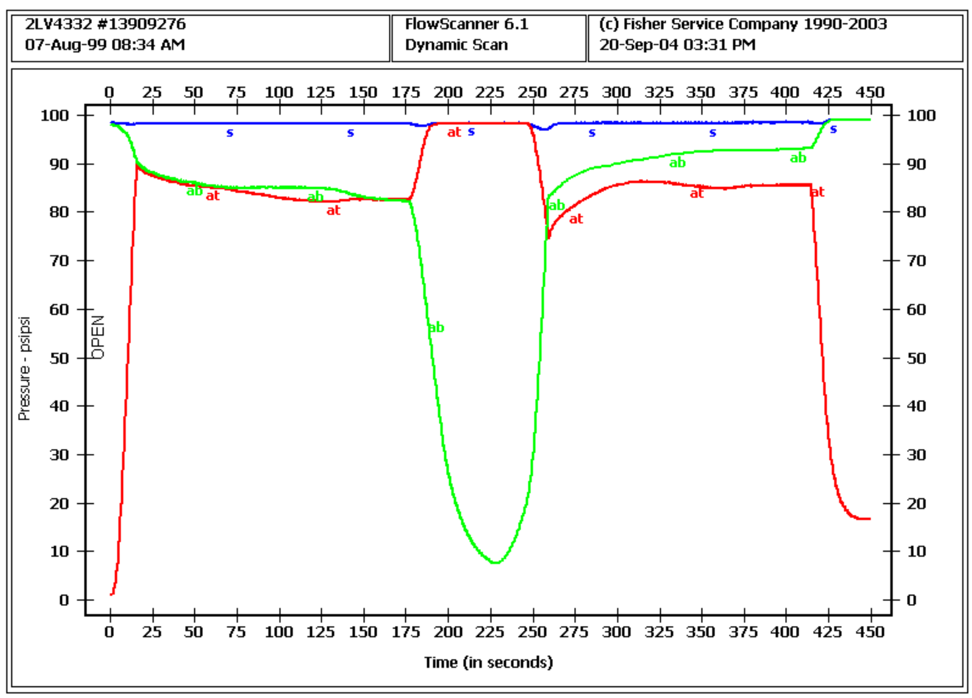


Figure 5-35
A double-acting piston actuator with a worn actuator shaft causing an air leak
(Notice that the pressure on the green line is higher than the red line.)
Used with permission of Southern Company

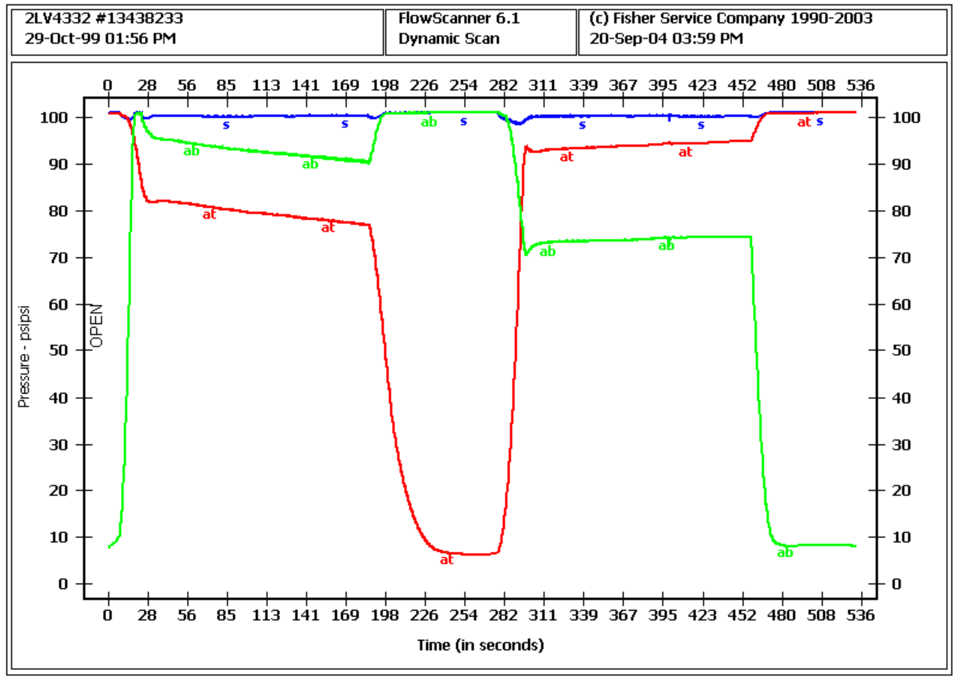


Figure 5-36
An as-left graph of the rebuilt actuator and valve
Used with permission of Southern Company

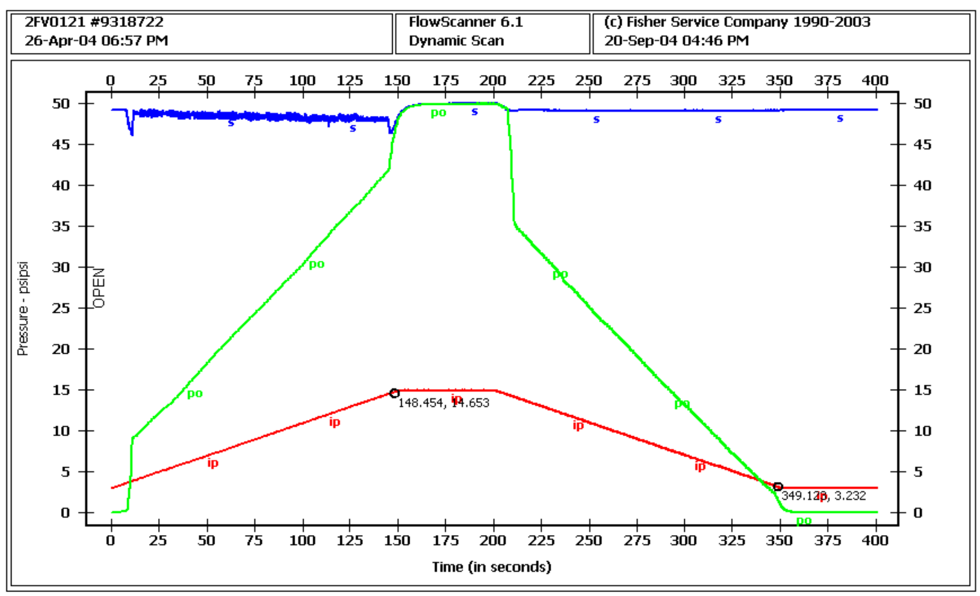


Figure 5-37
Verification of static end points using a versus-time graph
Used with permission of Southern Company

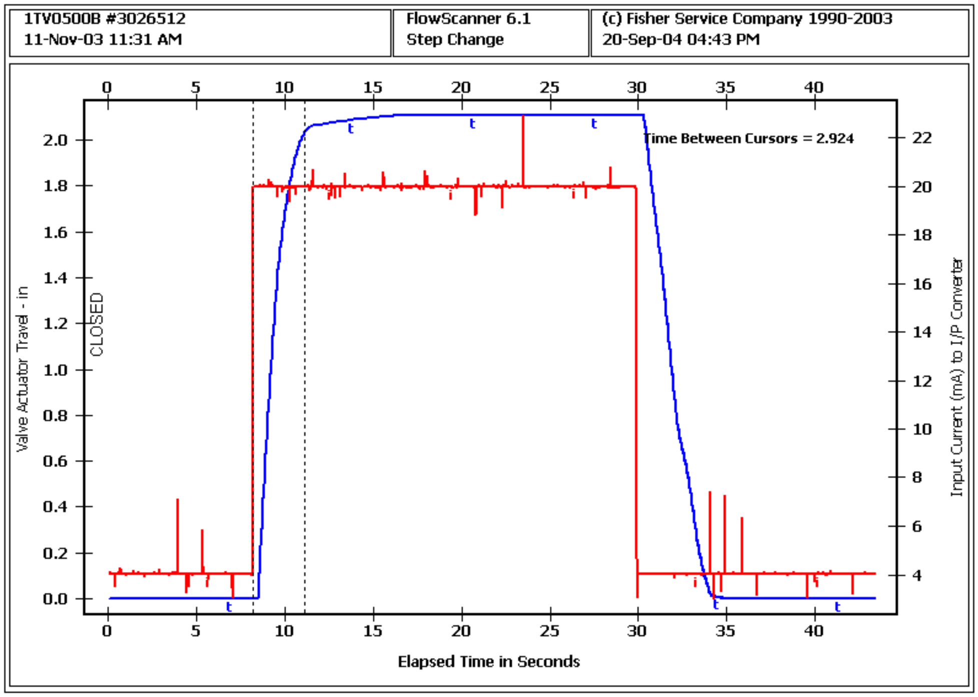


Figure 5-38
Stroke time on valve (The cursors can be positioned at the desired points and the time analyzed between the selected points.)
Used with permission of Southern Company

5.5.7 Overlays

The test overlay feature allows for a quick assessment of valve condition based on past performance. The test results can be overlaid to aid in analysis and identify any degradation over time. This is especially useful when looking for seat or valve stem wear. Travel changes over time can also be monitored. No automatic analysis can be performed when the graphs are overlaid. The example in Figure 5-39 looks at valve stem wear from one outage to the next.

Key Technical Point
The test overlay feature allows for a quick assessment of valve condition based on past performance.

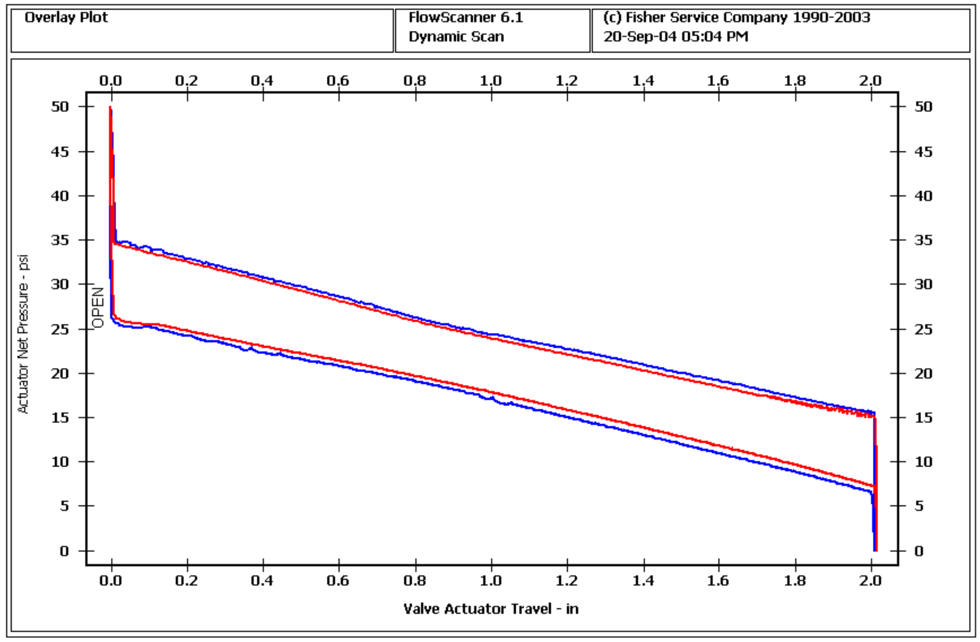


Figure 5-39
Overlay of valve stem wear from multiple outages
Used with permission of Southern Company

Section 6: Case Histories

6.1 Case History #1: Premature Failure of a New Digital Positioner

Unit: 900-MWe PWR

System impacted: Feedwater

Failed component: Positioner—Emerson DVC5010s

6.1.1 Background Information

An anomaly was detected in the I/P curve (see Figure 6-1) during a check of the internal signal. The driver signal was at 100%, and the cycle counter was too high compared with the record trace. The mechanical signature (see Figure 6-2) and calibration indicated that everything was correct. There were no unusual sounds. When the valve was opened from 0% to 100% with the manual relay from the control room (RCM) and checked with the implementation of the positioned from 0% to 30%, the positioner did not provide any air pressure. The valve stayed at 0%. From 30% to 100%, the valves positioned correctly, and air pressure was right. With the valve driven manually with a local current generator, the same scenario occurred.

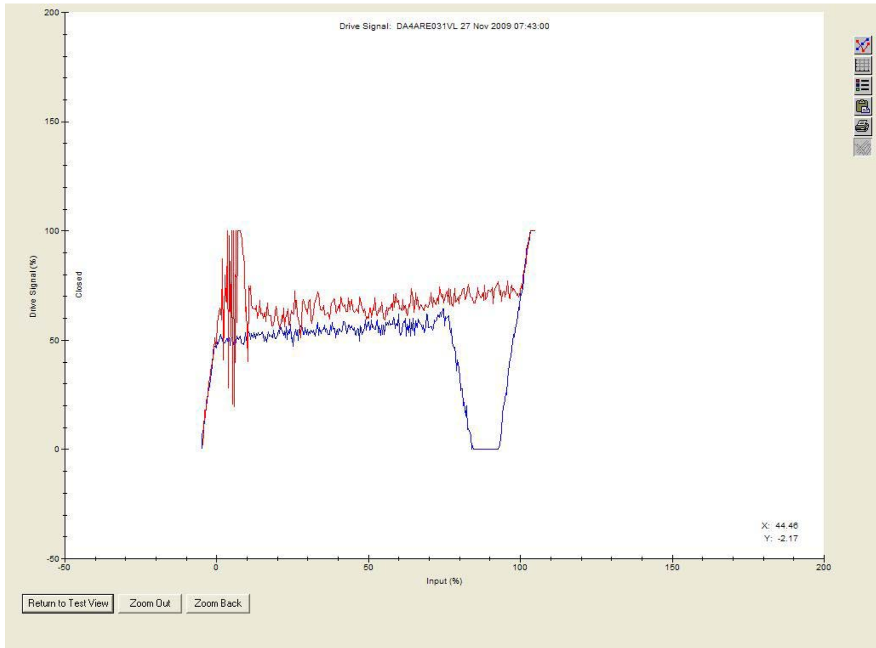
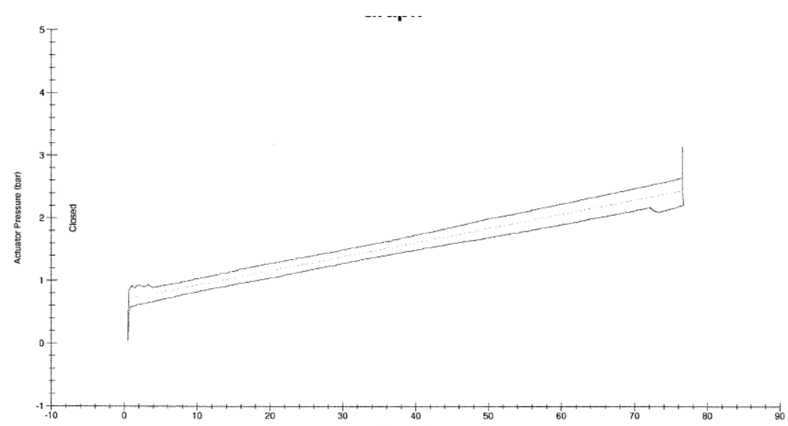


Figure 6-1
ValveLink data signature of drive signal vs. input (Notice the drop in demand signal from 70% to 100% due to a bad positioner.)
Courtesy of EDF



Analyzed

Minimum Friction:	1879 N
Maximum Friction:	3310.52 N
Average Friction:	2437 N
Spring Rate:	424.85 N/mm
Bench Set:	0.72 - 2.45 bar
Seat Load As Tested:	9904.36 N
Service Seat Load:	5552.23 N
Required Seat Load:	2235.92 N
Expected Packing Friction:	3003 N
Expected Total Friction:	3003 N

Figure 6-2
The as-found data/signatures for actuator pressure vs. travel (No apparent failure was noted in the signature.)
Courtesy of EDF

6.1.2 Root Cause (Summary of Actions Taken to Fix Issue)

The pressure regulator and DVC positioner were replaced (see Figures 6-3 and 6-4). It was determined that the positioner, which had been in operation for only four months, had failed. Prior to being placed in operation, the positioner had been in storage for five years.

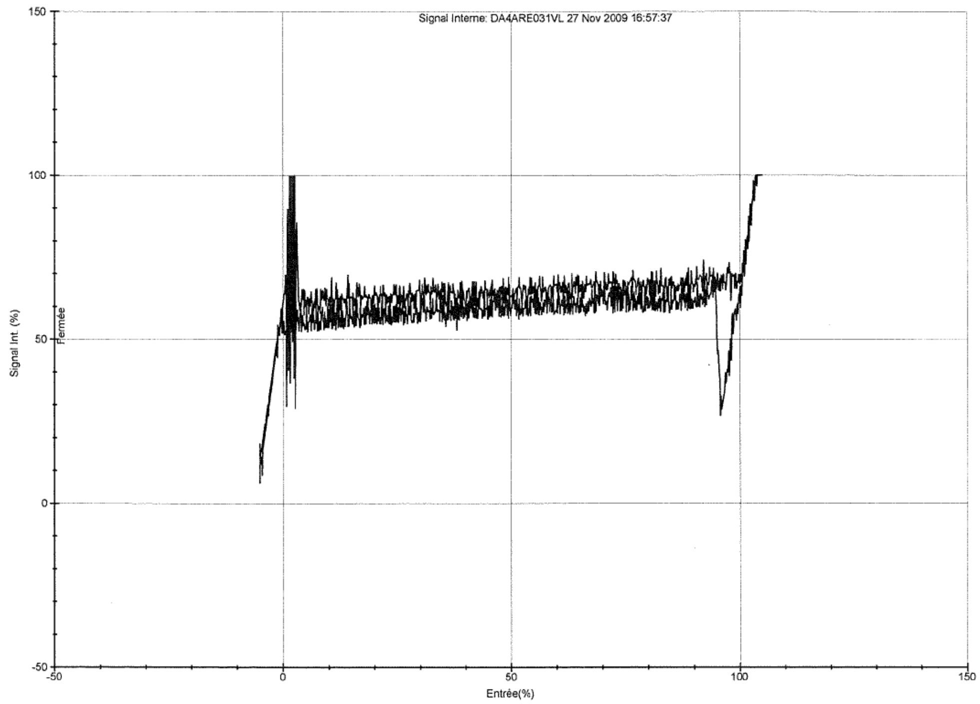
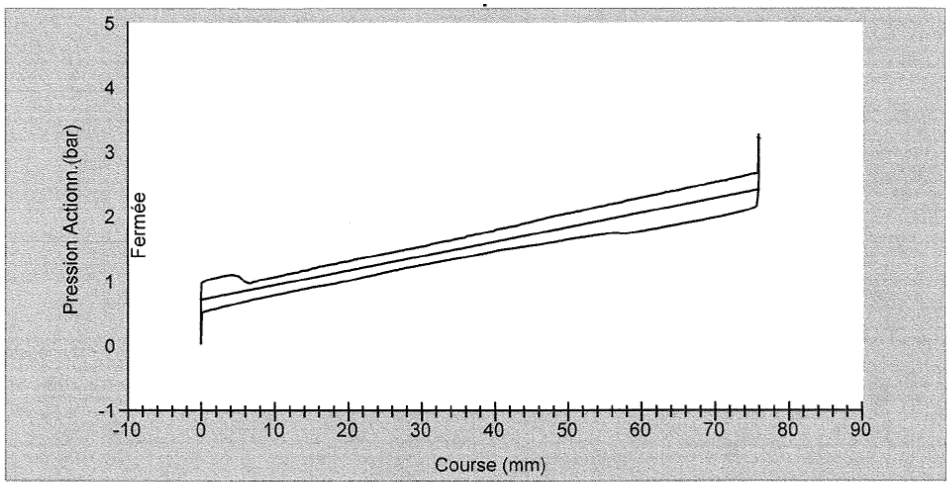


Figure 6-3
The corrected as-left ValveLink data/signature for drive signal vs. input
Courtesy of EDF



Analyse	
Friction Minimum:	2481 N
Friction Maximum:	5069.1 N
Friction Moyenne:	3327 N
Rdr Ressort:	416.55 N/mm
Tarage/B:	0.72 - 2.41 bar
Charge/siège Testée:	9478.32 N
Charg/sge Service:	5126.19 N
Charg/sge Requise:	2235.92 N
Friction au PE Prévue:	3003 N
Friction Tot. Prévue:	3003 N

Figure 6-4
The corrected as-left data/signature for actuator pressure vs. travel
Courtesy of Duke Energy

6.2 Case History #2: Bad Test I/P

Unit: 1180-MWe PWR

System impacted: Steam generator blowdown system

Failed component: Containment isolation

6.2.1 Background Information

The valve was a Borg Warner 2-in. (50.8-mm) solid wedge gate valve with a Miller piston actuator. Anomalies, specifically at 0.75-in. (19.1-mm) and 1.4-in. (35.6-mm) stroke, were noted in the diagnostic trace (see Figure 6-5).

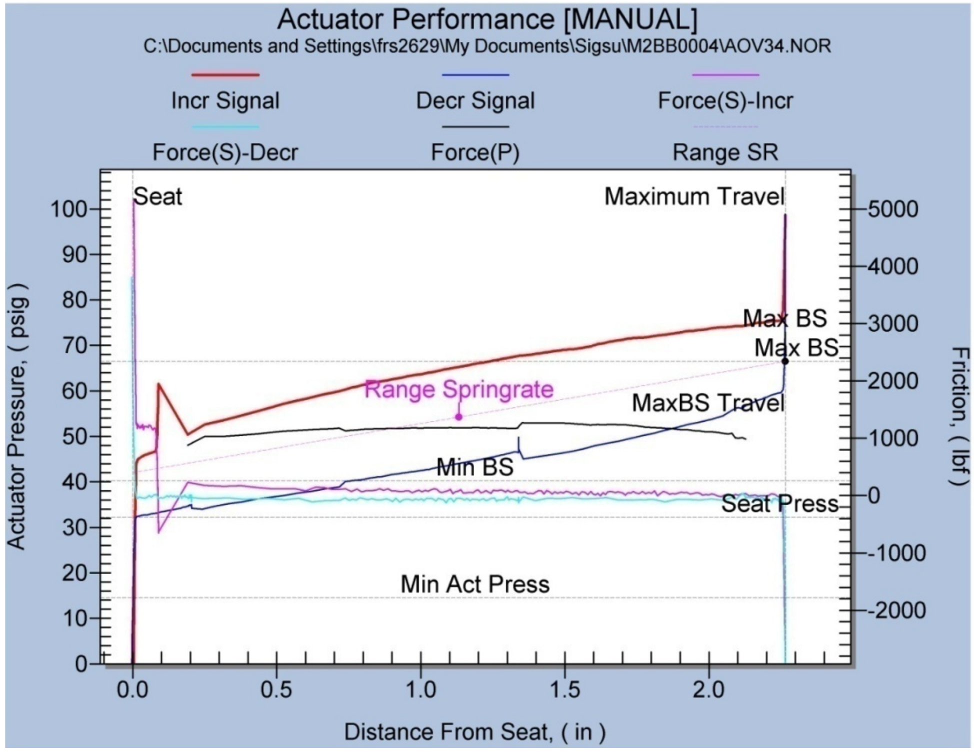


Figure 6-5
The as-found data/signature of pressure vs. travel with a defective test I/P
Courtesy of Duke Energy

6.2.2 Root Cause (Summary of Actions Taken to Fix Issue)

It was identified that the test I/P was not functioning properly. The defective I/P was replaced, and the test was rerun with the proper result (see Figure 6-6).

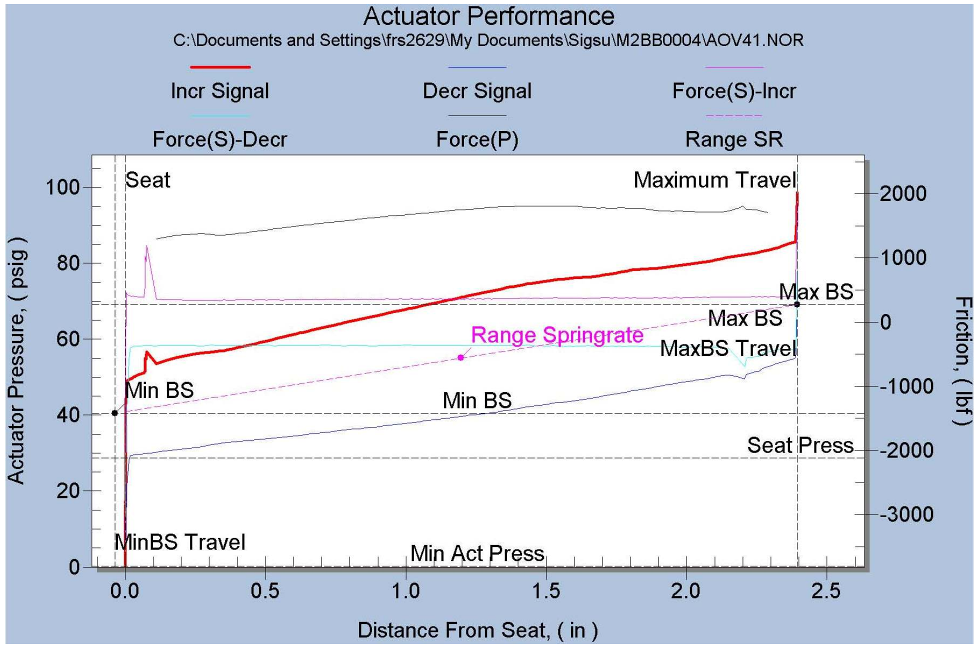


Figure 6-6
The as-left data/signature of pressure vs. travel with the corrected test I/P
Courtesy of Duke Energy

6.2.3 Lesson Learned

Ensure that all test components are tested properly and individually prior to performing valve calibration or maintenance.

6.3 Case History #3: Poor Strain Gauge Bond

Unit: 1180-MWe PWR

System impacted: Fire protection system

Failed component: Containment isolation

6.3.1 Background Information

The valve was a 4-in. (101.6-mm) ITT Grinnell diaphragm valve with a 32101 actuator and 130 spring. When comparing the seating force with pressure versus strain measurement, the strain value showed as approximately one-half the value calculated with pressure (see Figure 6-7). The approximate actuator area is 101 sq. in. (2565 sq. mm).

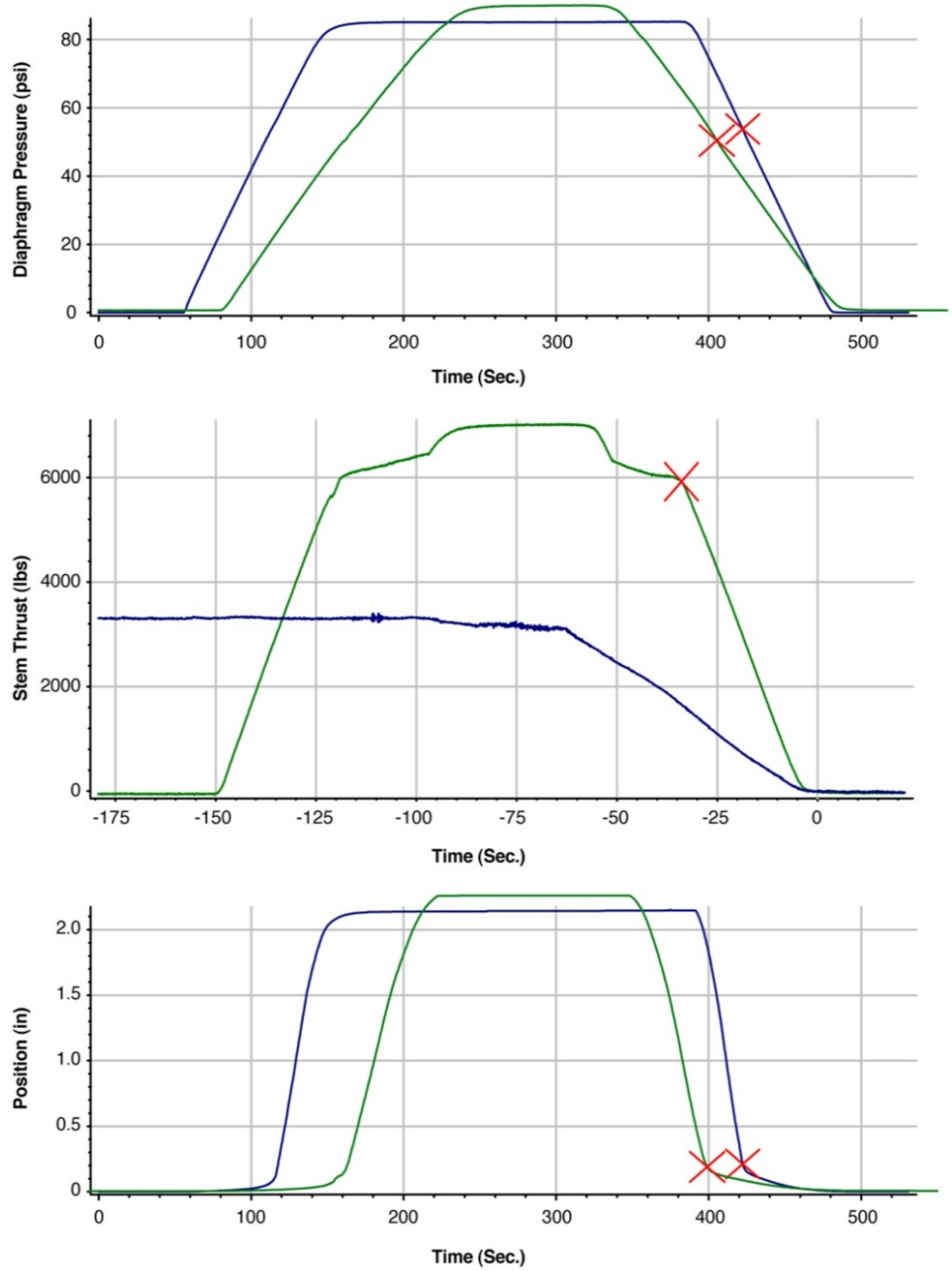


Figure 6-7
The as-found (blue) and as-left (green) data/signatures for diaphragm pressure (top), stem thrust (middle), and valve position (bottom), reflecting defective strain gauge
Courtesy of Duke Energy

6.3.2 Root Cause (Summary of Actions Taken to Fix Issue)

The strain gauge is constructed of two halves bonded to the valve stem 180° apart. The bond on one of the halves was not sufficient, resulting in the low strain reading.

6.3.3 Lesson Learned

Ensure that strain gauges are bonded correctly by comparing calculated values with actual stem thrust.

6.4 Case History #4: Loading Increases Due to Undrained Pipe

Unit: 1180-MWe PWR

System impacted: Nuclear service water system

Failed component: Reactor coolant pump motor cooler—containment isolation

6.4.1 Background Information

The valve was a 6-in. (152.4-mm) ITT Grinnell diaphragm valve with a 32251 diaphragm actuator. Small loading increases were noted on the valve closing stroke due to trapped water in the pipe (see Figure 6-8).

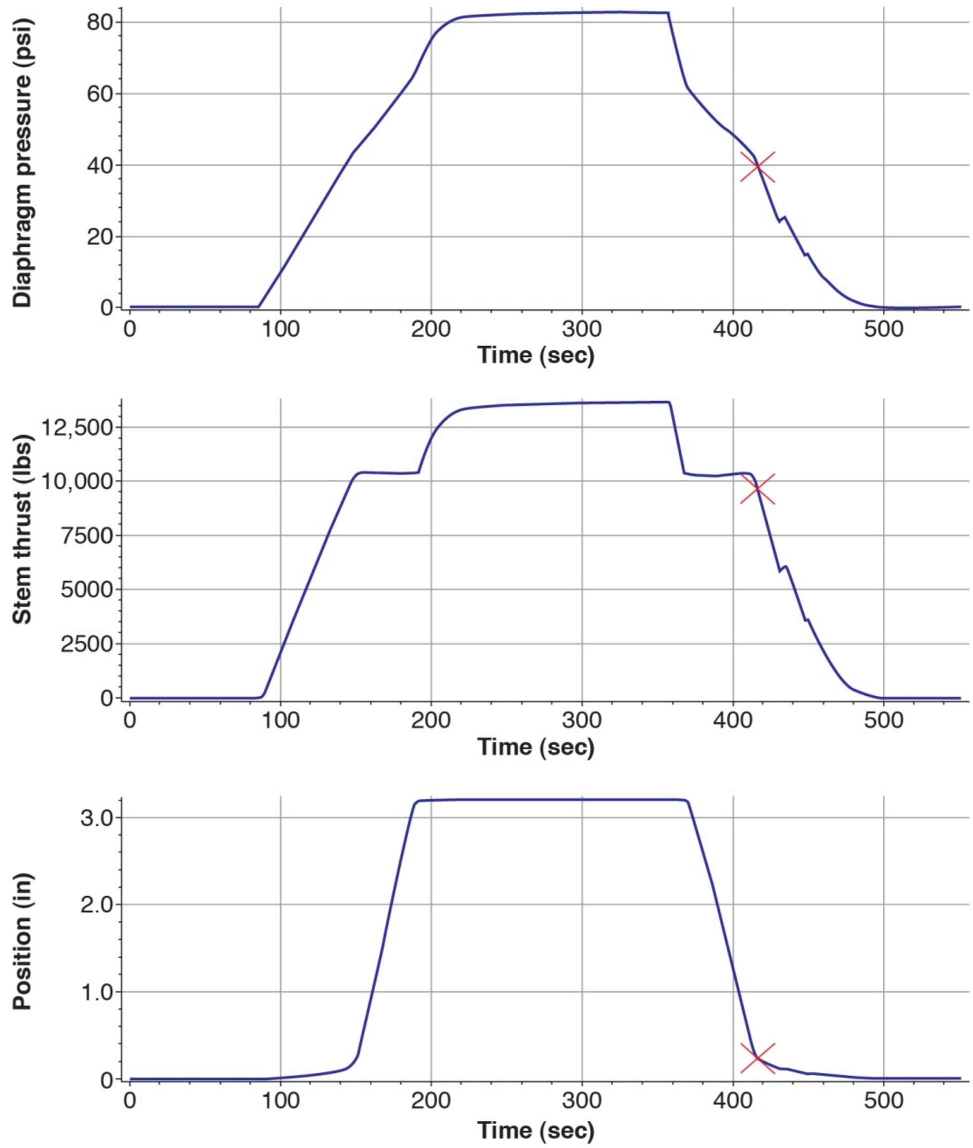


Figure 6-8
The as-found and as-left data/signatures for diaphragm pressure (top), stem thrust (middle), and position (bottom), reflecting improper venting and draining of system
Courtesy of Duke Energy

6.4.2 Root Cause (Summary of Actions Taken to Fix Issue)

The piping was not drained and vented. The large area of the valve diaphragm can compress fluid trapped in the piping, resulting in pressure changes that show up as a change to the valve forces.

6.4.3 Lesson Learned

To get a good static diagnostic test on a diaphragm valve, the line must be vented and drained.

6.5 Case History #5: Piston Bottoming Out

Unit: 1180-MWe PWR

System impacted: Main steam system

Failed component: Main steam isolation valve (MSIV)

6.5.1 Background Information

The valve was a Weir MSIV 34-in. (86.36-mm) Y-pattern globe with a piston actuator. The seating profile was not as expected (see Figure 6-9). An abnormality was noted in the ETT thrust of the seating profile (see Figure 6-10).

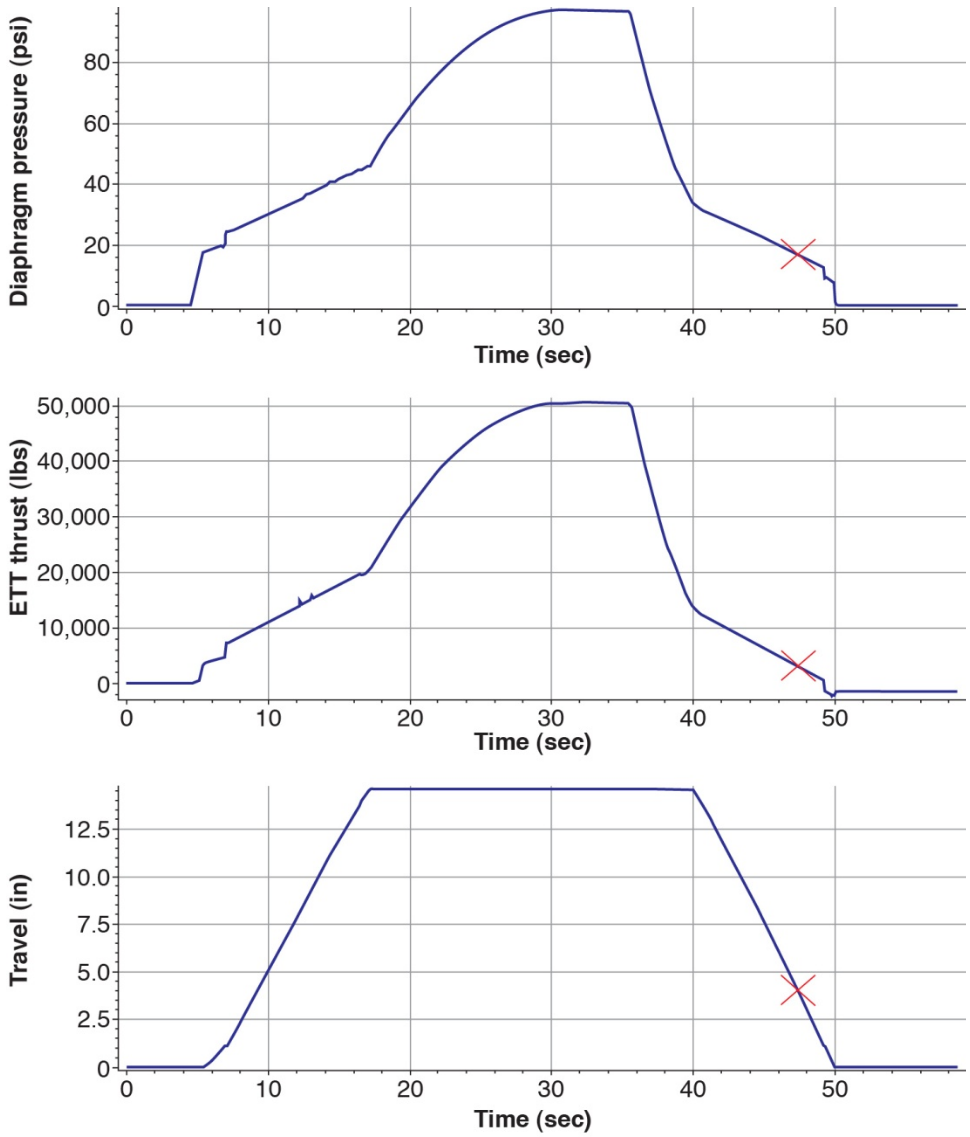


Figure 6-9
The as-found data/signatures for Case History #5: diaphragm pressure (top), Easy Torque Thrust (ETT) (middle), and travel (bottom), showing anomalies in the seating profile
Courtesy of Duke Energy

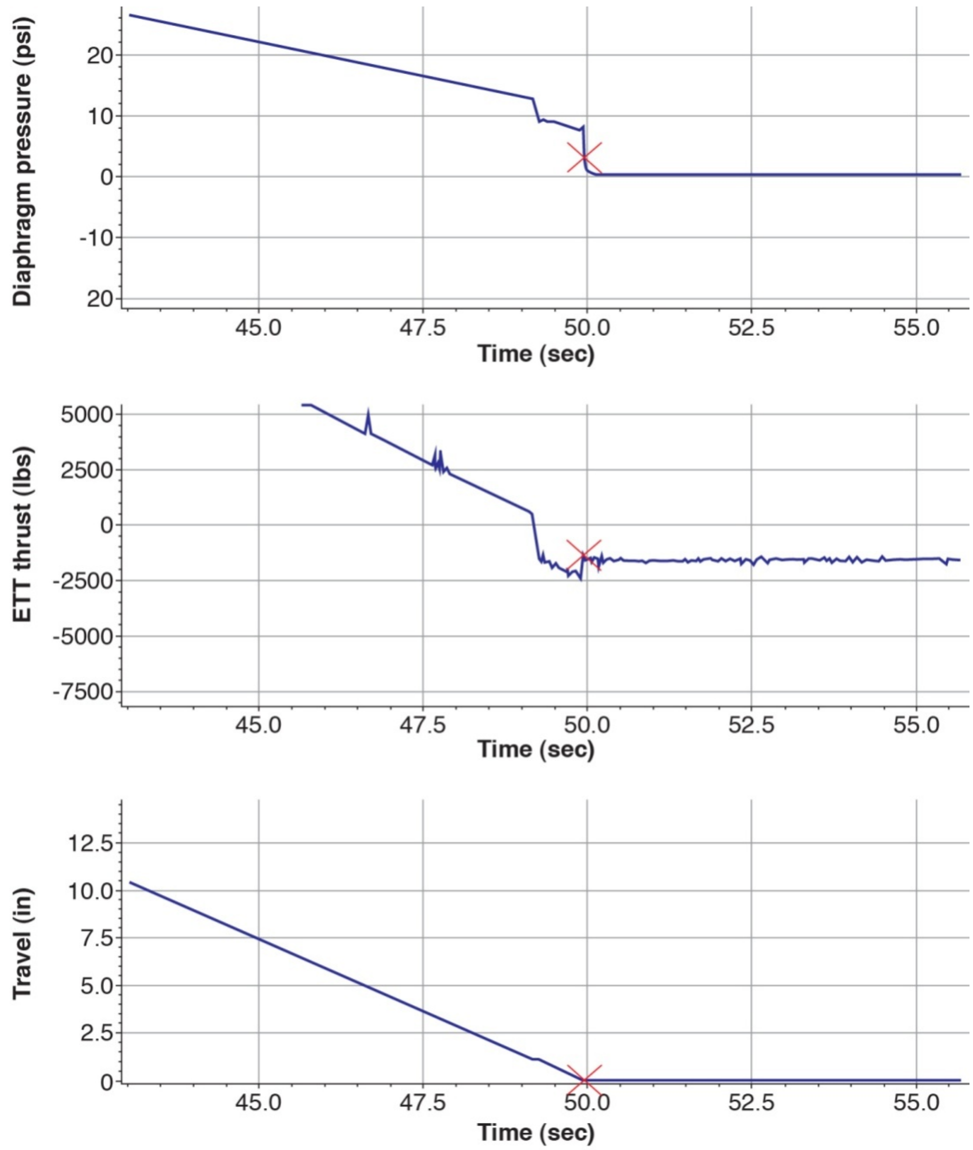


Figure 6-10
The as-found data/signatures for diaphragm pressure (top), ETT (middle), and travel (bottom) (Zoomed in to identify the seating anomaly.)
Courtesy of Duke Energy

6.5.2 Root Cause (Summary of Actions Taken to Fix Issue)

There was an incorrect valve-actuator coupling that resulted in the actuator piston bottoming out on the actuator end cap, thereby preventing the valve from fully seating (see Figure 6-11).

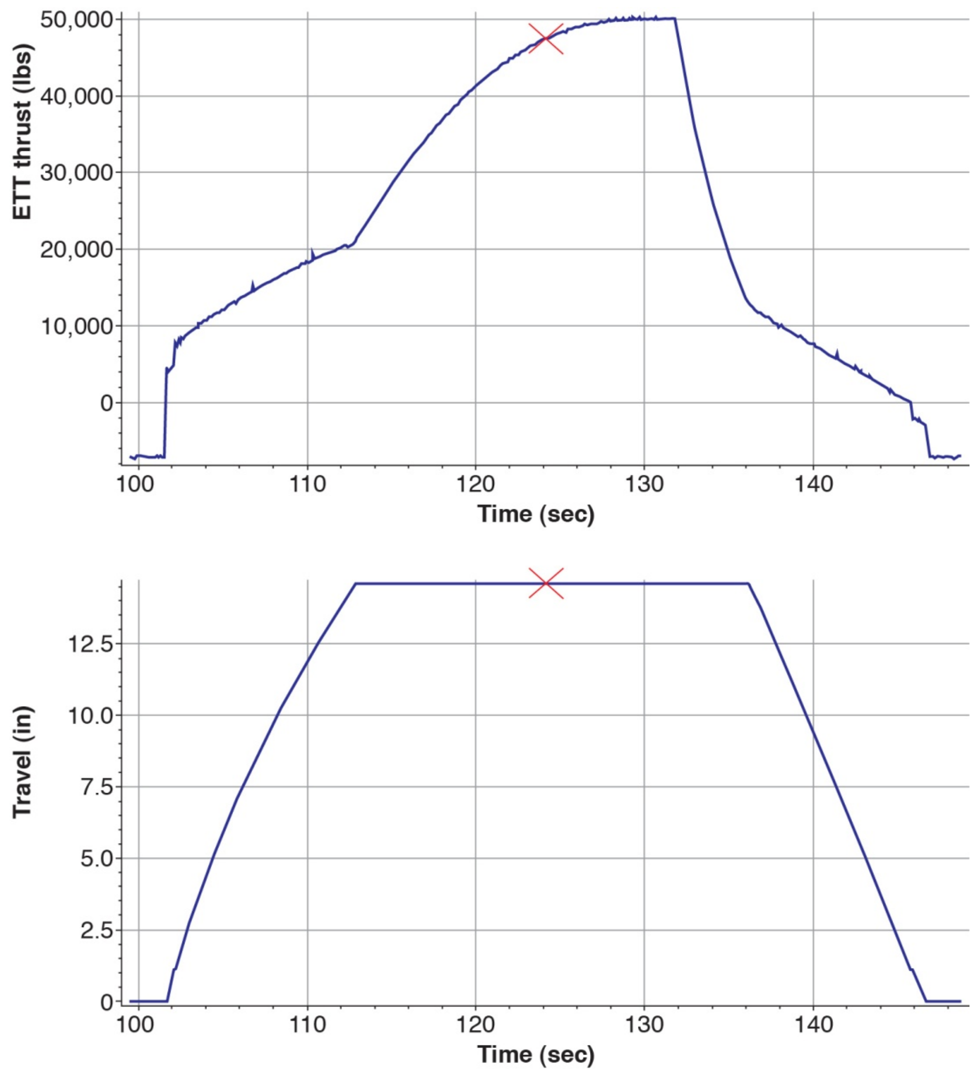


Figure 6-11
The as-left data/signature of ETT (top) and travel (bottom), reflecting proper seat load
Courtesy of Duke Energy

6.5.3 Lesson Learned

Compare strain data to pressure data to ensure proper setup with piston actuators and to ensure that the valve is properly seating.

Note: Piston operators can exhibit higher friction loads than typical spring/diaphragm actuators because of the pressure of piston seals and high sensitivity to side loading. Accordingly, it is a good practice to compare strain and pressure friction values on piston actuators to ensure that high friction is not masking low packing loads and to minimize the potential for packing leakage.

6.6 Case History #6: Feed Regulating Tube Stuck in Valve

Unit: 1180-MWe PWR

System impacted: Main feedwater system

Failed component: Feedwater regulating valve

6.6.1 Background Information

The valve was a Copes-Vulcan 12-in. (304.8-mm) balanced plug feed-regulating valve with a D100-160-3 diaphragm actuator. Operations identified steam generator level control issues. Performance of diagnostics identified valve excess loading and sticking (see Figure 6-12).

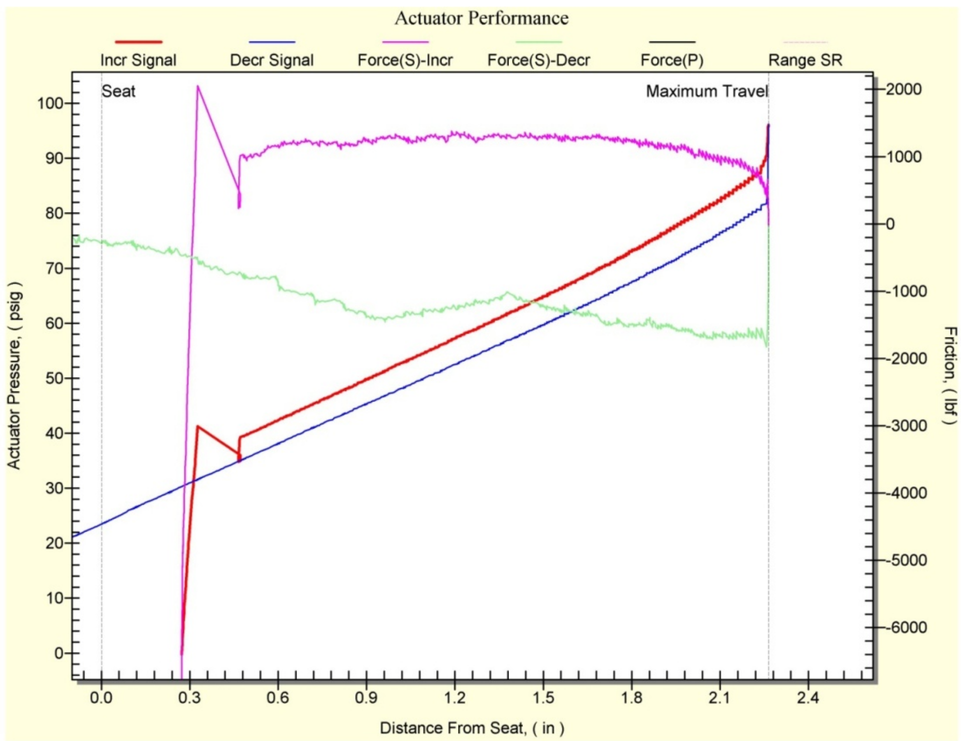


Figure 6-12
The as-found data/signature with excessive loading and sticking in the seat
Courtesy of Duke Energy

6.6.2 Root Cause (Summary of Actions Taken to Fix Issue)

Disassembly of the valve identified a heater tube plug stuck between the valve plug and the cage, which resulted in the valve sticking. The foreign material was removed, and an as-left signature was recorded (see Figure 6-13).

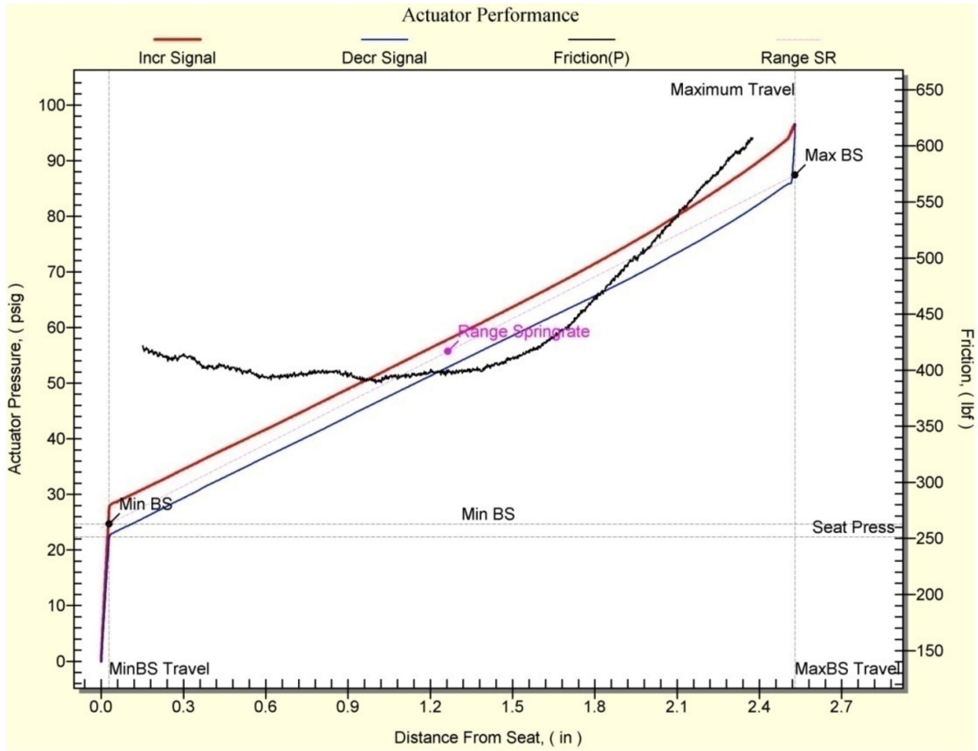


Figure 6-13
The as-left data/signature identifying proper valve stroke
Courtesy of Duke Energy

6.6.3 Lesson Learned

Foreign material that is interfering with valve operation can be identified through the diagnostics.

6.7 Case History #7: Incorrect Pilot Poppet Stroke

Unit: 1180-MWe PWR

System impacted: Main steam system

Failed component: MSIV

6.7.1 Background Information

This valve was a Weir MSIV 34-in. (863.6-mm) Y-pattern globe with a piston actuator. The pilot stroke should have been approximately 1 in. (25.4 mm) but instead was approximately 3/8 in. (9.5 mm) (see Figure 6-14).

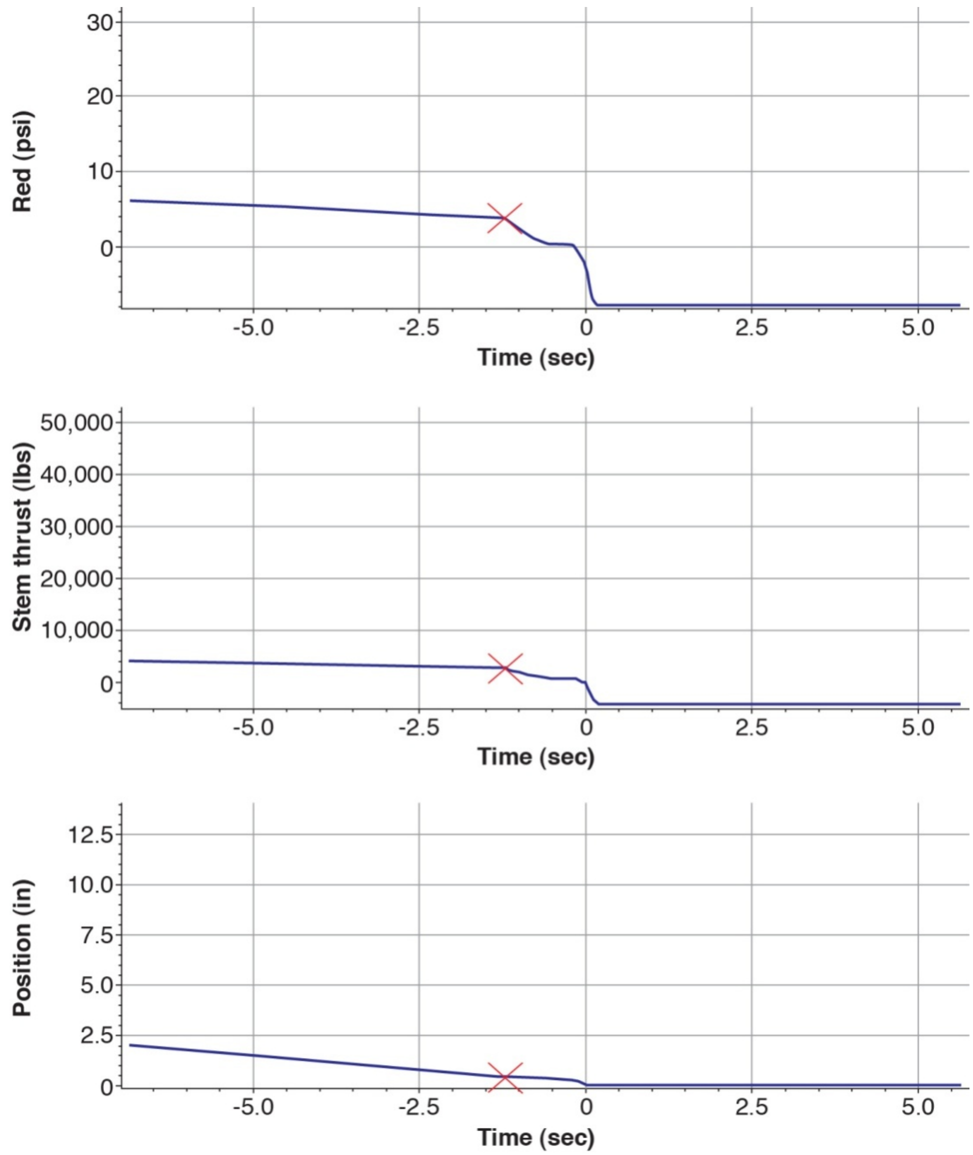


Figure 6-14
The as-found data and signature showing pressure (top), stem thrust (middle), and position (bottom), identifying incorrect pilot stroke
Courtesy of Duke Energy

6.7.2 Root Cause (Summary of Actions Taken to Fix Issue)

This particular design of MSIV has a pilot poppet assembly within the main poppet, which functions to balance the pressure across the disk to minimize actuation forces. Incorrect assembly of the pilot poppet resulted in the deficient pilot poppet stroke. The pilot assembly was reworked, and an as-left signature was recorded (see Figure 6-15).

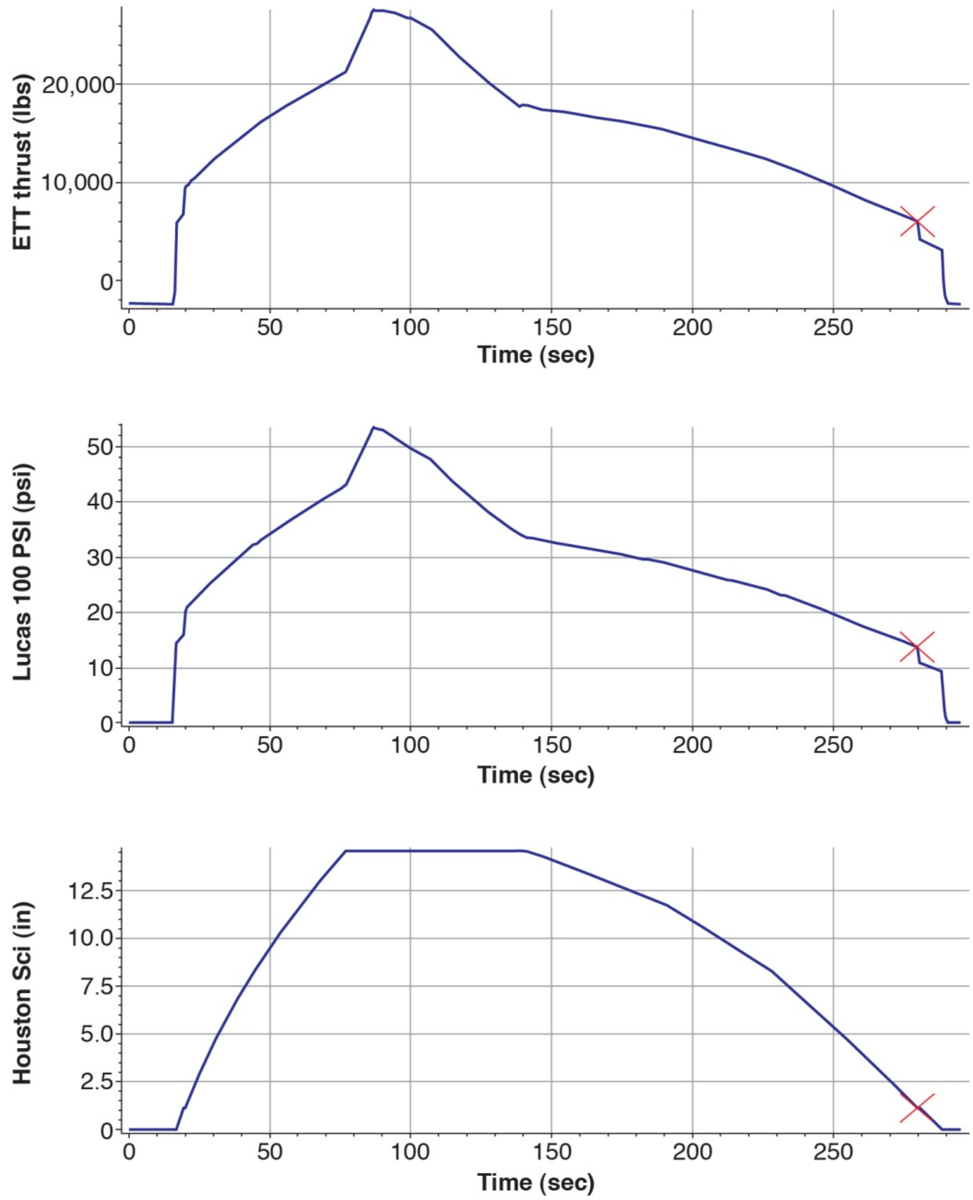


Figure 6-15
The as-left data and signature for ETT (top) and pressure (middle and bottom), identifying correct pilot stroke
Courtesy of Duke Energy

6.7.3 Lesson Learned

Diagnostic testing can be used to identify proper valve and pilot stroke.

Section 7: Bibliography

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Duke Energy, Fleet Air-Operated Valve Program Plan, DPM 1205.00-0011, Rev. 1.

Tennesee Valley Authority, AOV Program, NETP-114, Rev. 0.

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Progress Energy, Post-Test Evaluation of AOV Performance, TMM-127.

Fisher, 62.1: ValveLink Software Product Bulletin, D102227X012.

AREVA UltraCheck "A" training manual, Revision 07. October 2008.

Crane Nuclear, Signature Software, Air-Operated Valve User's Manual, Version 4.4.

Fisher, FlowScanner 6000 Valve Diagnostic System Product Bulletin 56.1:6000, January 2003.

Teledyne, Program Quiklook II User Manual, Revision 8, November 2009. TTS-CC-140.

Fisher, ValveLink Software Product Bulletin 62.1, November 2010. D102227X012.

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Nuclear Maintenance Applications Center: Air-Operated Valve Evaluation Guide—Revision 1. Electric Power Research Institute, Palo Alto, CA: 2011. 1022646.

Nuclear Maintenance Applications Center: Air-Operated Valve Maintenance Guide: Revision 2. Electric Power Research Institute, Palo Alto, CA: 2008. 1016682.

Appendix A: Key Points Summary

Key O&M Cost Point
Emphasizes information that will result in reduced purchase, operating, or maintenance costs.

Page	Key Points
3-8	Test connections will minimize time in the field, thereby reducing radiation exposure and costs while improving consistency between tests.
3-19	The EPRI STE is a cost-effective way to validate knowledge and qualify individuals. Using this process means that the equivalent that must be written in the training program will have to be performed only once. The EPRI STE process will ensure that all personnel are trained and qualified to the same standard.
4-1	To reduce the impact on diagnostic testing resources during an outage, many plants are making use of system unavailability time to perform diagnostic tests on-line. This requires a proficient team on diagnostics such that impact to the window of opportunity is not encountered by a team that is not efficient in their diagnostic practices.
4-2	Trending data will forecast when maintenance will be required. By taking this forecasting approach, plants can put themselves in control to budget repairs and determine a priority of the valves requiring maintenance. This allows informed decisions to be made during the outage scope validation meetings.

Key Technical Point
Targets information that will lead to improved equipment reliability.

Page	Key Points
3-1	It is a good practice to allow the data acquisition system to warm up 10–20 minutes prior to performing any diagnostic test. Consult the manufacturer for specifics on the proper warmup period for each system.
3-2	Air supply, tubing diameter, and length are important elements of the results and accuracy of the diagnostic tests. When performing diagnostics, mimic the existing tubing configuration as much as possible to minimize the introduction of false errors.
3-3	Based on a survey of plants in the Strategic Teaming and Resource Sharing (STARS) Utility Service Alliance, as a maximum leakage criterion, a drop of 1–2 psi per minute (6.9–13.8 kPa per minute) from the established supply pressure is common. Each plant or utility has established an acceptance criterion of its own; each compares to the criterion previously described.
3-3	If an actuator fails the drop test, maintenance can be performed prior to final testing. Any actuator air leakage will be evaluated to determine if maintenance is required. Typically, an actuator with less than 2-psi-per-minute (13.8-kPa-per-minute) air leakage at full rated pressure can remain in use, and maintenance can be scheduled for the next PM cycle. However, any air leakage should be reviewed by engineering or the responsible program owner.
3-4	An advantage of using a strain gauge can immediately be seen in verifying seat contact within the valve.
3-9	Mounting from the actuator to the stem is highly recommended and will give indication of the stretch of the yoke legs when the valve is under full load.
3-10	Regardless of the method chosen, consistency is the key requirement for trending travel.
3-12	To maintain a high degree of accuracy and repeatability, the test I/P should be used in the same position as it was calibrated. Additionally, most vendors require the I/P to be in the stable and upright position.
3-13	Clamp-on strain gauges are also sensitive to impact loads, and great care must be taken to ensure the health of the clamp-on transducer. Additionally, clamp-on gauges can be challenged by valves that have very short stroke times and a noticeable impact load upon stroking. The rapid change in acceleration can cause clamp slippage on the valve stem.

Page	Key Points
3-17	Test duration has a direct impact on the ability of a component to accurately show a response to a given signal change. Test durations need to be consistent for similar valve configurations to allow for trending of test results.
3-20	Acceptance criteria should be established for all valves that will be part of the diagnostic test programs. This could take the form of a plus or minus tolerance to a specific parameter or the meeting of conditions specified in a unique component calculation. The values typically include travel, bench set, friction, seat load, and air pressure.
4-1	Establishing testing frequency is a result of historical tests and results. The intent is to establish a time interval that is minimally intrusive to the maintenance environment and yet sufficient to predict impending failure or degradation and enable the plant to make repairs.
5-4	The overlay option allows the user to view two (or more) sets of cross-plot data on the same screen. This option is particularly useful for graphically depicting changes in a valve's performance over time or as adjustments are made to the performance.
5-35	The test overlay feature allows for a quick assessment of valve condition based on past performance.

Key Human Performance Point
Denotes information that requires personnel action or consideration in order to prevent injury or damage or ease completion of the task.

Page	Key Points
3-6	Consistent location of sensors is of prime importance for the trending of valve performance. Quick disconnects or designated testing connections will provide efficiency and consistency from test to test.
3-6	All of the commonly used items will provide sufficient information, but the skill and knowledge level of the installer will challenge the quality of data obtained.
3-18	Qualification of plant and supplemental workers is an important part of obtaining valid data.

Appendix B: Technical Literature and Links

B.1 Diagnostic Test Systems

- Westinghouse AirCEt 5000 (http://www.westinghousenuclear.com/Products_&_Services/docs/flysheets/NS-ES-0005.pdf)
- Emerson Flowscanner 6000 (http://www.documentation.emersonprocess.com/groups/public/ documents/bulletins/d103177x012.pdf)
- Teledyne Quiklook II (http://www.valvetest.com/products/qlii.asp)
- AREVA UltraCheck (http://www.areva-np.com/ common/liblocal/docs/product_sheet/9/9_3/UltraCheckDiagnosticGroup.pdf)
- Crane Viper 20 (http://www.cranenuclear.com/pdf/testing/Nuclear_Diagnostic_Services_VIPER.pdf)
- Crane VOTES Infinity (http://www.cranenuclear.com/admin/uploads/votesexecutive-weblibrary.pdf)

B.2 Strain Gauges

- Crane C-Clamp/D-Clamp (http://www.cranenuclear.com/pdf/testing/C_CLAMP.pdf)
- Crane Easy Torque-Thrust Cell (ETT) (http://www.cranenuclear.com/pdf/testing/ETT.pdf)
- Teledyne Quick Stem Sensor (QSS) (http://www.teledyne-ts.com/products/quickstem.asp)
- Crane nuC Sensor (http://www.cranenuclear.com/admin/uploads/nuc_product_sheet_1.pdf)
- Teledyne AOV Pressure Sensor (http://www.teledyne-ts.com/products/AOV_Pressure_Sensor.asp)
- Teledyne Stem Position Indicator (http://www.teledyne-ts.com/products/spi.asp)

- Teledyne Smartstem (http://www.valvetest.com/products/smartstem.asp)
- Celesco Position Transducer PT510 (http://www.celesco.com/_datasheets/pt510.pdf)
- Fairchild T7800 Transducer (http://www.fairchildproducts.com/products/39/Compact_I_P,_E_P_Transducer.php)

B.3 Connectors

- Connectors for Diagnostic Testing with Flowscanner (http://www.candksouth.com/tasks/ render/file/?fileID=82BF0604-FF66-B789-04FFBA229A4DBD4E&fileEXT=.pdf)

Appendix C: Actuator Drop Test: Industry Leakage Acceptance Criteria

Table C-1 presents the data for an actuator drop test and industry leakage acceptance criteria. The survey was conducted by STARS in 2005 and converted to psig/minute.

Table C-1
Survey results: leakage acceptance criteria for an actuator drop test

Plant	Acceptance Criteria	Acceptance Criteria (Converted to psig/minute)
Beaver Valley	5 psig/5 min	1
Fermi	1 psig/3 min	0.33
San Onofre	Left to valve personnel and engineering discretion	Left to valve personnel and engineering discretion
Robinson	5% regulator/1 min	1–5 (regulator range of 20–100 psig)
Vogtle	2 psig/1 min for regulators at ≤35 psig 3 psig/1 min for regulators ≥35 psig	2–3
Harris	5% of regulator/1 min	1–5 (regulator range of 20–100 psig)
South Texas	0% leakage	0
Palo Verde	5% of regulator press/1 min	1–5 (regulator range of 20–100 psig)
Sequoyah	5% regulator pressure/10 min	0.1–0.5 (regulator range of 20–100 psig)
Oconee	1 psig/5 min	0.2
Columbia	5% regulator pressure/2 min	0.5–2.5 (regulator range of 20–100 psig)
Nine Mile Point	10% max regulator pressure/10 min	0.2–1 (regulator range of 20–100 psig)
Susquehanna	<2 psig/1 min	<2
Bruce Power (Canada)	<15% of operating pressure/10 min: pass	0.3–1.5 (regulator range of 20–100 psig)
	>25% of operating pressure/10 min: fail	0.5–2.5 (regulator range of 20–100 psig)
	>15% <25% of operating pressure: evaluate	Between 0.3 and 0.5 up to between 1.5 and 2.5
Watts Bar	1 psig/1 min	1
Survey average based on data from 14 sites		**0.75–2 psig/minute**

Appendix D: Example Diagnostic Test Procedures (Courtesy of Progress Energy)

This appendix presents the diagnostic test procedures used by Progress Energy.

D.1 Analysis of Category 1 AOV Diagnostic Data, Sliding Stem Valve with Spring/Diaphragm Actuator Spring to Close Configuration

Valve Tag # ____________________ Description ________________________________

Setup Calculation and Revision ____

Diagnostic Test Used for Evaluation ____________________________________

Safety Function: Close ☐ Open ☐

Qualitative assessment of Time and Performance Traces: Sat. ☐ Unsat ☐

Evidence of binding or other anomaly: Yes ☐ No ☐

Comments____

____

____

Evaluation of Drop Test Sat.☐ Unsat ☐

(Maximum Diaphragm Pressure * .05) = (A)

Pressure drop over 60 sec time frame = (B)

is (A) > (B) Yes ☐ No ☐

Comments____

____

____

I/P Trace linearity and Hysteresis Sat.☐ Unsat. ☐ N/A ☐

Is I/P In Calibration Yes ☐ No ☐

Dynamic Linearity ____________ Maximum Acceptable Linearity ____________

Comments____

____

____

Positioner Trace Linearity Sat. ☐ Unsat. ☐ N/A ☐

Is the Positioner in Calibration Yes ☐ No ☐

Dynamic Linearity ___________ Maximum Acceptable Linearity ___________

Comments____
____
____

Supply Pressure Review: Sat. ☐ Unsat. ☐

Current Setting __________ Allowable Setting _________ Tol. _________

Pressure Drop during test ________ Pressure drop during previous test _________

Comments____
____
____

Bench Set

Bench Set Lower ________ Upper

Design Bench Set:

Lower Bench set Minimum Value ______ Lower Bench set Maximum Value

Upper Bench set Minimum Value ______ Upper Bench set Maximum Value

(If tested value is within 4% of minimum or maximum value, consider test equipment error)

Comments____
____
____

Travel/Stroke Length review: Sat. ☐ Unsat. ☐

Travel/Stroke Length ________ Design Stroke Length ________ Tol. ________

Pilot Travel Length ________ Design Pilot Travel ________ Tol. ________

(If tested value is within 4% of minimum or maximum value, consider test equipment error)

Comments____

____

____

Packing Load

Assumed Packing Load from Calculation F_{PL} = ____________ lbs
(AA)

Maximum Friction from FlowScanner F_{MAX} = ____________ lbs
(BB)

Is AA > BB: Yes ☐ No ☐ If no, discuss in comments below:

Comments:

____

____

____

____

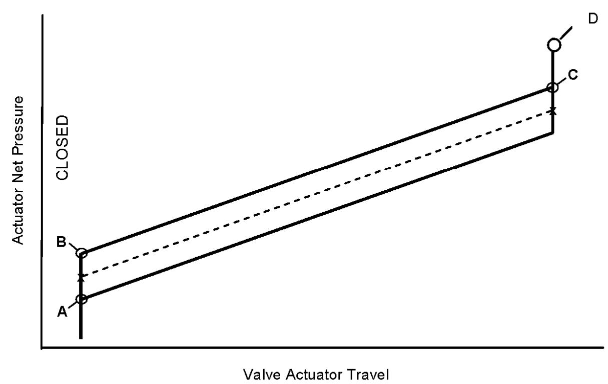
Spring Rate Evaluation Sat. ☐ Unsat. ☐

Spring Rate ________ Design Spring Rate ________ Tol. ________

Comments____

____

____



Typical Valve Performance Trace

Record Actuator Effective Diaphragm Area EDA = ________ in^2

Record F_{PL} from Calculation F_{PL} = ________ lbf

<u>Seating Force</u>

Min Req'd Thrust to Close from Calculation $MRST_C$ = ____________ lbf

Min Req'd Calculated Seating Load $F_{SL\text{-}CALC} = MRST_C - F_{PL}$ = __________ lbf
(CC)

Pressure at Point A on Trace P_A = ___________ psi

Seating Load from Trace $F_{SLC\text{-}TEST} = P_A \times EDA$ = ____________ lbf
(DD)

Is DD > CC ? Yes ☐ No ☐ If no, discuss in comments below:

Comments:

Comments (Continued)

____

____

Available Unseating Force

Min Req'd Thrust to Open from Calculation $MRST_O$ = __________ lbf

Min Req'd Calculated Unseating Force (psi) $F_{O\text{-}CALC} = (MRST_O - F_{PL}) / EDA$ = __________ psi (EE)

Pressure at point D on trace P_D = __________ psi (FF)

Pressure at Point B on Trace P_B = __________ psi (GG)

Available Unseating Force from Trace $F_{OC\text{-}TEST} = (P_D - P_B)$ = __________ psi (HH)

Is HH > EE ? Yes ☐ No ☐ If no, discuss in comments below:

Comments:

____

____

____

____

Full Open

Upper Bench Set (Maximum) From Calculation BS_{UMAX} = __________ lbf

Calculated Required Force to Fully Open Valve $F_{FO\text{-}CALC} = BS_{UMAX} + F_{PL}$ = __________ lbf

Calculated Required Pressure to Fully Open Valve $P_{FO\text{-}CALC} = F_{FO\text{-}CALC} / EDA$ = __________ psi (II)

Pressure at point D on trace P_D = __________ psi (JJ)

Pressure at Point C on Trace P_C = ____________ psi (KK)

Is JJ > II and KK ? Yes ☐ No ☐ If no, discuss in comments below:

Comments:

____
____
____
____

Margin Calculation

Closing

$$\frac{DD-CC}{CC} \times 100 = \underline{\qquad\qquad\qquad}$$

Unseating

$$\frac{FF-EE}{EE} \times 100 = \underline{\qquad\qquad\qquad}$$

Full Open

$$\frac{JJ-II}{II} \times 100 = \underline{\qquad\qquad\qquad}$$

General Comments:

____
____
____
____
____
____
____
____

Preparer	Date	Reviewer	Date

D.2 Analysis of Category 1 AOV Diagnostic Data, Sliding Stem Valve with Spring/Diaphragm Actuator Spring to Open Configuration

Valve Tag # ____________________ Description _________________________________

Setup Calculation and Revision ____

Diagnostic Test Used for Evaluation ____________________________________

Safety Function: Close ☐ Open ☐

Qualitative assessment of Time and Performance Traces: Sat. ☐ Unsat. ☐

Evidence of binding or other anomaly: Yes ☐ No ☐

Comments____

____

____

Evaluation of Drop Test: Sat. ☐ Unsat. ☐

(Maximum Diaphragm Pressure * .05) = (A)

Pressure drop over 60 sec time frame = (B)

Is (A) > (B): Yes ☐ No☐

Comments____

____

____

I/P Trace linearity and Hysteresis: Sat. ☐ Unsat. ☐ N/A ☐

Is I/P In Calibration: Yes ☐ No ☐

Dynamic Linearity ____________ Maximum Acceptable Linearity ____________

Comments____

____

____

Positioner Trace Linearity: Sat. ☐ Unsat. ☐ N/A ☐

Is the Positioner in Calibration: Yes ☐ No ☐

Dynamic Linearity ___________ Maximum Acceptable Linearity ___________

Comments____
____
____

Supply Pressure Review: Sat. ☐ Unsat. ☐

Current Setting __________ Allowable Setting _________ Tol. ________

Pressure Drop during test ________ Pressure drop during previous test ________

Comments____
____
____

Bench Set

Bench Set Lower ________ Upper

Design Bench Set:

Lower Bench set Minimum Value ______ Lower Bench set Maximum Value

Upper Bench set Minimum Value ______ Upper Bench set Maximum Value

(If tested value is within 4% of minimum or maximum value, consider test equipment error)

Comments____
____
____

Travel/Stroke Length review: Sat. ☐ Unsat. ☐

Travel/Stroke Length ________ Design Stroke Length ________ Tol. ________

Pilot Travel Length ________ Design Pilot Travel ________ Tol. ________

(If tested value is within 4% of minimum or maximum value, consider test equipment error)

Comments____

____

____

Packing Load

Assumed Packing Load from Calculation F_{PL} = ____________ lbs
(AA)

Maximum Friction from FlowScanner F_{MAX} = ____________ lbs
(BB)

Is AA > BB: Yes ☐ No ☐ If no, discuss in comments below:

Comments:

____

____

____

____

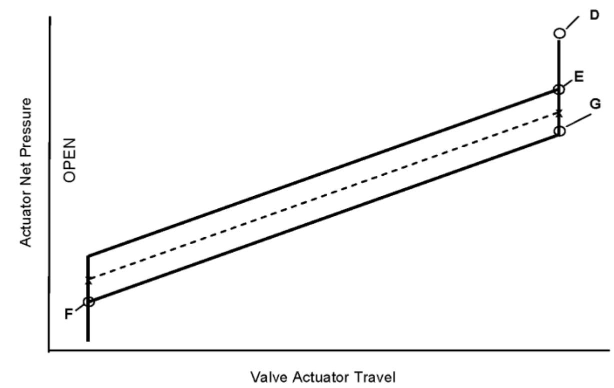
Spring Rate Evaluation: Sat. ☐ Unsat. ☐

Spring Rate ________ Design Spring Rate ________ Tol. ________

Comments____

____

____



Typical Valve Performance Trace

Record Nominal Actuator Effective Diaphragm Area EDA = ________ in^2

Record F_{PL} from Calculation F_{PL} = ________ lbf

Closing

Min Req'd Thrust to Close from Calculation $MRST_C$ = ____________ lbf

Min Req'd Pressure to Close $MRSP_C = MRST_C / EDA$ = __________ psi (CC)

DP Load (Closing) From Calculation DPL_C = ___________lbf

DP Load Closing From Calculation (Pressure) $DPL_P = DPL_C / EDA$ = ___________ psi

Pressure at Point D P_D = ___________ psi (DD)

Pressure at Point E on Trace P_E = ___________ psi

As – Tested Pressure at Point E plus DP load $P_{E+DP} = P_E + DPL_p$ = __________ psi EE

Is DD > CC and EE: Yes ☐ No ☐ If no, discuss in comments below:

Comments:

____
____
____
____

<u>Unseating</u>

DP Load (opening) from Calculation DPL_O = ____________ lbf

Pressure at Point G on Trace P_G = ___________ psi

Calculated Unseating Force from Trace $F_{OU\text{-}TEST} = (P_G \times EDA) + DPL_O$ = __________ lbf
(FF)

Is FF > 0: Yes ☐ No ☐ If no, discuss in comments below:

Comments:

____
____
____
____

<u>Full Open</u>

Min Req'd Thrust to Open from Calculation $MRST_O$ = ___________ lbf
(GG)

Min Req'd Calculated Full Open Force $F_{FO\text{-}CALC} = MRST_O - F_{PL}$ = __________ lbf
(HH)

Pressure at point F on trace P_F = ____________ psi

Full Open Force from Trace $F_{FO\text{-}TEST} = P_F \times EDA$ ___________ lbf
(II)

Is II > HH: Yes ☐ No ☐ If no, discuss in comments below:

Comments:

Margin Calculation

Closing

$$\frac{EE-CC}{CC} \times 100 = \_\_\_\_\_\_\_\_\_\_$$

Unseating

$$\frac{FF-GG}{GG} \times 100 = \_\_\_\_\_\_\_\_\_\_$$

Full Open

$$\frac{II-HH}{HH} \times 100 = \_\_\_\_\_\_\_\_\_\_$$

General Comments:

Preparer	Date	Reviewer	Date

D.3 Analysis of Category 1 AOV Diagnostic Data, Quarter-Turn Valves

Valve: ______________________ Test Date: ______________________

Test No.: ______________________ Calc. No.: ______________________

Safety Function: Close ☐ Open ☐

Qualitative assessment of Time and Performance Traces: Sat. ☐ Unsat. ☐

Evidence of binding or other anomaly: Yes ☐ No ☐

Comments: ____

____

Evaluation of Drop Test: Sat. ☐ Unsat. ☐

(Maximum Diaphragm Pressure * .05) = (A)

Pressure drop over 60 sec time frame = (B)

Is (A) > (B): Yes ☐ No ☐

Comments: ____

____

____

I/P Trace linearity and Hysteresis: Sat. ☐ Unsat. ☐ N/A ☐

Is I/P In Calibration: Yes ☐ No ☐

Dynamic Linearity: __________ Maximum Acceptable Linearity: __________

Comments: ____

____

Positioner Trace Linearity: Sat. ☐ Unsat. ☐ N/A ☐

Is the Positioner in Calibration: Yes ☐ No ☐

Dynamic Linearity: __________ Maximum Acceptable Linearity: __________

Comments: ____

____

____

Supply Pressure Review: Sat. ☐ Unsat. ☐

Current Setting: __________ Allowable Setting: __________ Tol.: __________

Pressure Drop during test: ________ Pressure drop during previous test: __________

Comments:____

____

____

Bench Set: Lower: ________ Upper: ____________ NA ☐

Design Bench Set:

Lower Bench set Minimum Value: _________ Lower Bench set Maximum Value:_________

Upper Bench set Minimum Value: _________ Upper Bench set Maximum Value:_________

(If tested value is within 4% of minimum or maximum value, consider test equipment error)

Comments:____

____

____

Travel/Stroke review: Sat. ☐ Unsat. ☐

Travel/Stroke __________ Design Stroke: ________ Tol.: ___________

(If tested value is within 4% of minimum or maximum value, consider test equipment error)

Comments:____

____

____

Running Load

Assumed Running Load from Calculation: T_{P} = ______________ ft-lbs
(AA)

Maximum Friction from FlowScanner: T_{MAX} = _____________ ft-lbs
(BB)

Is AA > BB: Yes ☐ No ☐ If no, discuss in comments below:

Comments:____

____

____

Spring Rate Evaluation: Sat. ☐ Unsat. ☐

Spring Rate: ___________ Design Spring Rate:___________ Tol.: ___________

Comments:____

____

____

Seat contact: Sat. ☐ Unsat. ☐

Comments: ____

____

____

Actuator Output Torque:

Close Stroke

Max Required Closing Stem Torque (MRST_op) from Calc: (MRSTC_op) ________ ft-lbs

MRSTC_op___________– T_P ____________= MRSTC _________________ ft-lbs
CC

Pressure at seating (P_s): _______ psi

Moment Arm (M_a) (_______________ in / 12) = (M_a) ________________ ft

Torque at seating (Tq_s) = (P_s) _______ * EDA ____________ * (M_a) ______________ =

(Tq_s) ________________ ft-lbs
DD

Is DD > CC Yes ☐ No ☐ If no evaluate DD at the point of CC and discuss in comments below:

<u>Open Stroke:</u>

Max Required Open Stem Torque (MRST_op) from calc: (MRSTO_op) ____________ ft-lbs

MRSTO_op____________– T_P _____________= MRSTO __________________ ft-lbs
EE

(Max Regulator Pressure ___________– Unwedging pressure ____________) =

Available pressure (A_p) = _________________________ psi

A_p * EDA * M_a = Available opening torque (Tq_o) __________________ ft-lbs
FF

Is FF > EE Yes ☐ No ☐ If no evaluate FF at the point of EE and discuss in comments below:

Comments: ____
____
____
____
____

General Comments / ARs and Work Orders initiated:______________________________
____
____
____

Performed By: ____ Date: ________________

Reviewed By: ____ Date: ________________

D.4 Analysis of Category 2 and 3 AOV Diagnostic Data

Valve Tag # ______________ Test # __________________ Date ___________

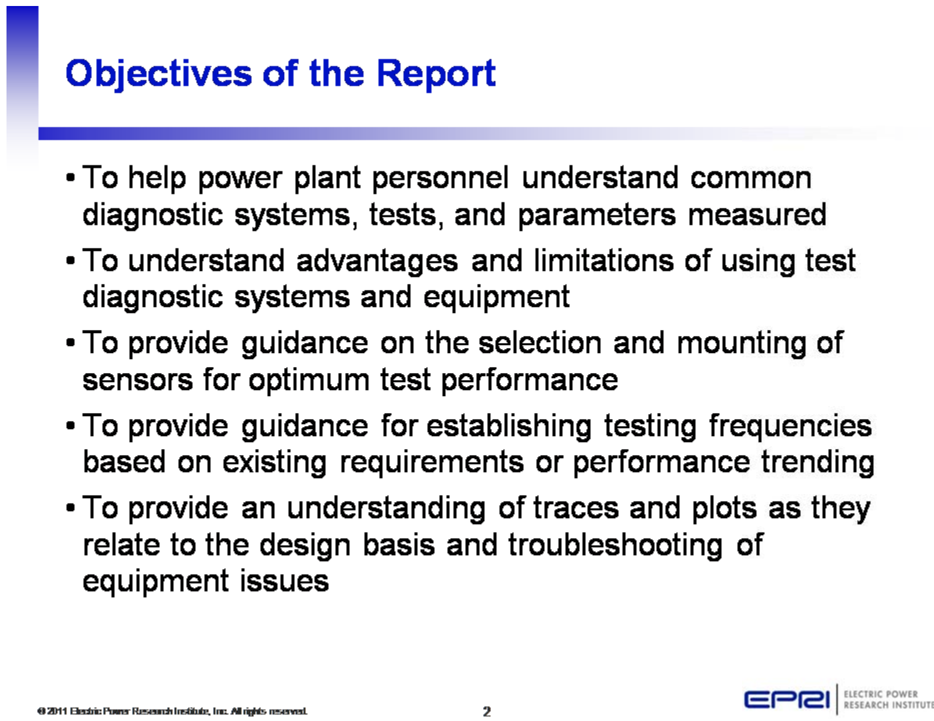
Perform Qualitative Assessment of Time Traces.	Sat/Unsat/NA
Perform Qualitative Assessment of Performance Traces.	Sat/Unsat/NA
Verify Valve fully opens.	Sat/Unsat/NA
Review evidence of valve hitting seat.	Sat/Unsat/NA
Verify correct Travel or Stroke Length	Sat/Unsat/NA
I/P - Verify linear calibration.	Sat/Unsat/NA
Positioner - Verify full supply pressure or zero pressure (as appropriate) at each end of travel.	Sat/Unsat/NA
Booster - Check for linear response	Sat/Unsat/NA.
Look for excessive Supply Pressure dips.	Sat/Unsat/NA
Check Average Friction Force.	Sat/Unsat/NA
Review bench set against required setting.	Sat/Unsat/NA

Comments:

____
____
____
____
____
____
____

Evaluation Performed By: ___________________________ Date ____________

Appendix E: Report Overview



Scope and Contents of Report

- Section 1 - Introduction
- Section 2 - Diagnostic Systems, Tests, and Parameters Measured
- Section 3 - Testing Experience
- Section 4 - Testing Frequency
- Section 5 - Trace Analysis
- Section 6 - Case Histories
- Section 7 – References
- Appendices
  – Technical Literature and Links
  – Actuator Drop Test: Industry Leakage Acceptance Criteria
  – Example Diagnostic Test Procedure

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Section 2 - Diagnostic Systems, Tests, and Parameters Measured

Diagnostic systems currently on the market

The primary systems that are purchased in the U.S. nuclear industry are listed below:

– Emerson FlowScanner
– Crane Viper
– Crane VOTES Infinity
– Areva UltraCheck
– Teledyne Quiklook
– Westinghouse AirCEt

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Section 2 - Diagnostic Systems, Tests, and Parameters Measured

Common Diagnostic Tests and Parameters Measured

- Ramp: Overall valve performance and calibration
- Step Response: Stroking speed and valve dynamic response
- Static Point: Hysteresis, Deadband, Repeatability, and Linearity error
- Step Sensitivity: Sensitivity to step changes of progressively decreasing magnitudes in the same direction
- Step Resolution: Positioning resolution about a setpoint with small input changes and inclusive of deadband
- Frequency Response: Frequency response to certain sinusoidal input signals
- Other

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Section 3 – Testing Experience

Overview

Discussion includes travel transducer installation, the proper use of tubing, and typical problems encountered. The use and advantages of strain gauges for the purpose of providing thrust and torque data are discussed in detail. Sensor selection and placement are described along with test time requirements and worker qualification.

Key Points

- ***System Warmup:*** It is a good practice to allow the data acquisition system to warm up 10–20 minutes prior to performing any diagnostic test. Consult the manufacturer for specifics on the proper warmup period for each system.
- ***Tubing Diameter:*** When performing diagnostics, you want to mimic the existing tubing configuration as much as possible to minimize the introduction of any false errors.

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Section 3 – Testing Experience cont..

- ***Leakage Criteria*** - A generic leakage criterion of 1-psi to 2-psi maximum drop per minute from the established supply pressure is common (based on the U.S. STARS survey).
- ***Actuator Drop Test*** - If an actuator fails the drop test, maintenance can be performed prior to final testing. Any actuator air leakage will be evaluated to determine if maintenance is required. Typically, an actuator with less than 2-psi-per-minute air leakage at full rated pressure can remain in use, and maintenance can be scheduled for the next PM cycle; however, any air leakage should be reviewed by engineering or the responsible program owner.
- ***Selecting and Mounting Sensors*** - Consistent location of these items is of prime importance for the trending of valve performance.
- ***Test Connections*** - The use of test connections will minimize time in the field, thus reducing radiation exposure and cost while increasing consistency between tests.

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Section 3 – Testing Experience cont..

- ***Linear Transducers*** - Mounting from the actuator to the stem is highly recommended and will give indication of the stretch of the yoke legs when the valve is under full load.
- ***Control Signal Transducer*** - The test I/P should be used in the same position as it was calibrated to maintain a high degree of accuracy and repeatability. Additionally, most vendors require the I/P in the stable and upright position.
- ***Portable, Clamp-On Strain Gauges*** – Clamp-on strain gauges are also sensitive to impact loads, and great care must be taken to ensure the health of the clamp-on transducer. Additionally, clamp-on gauges can be challenged by valves that have very short stroke times and a noticeable impact load upon stroking. The rapid change in acceleration can cause clamp slippage on the valve stem.
- ***Test Duration*** - Test duration has a direct impact on the ability of a component to accurately show a response to a given signal change. Test durations need to be consistent for similar valve configurations to allow for trending of test results.

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Section 3 – Testing Experience cont'd

- ***Worker Qualification*** - Qualification of plant and supplemental workers is an important part of obtaining valid data.
- ***Acceptance Criteria*** - Acceptance criteria should be established for all valves that will be part of the diagnostic test programs. This may take the form of a plus or minus tolerance to a specific parameter or the meeting of conditions specified in a unique component calculation. The values typically include travel, bench set, friction, seat load, and air pressure.

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Section 4 – Testing Frequency

- Establishing testing frequency is a result of historical tests and results. The intent is to establish a time interval that is minimally intrusive to the maintenance environment and yet sufficient to predict impending failure or degradation and still be able to perform repairs.
- To reduce the impact on diagnostic testing resources during an outage, many plants are making use of system unavailability time to perform diagnostic tests on-line. This requires a proficient team on diagnostics such that impact to the window of opportunity is not encountered by a team that is not efficient in their diagnostic practices.

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Section 5 – Trace Analysis

Diagnostic trace analysis is a comparison of the design requirements for the component to the actual condition, identification of the deltas, and determination of the results and actions to be taken.

- Test Plot Formats
  - ***Valve/Actuator Plot:*** This plot will typically show the results of the diaphragm pressure plotted on the Y-axis vs. the displacement on the X-axis.
  - ***Positioner Plot:*** This plot shows the relationship between signal and position.
  - ***I/P Plot or E/P Plot:*** This plot displays the relationship of the control signal current generated by the diagnostic unit (typically, 4–20 mA) to the signal sent to the positioner.
  - ***Control Loop Plot:*** This plot tells if you are getting the expected response from a given signal.

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Section 5 – Trace Analysis cont..

- Time Plots - The time-based plot displays parameters individually on the Y-axis and plots the time of the test on the X-axis. This type of representation allows cause-and-effect relationships to occur in the proper order or with the correct delay.
- Overlay - The overlay option allows the user to view two (or more) sets of cross-plot data on the same screen. This option is particularly useful for graphically depicting changes in a valve's performance over time or as adjustments are made to the performance.

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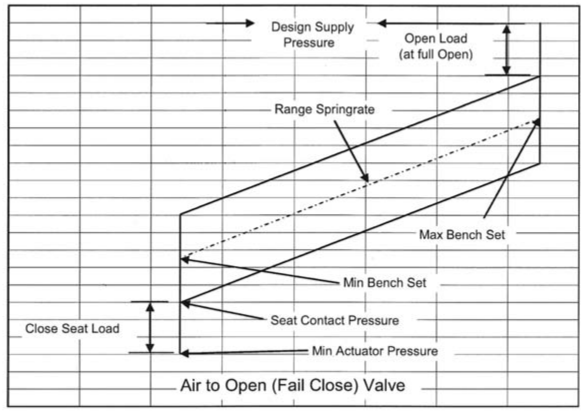
Section 5 – Trace Analysis cont..

- Analysis Preview Marking



Example of markings for an air to open valve

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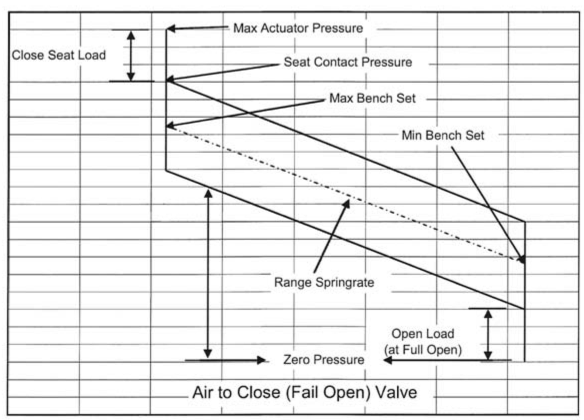
Section 5 – Trace Analysis cont..

- Analysis Preview Marking



Example of markings for an air to close valve

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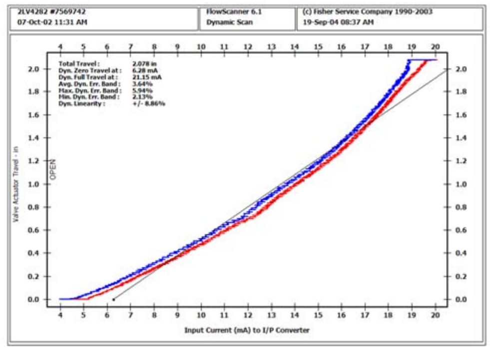
Section 5 – Trace Analysis cont..

Data Analysis with Example Signatures



Isolations in opening and closing strokes. Notice the bump at 12 mA dc input and 0.7 in. valve travel that is likely due to cam/cam roller wear or wear in the feedback arm (Courtesy of Southern Company)

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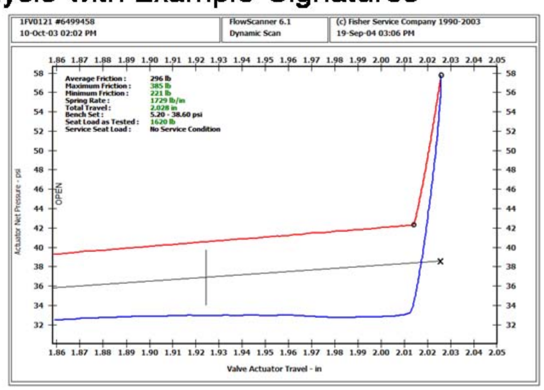
Section 5 – Trace Analysis cont..

Data Analysis with Example Signatures



Sliding stem globe valve with valve seating points verified (Courtesy of Southern Company)

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Section 6 – Case Histories

This section includes example traces of common issues that can be found using diagnostics. Examples include:

- Premature failure of new digital positioner
- Bad test I/P
- Poor strain gauge bond
- Loading increases due to undrained pipe
- Piston bottoming out
- Feed regulating tube stuck in valve
- Incorrect pilot poppet stroke

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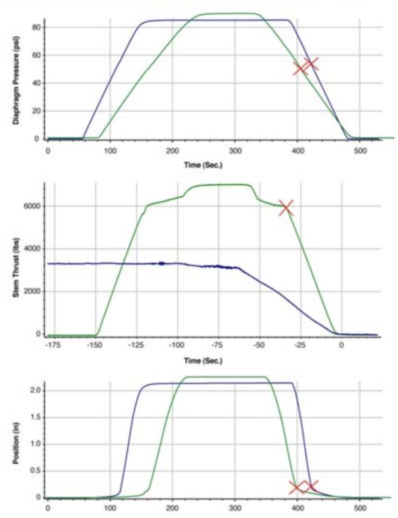
Section 6 – Case Histories cont'd



Before and after trace of a bad strain bond. The strain value was half the value calculated with pressure.

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Appendices

- Appendix A – Key Points
- Appendix B – Technical Literature and Links
- Appendix C – Actuator Drop Test: Industry Leakage Acceptance Criteria
- Appendix D – Example Diagnostic Test Procedures (Courtesy of Progress Energy)
  - D.1 Analysis of Category 1 AOV Diagnostic Data, "Sliding Stem Valve with Spring/Diaphragm Actuator Spring to Close Configuration"
  - D.2 Analysis of Category 1 AOV Diagnostic Data, "Sliding Stem Valve with Spring/Diaphragm Actuator Spring to Open Configuration"
  - D.3 Analysis of Category 1 AOV Diagnostic Data, Quarter-Turn Valves
  - D.4 Analysis of Categories 2 and 3 AOV Diagnostic Data

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