PARTIAL-STROKE TESTING OF BLOCK VALVES

Angela E. Summers, Ph.D., P.E., President, SIS-TECH Solutions, LP

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Successful implementation of the safety lifecycle model, associated with ANSI/ISA 84.01-1996 (ISA 84) and IEC 61508, hinges on one design constraint---the safety integrity level (SIL). The SIL is a numerical benchmark, related to the probability of failure on demand (PFD). SIL is affected by the design robustness, e.g., device integrity, voting, and common cause faults. It is also affected by the operation and maintenance strategy, e.g., diagnostics and testing interval.

For many operating companies, the most difficult part of SIL compliance is the testing of final elements, especially emergency block valves. Traditionally, emergency block valves have been tested at unit turnaround, using a full-stroke test to demonstrate performance. Thirty years ago, turnarounds were every two to three years. Due to mechanical reliability and preventive maintenance programs, companies are now extending unit turnarounds to every five to six years. Extended turnarounds yield great economic returns through increased production. Extended turnaround intervals also mean that emergency block valves are expected to go longer between function tests, yet still achieve the same performance. This is not possible.

Partial-stroke testing can be used to supplement full-stroke testing to reduce the block valve PFD. The amount of the reduction is dependent on the valve and its application environment. This paper will discuss how to determine the actual impact of the partial-stroke test on PFD. It will also present a discussion of the three partial-stroke testing methodologies that are currently being evaluated and used by industry.

SIL VERIFICATION FOR BLOCK VALVES

The probability to fail on demand (PFD) can be calculated using the dangerous failure rate (λ^D) and the testing interval (TI). The mathematical relationship, assuming that systematic failures are minimized through design practice, is as follows:

$PFD = \lambda^D * TI/2$

The equation shows that the relationship between PFD and TI is linear. Longer test intervals yield larger PFDs. The OREDA database has data for various valve types and sizes. For the purposes of illustration, a dangerous failure rate of 3.03E-06 failures per hour will be used. The valve failure rate varies with type, size, and operating environment (e.g., process chemicals, deposition, polymerization, etc.). The reader should determine the appropriate failure rate for the specific application.

SIS-TECH
12621 Featherwood Drive • Suite 120 • Houston, Texas 77034
Tel: (281) 922-8324 • Fax: (281) 922-4362
www.SIS-Tech.com

The PFD, based on the 3.03E-06 per hour failure rate, is shown in Table 1 for various testing frequencies. As expected, the valve performance at a 5-year testing interval is not the same as the valve performance at a 2-year testing interval. Reliability data for operating equipment provided justification to extend the turnaround period, in many cases by a factor of three or more. However, the impact of longer testing intervals on standby devices, such as block valves, was not evaluated. Longer turnaround intervals result in improved financial performance. The side effect is increased risk of an incident due to lower performance of safety critical devices, such as the SIS final elements.

Table 1. PFD_{avg} for a Typical Block Valve as a Function of Testing Interval (λ=3.03E-06)

Testing Interval	PFD_{avg}
1 year	1.33E-02
2 years	2.65E-02
3 years	3.98E-02
4 years	5.31E-02
5 years	6.64E-02
6 years	7.96E-02

Due to the degraded performance at longer testing intervals, many companies have found that they must test the block valves on-line. Once facilities for on-line testing are installed, full-stroke testing can easily be performed. However, since a full-stroke test involves full contact of the valve seating members, frequent stroking can cause excessive wear to the block valve seat. This is a serious concern for soft-seated valves. Increased testing may achieve a higher integrity, but cause damage to the valve seat, leading to earlier valve failure.

Another major concern is that the plant is unprotected while the block valve is in bypass for testing. The fraction of the time that the valve is in bypass must be considered in the PFD calculation. If the valve is bypassed every six months for testing and the test takes 1-hour, the PFD is increased by 2.3E-04. For longer bypass periods or more frequent testing, the impact on the PFD is even more significant. To maintain safety, operating procedures must include a list of the actions to be taken when the valve is in bypass, such as reducing production rates, monitoring certain process variables, or executing shutdown.
An option to a full-stroke test is a partial-stroke test. The test involves moving the valve a minimum of 15 percent, which tests a portion of the valve failure modes. The remainder of the failure modes are tested using a full-stroke test. The main purpose of the partial-stroke test is to reduce the required full-stroke testing frequency.

Partial-stroke testing does not eliminate the need for a full flow bypass. If the valve is partial-stroke tested and determined to be non-functional, maintenance will need a bypass or the process will have to be shutdown for valve repair. Since the bypass is not required for testing, there is no loss of safety integrity. The bypass is only used during valve maintenance.

How does partial-stroke testing affect the PFD? A complete functional test of the valve can be viewed as consisting of two parts: the partial-stroke (PS) and the full-stroke (FS). For the calculation, the dangerous failure rate, λ^D, must be divided into what can be tested at the partial-stroke (λ^D_{PS}) and what can only be tested with a full-stroke (λ^D_{FS}). The resulting equation for the PFD is as follows:

$$PFD = \lambda^D_{PS} * TI_{PS}/2 + \lambda^D_{FS} * TI_{FS}/2$$

The division of λ^D into parts requires an evaluation of the failure modes of the valve. Table 2 provides a listing of typical dangerous failure modes for block valves and the corresponding effect of these failure modes. The test strategy indicates whether the failure mode can be detected by partial-stroke testing or only by full-stroke testing.

Table 2. Dangerous Failure Modes and Effects with Associated Test Strategy

Failure Modes	Effects	Test Strategy
Actuator sizing is insufficient to actuate valve in emergency conditions	Valve fails to close (or open)	Not tested
Valve packing is seized	Valve fails to close (or open)	Test valve – Partial or full-stroke
Valve packing is tight	Valve is slow to move to closed or open position	Not tested unless speed of closure is monitored.
Air line to actuator crimped	Valve is slow to move to closed or open position	Not tested unless speed of closure is monitored. Physical inspection
Air line to actuator blocked	Valve fails to move to closed or open position	Test valve – Partial or full-stroke
Valve stem sticks	Valve fails to close (or open)	Test valve – Partial or full-stroke
Valve seat is scarred	Valve fails to seal off	Full-stroke test with leak test
Valve seat contains debris	Valve fails to seal off	Full-stroke test
Valve seat plugged due to deposition or polymerization	Valve fails to seal off	Full-stroke test

The failure modes listed in Table 2 can be compared to the failure mode distributions presented in the Offshore Reliability Data Handbook (OREDA) for various valve types and sizes. Based on the OREDA data, the *maximum percentage* of the failures that can be detected by a partial-stroke test is 70%. The remaining 30% of the failures can only be detected using a full-stroke test.

The reader is cautioned that this breakdown is based on average valve performance in off-shore installations and may not represent the breakdown for the reader's application. This evaluation should be done for each valve type, based on the application environment and the shutoff requirements. If the service is erosive, corrosive, or plugging, the failure rate and failure mode breakdown will be different from that shown in this paper. If the valve is specified as tight-shutoff, the contribution of minor seat deformation or scarring will be more significant than shown in this paper. For these reasons, it is recommended that partial-stroke testing not used as a substitute for full-stroke testing for a single block valve application when:

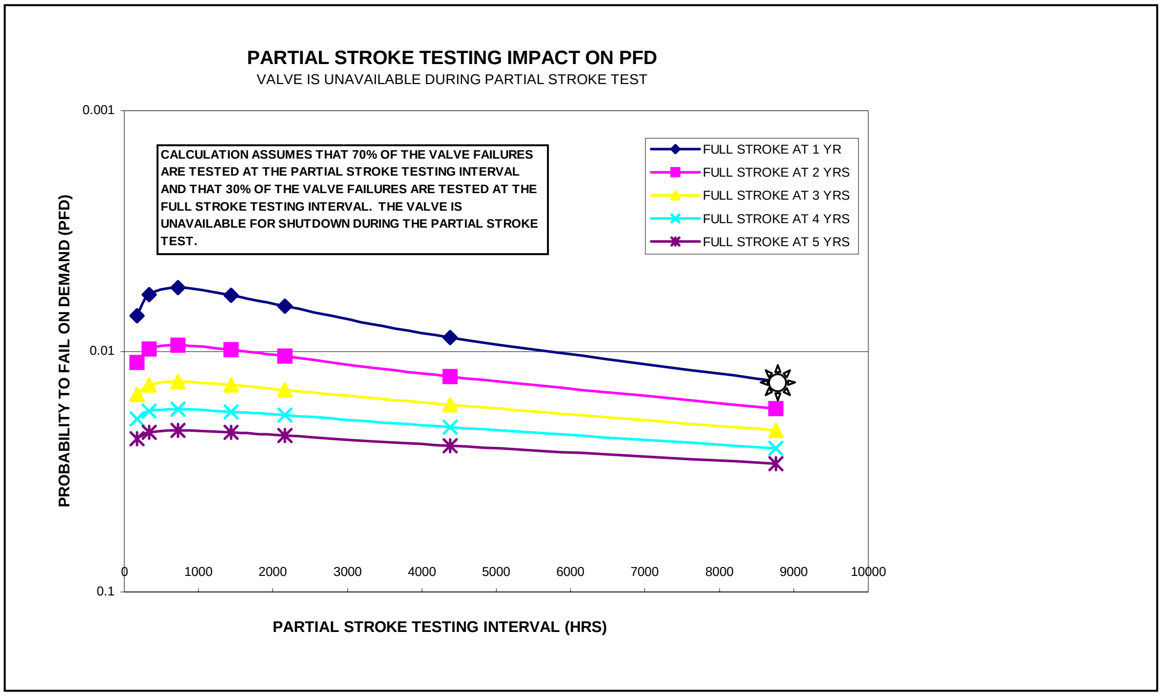
a. the valve has been shown to fail in the service due to process deposition or plugging,
b. the valve is specified as tight-shutoff for safety reasons,
c. valve leakage can generate a hazardous incident.

Using 70% as the breakdown of the dangerous failure rate, λ^D, the equation for the PFD can be written as follows:

$$PFD = 0.7\lambda^D * TI_{PS}/2 + 0.3\lambda^D * TI_{FS}/2$$

Using a dangerous failure rate of 3.03E-06 per hour, Figure 1 shows the PFD when the test procedure requires removing the valve from service during the test. As expected, the partial-stroke testing does improve the PFD performance of the valve. The star illustrates the point where the partial-stroke testing interval and full-stroke testing interval are both at 8760 hours (1 year). This corresponds to the results for a 1 year full-stroke test, as shown in Table 1.

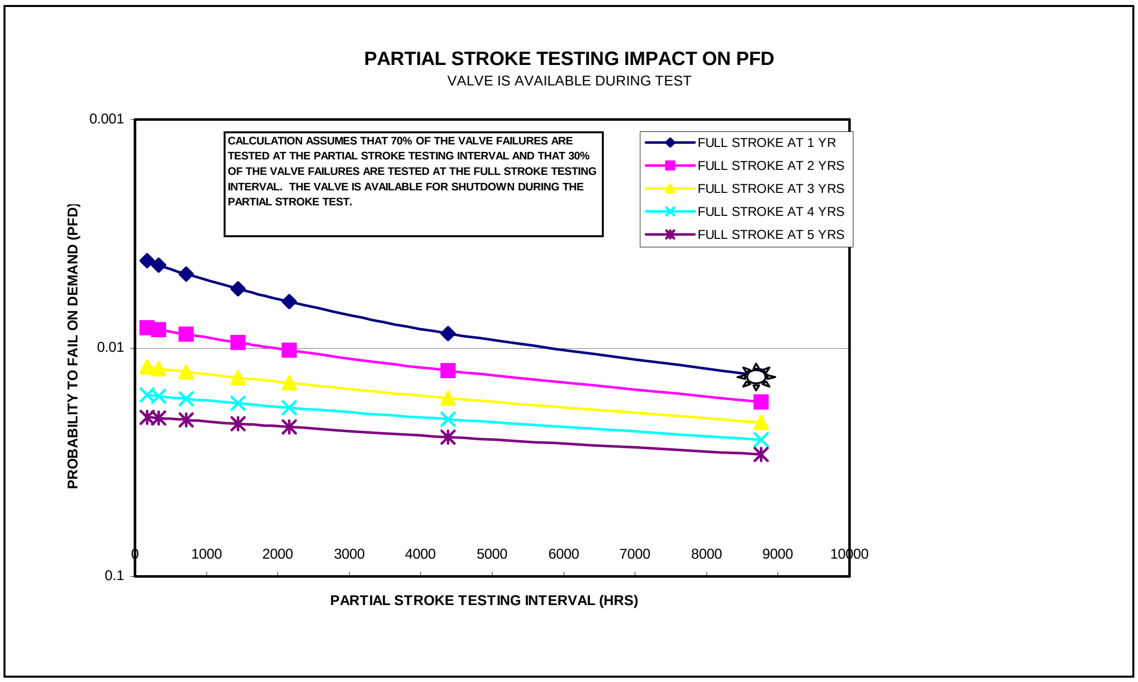
Figure 1. Relationship Between Partial-stroke Testing Interval and PFD – Valve is Unavailable During the Test



The downward trend of the curves for very frequent partial-stroke testing is due to the valve being removed from service during the test. This removal results in the valve not being available for the fraction of time that the valve is being tested. The calculation assumes that the total test time is 30 minutes. If the actual test time is longer, the effect will be more pronounced.

Figure 2 shows the PFD when the test procedure allows the valve to remain in service during the test. Very frequent partial-stroke tests improve the PFD substantially, because there is no loss of functionality during the test. Again, the star illustrates the point where the partial-stroke testing interval and full-stroke testing interval are both at 8760 hours (1 year).

Figure 2. Relationship Between Partial-stroke Testing Interval and PFD – Valve is Available During the Test



For both test procedures, partial-stroke testing does improve the valve performance. For example, 5-year full-stroke testing achieved a PFD of 6.64E-02 (Table 1). A 5 year full-stroke test supplemented with a 6-month (4380 hours) partial stroke test achieved a PFD of 2.46E-02, which is a 37% reduction in PFD. In the cases of 1-year and 2-year full-stroke testing, a single block valve can potentially achieve SIL 2 performance when supplemented with frequent partial-stroke tests. For longer full-stroke testing intervals, the valve performance can increase from low SIL 1 to high SIL 1, depending on the partial-stroke testing interval. From the graphs, it is easy to see that no amount of partial-stroke testing is going to allow a single valve to achieve high SIL 2 performance, let alone SIL 3 performance, at full-stroke testing intervals of 1 year or more.

PARTIAL-STROKE TEST METHODOLOGY

There are three basic types of partial-stroke test equipment: mechanical limiting, position control, and solenoids. Each type involves different levels of sophistication and risk. Consequently, each type will be discussed separately.

Mechanical Limiting

Mechanical limiting methods involve the installation of a mechanical device to limit the degree of valve travel. When mechanical limiting methods are used, the valve is not available for process shutdown (see Figure 1).

The mechanical devices used for partial stroke testing include collars, valve jacks, and jammers.

- ✓ Valve collars are slotted pipes that are placed around the valve stem of a rising stem valve. The collar prevents the valve from traveling any farther than the top of the collar. Any fabrication shop can build a valve collar, suitable for test use.
- ✓ A valve jack is a screw that is turned until it reaches a set position. The valve jack limits the actuator movement to the screw set position. The valve jack is ordered from the valve manufacturer when the valve is purchased. Valve jacks work with both rising stem valves and rotary valves.
- ✓ Mechanical jammers are integrated into the rotary valve design. They are essentially slotted rods that limit valve rotation when placed in position using an external key switch. Since the jammer is integrated into the rotary valve, the jammer must be purchased from a valve manufacturer. A contact can be provided for the key switch to allow annunciation in the control room whenever the key is used.

Mechanical limiting methods are inexpensive in terms of capital and installation costs. These methods are manually initiated in the field and are manpower intensive.

A limit switch or visual inspection is used to confirm valve movement. Successful implementation and return to normal operational status are completely procedure driven. For valve collars and jacks, bypass notification to the control room is entirely procedural. For the jammer, automatic notification using the key switch contact can be provided.

One of the biggest drawbacks to these methods is the lack of assurance that the valve is in or has been returned to normal status. There is no way to know for certain that the jack or jammer has been completely retracted without actuating the valve. Furthermore, unauthorized use of the valve jack or jammer cannot be determined by casual inspection. This means that the valve could potentially be out of service with operations personnel unaware of the situation.

These methods do not add to the normal operating spurious trip rate. However, there is the potential for a spurious trip during the partial-stroke test. For valve collars, the main culprit of spurious trips is improper installation, causing the collar to pop off the stem when the valve begins to move. Jacks and jammers must be placed in service by the technician; so procedural mistakes can result in the valve closing completely rather than just partially. Therefore, these methods are really only as good as the written procedures and technician training.

Position Control

Position control uses a positioner to move the valve to a pre-determined point. This method can be used on rising stem and rotary valves. Since most emergency block valves are not installed with a positioner, this method does require installation of additional hardware. Positioner operation also requires an analog output, which is typically not installed in SIS applications. Consequently, cost is a major drawback for the position control method.

A limit switch or position transmitter can be used to determine and document the successful completion of the tests. If a smart positioner is used for the position control, a HART maintenance station can collect the test information and generate test documentation. Of course, the use of a smart positioner and maintenance station further increases the capital cost.

Some vendors have promoted the use of the positioner in lieu of a solenoid for valve actuation. However, most positioners do not have a large enough vent port (C_v) for rapid valve closure. Consequently, a solenoid should still be used for valve actuation. This solenoid valve must be installed between the positioner and the actuator.

The positioner does contribute to the spurious trip rate during normal operation, since the positioner can fail and vent the air from the valve. When a solenoid is installed between the positioner and the actuator, the safety functionality is never lost during the partial-stroke test (See Figure 2). De-energizing the solenoid will shut the valve regardless of the positioner action.

Solenoid

A partial-stroke test can be accomplished by pulsing a solenoid valve. The solenoid can be the same solenoid used for valve actuation, resulting in a low capital and installation costs for the method. If the actuation solenoid valve is used, this method will also test the solenoid valve functionality.

The time of the pulse must be adjusted for each valve and solenoid pair to achieve the desired valve travel. Valve travel confirmation is accomplished by a limit switch or position transmitter, allowing automatic documentation of test status. Since a serious failure of the valve may result in more movement of the valve during the pulse than desired, the pulse timer should be voted with the limit switch or position transmitter. If the valve reaches its desired travel point before the pulse timer is finished, the solenoid valve should be reset. The test can be programmed in the SIS logic solver with the test being implemented automatically based on a programmed cycle time or initiated by the operator on a maintenance schedule.

Since the valve is never bypassed or disabled, the valve remains available for shutdown during the test (see Figure 2). As with the other partial-stroke testing methods, a maintenance bypass is required to allow maintenance to be performed on-line without a process shutdown.

Spurious trips during testing can be a problem, if non-redundant solenoids are used for valve actuation. After all, the solenoid is being de-energized for the test and re-energized to stop the test. If the solenoid valve does not reset, the test becomes a trip. The use of redundant solenoids can seriously reduce the probability of the spurious trip.

CONCLUSION

Partial-stroke testing does provide measurable improvement of the PFD over full-stroke testing alone. The amount of improvement is dependent on the specification, configuration, and application environment. The three partial-stroke testing methodologies offer choices between manual and automated testing.

Whichever method is selected, procedures must be written to ensure that the block valve is not tripped during testing, the test is properly carried out, incorrect valve performance is documented, and maintenance is performed to return valve to fully functional status. This means that the documentation requirements for the partial-stroke test are the same as for the full-stroke test. Since a bypass is still required for maintenance, facilities and procedures must be in place to ensure that use of the bypass valve is restricted. The main benefit is that partial stroke testing can reduce the full-stroke testing interval required to achieve the SIL.

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