SILstroke: A 2oo4D Partial Stroke Testing Device for Safety and Critical Valves

by
Dr. Lawrence Beckman
SafePlex Systems, Inc., Houston, Texas

Abstract

Valves lack internal diagnostics and in order to reveal valve failures it is necessary to perform partial or full stoke testing. While performing the testing, it is essential not to interfere with the inherent safety function (SIF), or cause a spurious trip of the process. The purpose of this paper is to give the reader an overview and comparison of different partial stroke testing options, and to demonstrate the benefits of the 2oo4D SILstroke fail safe, fault tolerant solution.

Introduction

In process Facilities there are many valves in use. Some are for control of the process; others are used for process safety, as part of the Safety Instrumented System (SIS). Some non-safety process valves are critical as well, in that their failure could result in a shutdown of the process – a spurious trip.

The focus of this paper is directed to these safety-related or critical valves and their operation. From a production prospective, the operation of these valves is a major concern addressing both operational availability and safety availability. Both need to be considered to achieve optimal production and process safety performance.

Given that valves lack internal diagnostics, functional diagnostics must be utilized to perform diagnostic testing of the valve, while it is in operation. One method to perform this functional testing on-line is called Partial Stroke Testing (PST), which is suitable for use on safety (ESD) valves, as well as other critical valves.

Partial Stroke Testing (PST) – Supplemental Testing

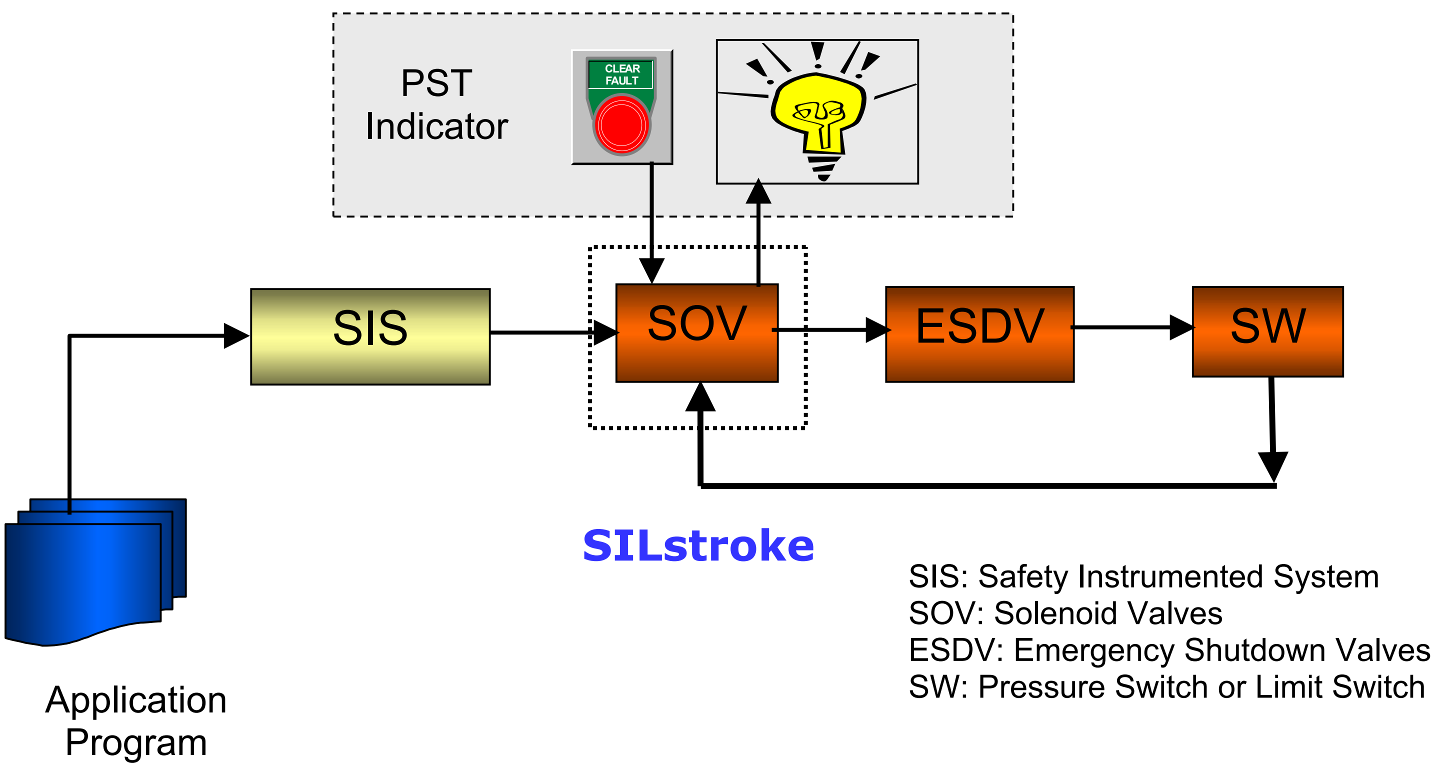
This technique offers a method of testing the SIS valve by moving it, typically 15-25%, and back to the original position in a short period of time. The purpose of the test is to confirm the valve's ability to move (not stuck in place), and its suitability for continued SIS service.

- Only a portion of the valve's dangerous failure modes can be tested during the partial stroke test; the remainder can only be tested by full stroke testing and seating during the Proof Test. However, it should be noted that it is not necessary to close the valve completely to initiate a safe shutdown of the process.

- It is estimated that the coverage factor of the PST is between 60 - 80% of the possible dangerous failure modes, based on an FMEDA for the type of valve under consideration. Comprehending this coverage factor in the reliability analysis will reveal that the safety performance of the valve has been improved, and its Risk Reduction Factor (RRF) increased.

Safety Instrumented Function (SIF)

As part of an SIS, a typical SIF consists of the following: Sensors, Logic Solver and Final Elements. The Final Elements are the valves with attached devices, and they typically contribute about fifty (50%) of the total PFD_{avg} of the SIF. An SIF's performance to a target Safety Integrity Level (SIL) is determined by its total PFD_{avg}. As such, improving the PFD_{avg} of the final element (valve and its operator) is the area of greatest opportunity for significant reduction of PFD_{avg}; thereby increasing the SIL of the safety function, or extending its Proof Test Interval.



Typical Diagram for Partial Stroke Testing

Goals of Partial Stroke Testing

In order to implement PST successfully, the following goals should be established:

- Cost effective installation.
- Simple to calibrate, operate, and test.
- Safe, on-line repair.
- Minimum impact on the existing SIF.
- Does not decrease the availability of the SIF. No spurious trips.
- Does not degrade the SIL rating of the safety function (SIF) to which it is attached.
- Does not violate the Process Safety Time Constraints of the ESD valve, or the minimum HFT = 1 requirement for SIL 3 (per IEC 61511).

It is important to note that if the installation of a PST device alters the dynamics of the valve (i.e., slower closing rate), the valve may no longer be suitable for use in the SIF, as it can no longer respond in the time (process safety time) required. If this is indeed the case, other means must be used to meet the process safety time constraint, and they must be included in the computation of the PFD_{avg} for the valve and its associated SIF.

Benefits of PST

Given that Partial Stroke Testing of the valve and it attached devices (per the above Diagram) have been implemented successfully, the following benefits can be achieved:

- Increase the SIL (lower PFD_{avg}) of the valve, keeping the Proof Test Interval constant.
- Lengthen the Proof Test Interval of the valve, keeping the SIL constant.
- Combination of both of the above.
- Eliminates the need for a second ESD valve in some cases.

However, it is imperative that performing a PST of a critical or safety (ESD) valve does not cause a spurious trip of the process, due to a failure in the device performing the PST. Most spurious trips are caused by SOV failures, and not by failures related to the valve itself. As such, the PST device should have internal diagnostics, be fully fault tolerant, and fail safe. Ideally, it should be capable of being repaired on-line without by-passing or disabling the safety function to which it is associated. In addition, it should prohibit over-stroking of the valve (because of a sluggish response) which could also initiate a spurious trip of the process due to excessive valve closure.

Methods of Implementation

Typical devices used for implementing PST are as follows:

I) Use the ESD system to perform the test
II) Use a positioner based device
III) Use a 2oo2 or 2oo3 redundant device
IV) Use a 2oo4D device, such as SILstroke from SafePlex Systems, Inc.

We will discuss each of the above alternatives and evaluate the best option.

I) While an ESD based PST seems like an obvious solution, it has considerable deficiencies as follows:

a) It is expensive due to the cost of additional ESD I/O and field wiring.
b) It utilizes the same field devices, and as such provides no reduction in the dangerous or spurious failure rate of the SOV.
c) Minimal improvement in the PFD_{avg} of the SIF.
d) No local testing capability.
e) No improvement in the operational availability of the SIF resulting from spurious trips due to SOV failure.
f) No on-line replacement of failed SOV.
g) Constrained by MOC restrictions for the Logic Solver (PES).

II) Using a positioner based device is perhaps the worse option, as it is a complete misapplication of technology. Positioners were developed for modulating control valves, whose movement is very small. ESD valves on the other hand are fully open or fully closed, and go from one state to the other as quickly as possible. An SOV is far better suited for this application. Because positioners have a very small Cv, they cannot vent an ESD valve diaphragm quickly as required to satisfy the process safety time, and are suitable only for smaller valves. To compensate for this deficiency, an interposing SOV or QEV is used to vent the ESD valve diaphragm. This SOV or QEV is not tested during the PST and remains in a static position for an extended period of time. As such, it may not be able to close (vent) the ESD valve upon demand, and is itself a source of both dangerous failures and spurious trips.

In addition to the interposing SOV or QEV, positioners use a pneumatic vane-nozzle arrangement (I/P converter) which operates independently of the positioner electronics. Given the nozzle orifice is plugged (by a tiny spec of dirt or oil/water in the air supply), shutting off the electronics will not vent the valve diaphragm. This is a dangerous failure mode, as venting the diaphragm (closing the ESD valve) is critical to achieving the safe state. Unfortunately this dangerous failure mode is not addressed in most positioner product safety evaluations.

III) Using either 2oo2 or 2oo3 redundant devices also has some issues as follows:

a) These devices are not tested prior to conducting the PST, and could fail during the PST thus tripping the process.
b) To perform on-line repair both devices require by-passing (completely disabling) the safety function.
c) The 2oo2 device is only fault tolerant in the air supply mode. To vent the ESD valve diaphragm, both SOVs have to operate properly (close). If either SOV is stuck open and fails to close, the valve diaphragm does not vent, the ESD valve does not close; and we experience a dangerous failure of the SIF due solely to a fault in the 2oo2 device.
d) The safety certification and SIL rating for the 2oo2 device mandates that it operate only as a 1oo1 device with hot backup. As such, only one of the SOVs is active. Frequent switching between SOVs is required to maintain the SIL rating, and these transitions could be a source of spurious trips.
e) The 2oo3 device contains numerous check valves which can stick because of dirt or water in the air supply. As such, this can itself be a source of both dangerous failures and spurious trips.

IV) The ideal PST configuration is the 2oo4D architecture used in the SILstroke device. This patented architecture provides two parallel paths, each path having two SOVs in series. It has the following operational advantages:

a) It is fail safe and fully fault tolerant (both air supply and exhaust). No single failure will prevent the correct operation of this device. It meets the minimum HFT = 1 requirement for SIL 3 (per IEC 61511).
b) The device is completely tested prior to performing the PST. If a fault is detected by internal diagnostics, the PST is cancelled and the fault is alarmed.
c) The device is certified to SIL3 by TÜV Rheinland, and provides superior immunity to spurious trips due to failures in the PST device.
d) The device can be repaired on-line without disabling or by-passing the associated safety function.
e) Elimination of dangerous and spurious failures associated with the SOVs.
f) Immediate detection and alarm of SOV failures resulting from an uncommanded change of state.
g) The Cv of the device is large, and it is suitable for use on larger valves without external venting devices.
h) Local testing, diagnostic and alarm capability.
i) Over stroking of the safety valve due to sluggish response is prevented.
j) The device automatically calibrates to the valve under actual process operating conditions.
k) The device is simple to install, operate, and maintain., and need not be installed directly on the ESD valve
l) The device does not affect the MOC requirements for the Safety Logic Solver (PES).

Calculation of Benefits

Calculate Extended Proof Test Interval and Improved PFD_{avg}

In the design of the SIS, a quantitative determination is done to see if the design meets the SIL required by the Safety Requirements Specification (SRS). For the single valve, the equation given in ISA-TR84.00.02-2002 – Part 2 for the average probability of failure on demand (PFD_{avg}) is as follows:

$$PFD_{avg} = \lambda_D \times \frac{TI}{2} \qquad \text{Equation 1}$$

where PFD_{avg} is the average probability of failure on demand, λ_D is the failure-dangerous rate of the valve, and TI is the proof test interval.

There is an inherent assumption herein that the full stroke test at test interval (TI) has a diagnostic coverage of 100%. This may not always be the case, as many times a valve tested during a shutdown or turnaround is not tested at operating conditions, the leak tightness may not be tested, the valve may not be fully inspected, and the test is done by a human being who is subject to error. So what some people call a full stroke test may in fact be a form of partial testing.

Now if we consider that we can stroke the valve a short distance that will test a portion of the possible failure modes, and we are doing this at a test interval different than the full stroke test interval, then we can expand Equation 1 to account for this as follows:

$$PFD_{avg} = DF_{PST} \times \lambda_D \times \frac{TI_{PST}}{2} + (1 - DF_{PST}) \times \lambda_D \times \frac{TI_{PT}}{2}$$

where PFD_{avg} is the average probability of failure upon demand, DF_{PST} is the Diagnostic Coverage Factor of the partial stroke valve test, λ_D is the dangerous failure rate of the valve and SOV, TI_{PST} is the partial stroke test interval, TI_{PT} is the proof (full stroke) test interval; and the full stroke valve test diagnostic coverage is considered to be 100%.

Note: MTTR was considered negligible when compared to the PST interval.

Improved PFD_{avg} and SIL

Base Case – No "PST" (0% Coverage) 1oo1 Ball Valve with 1oo1 Solenoid
(PT Interval = 1 year)

$PFD_{avg} = 2.25 \times 10^{-2}$ (SIL = 1.65)

Base Case – With "PST" (70% Coverage) 1oo1 Ball Valve with 1oo1 Solenoid

(PT Interval = 1 year)

PFD_{avg} = 7.36 x 10^{-3} (SIL = 2.13) PFD_{avg} Reduction of 67%

SILstroke Case – With "PST" (70% Coverage) 1oo1 Ball Valve with 2oo4D Solenoids
(PT Interval = 1 year)

PFD_{avg} = 3.31 x 10^{-3} (SIL = 2.50) . . . . . .
. . . . PFD_{avg} Reduction of 85%

* Solenoid MTBFdu = 50 years
* Ball Valve MTBFdu = 40 years
* PST Coverage Factor = 70%
* PST Interval = 2 weeks
* PT Interval = 1 year

<u>Extended Proof (Full Stroke) Test Interval</u>

Base Case – No "PST" (0% Coverage) 1oo1 Ball Valve with 1oo1 Solenoid

PFD_{avg} = 2.25 x 10^{-2} (SIL = 1.65) PT Interval = 1 year

Base Case – With "PST" (70% Coverage) 1oo1 Ball Valve with 1oo1 Solenoid

PFD_{avg} = 2.25 x 10^{-2} (SIL = 1.65) PT Interval = 3.24 years

---

SILstroke Case – With "PST" (70% Coverage) 1oo1 Ball Valve with 2oo4D Solenoids
(No Dangerous SOV Failures)

PFD_{avg} = 2.25 x 10^{-2} (SIL = 1.65). . . . .
. . . . PT Interval = 5.91 years

* Solenoid MTBFdu = 50 years
* Ball Valve MTBFdu = 40 years
* PST Interval = 2 weeks
* PST Coverage Factor = 70%

Discussion of Results

Using the above equation for PFD_{avg} for a 1oo1 device, we obtained the above results. Depending upon your objective (reduce the PFD_{avg} or extend the Proof Test Interval), significant improvement was achieved.

For the case of Reducing the PFD_{avg} of the Final Element, the Base Case (utilizing a 1oo1 Ball Valve and 1oo1 SOV with no PST) produced a SIL of 1.65. Conducting a PST of the Ball Valve increased the SIL to 2.13, a 67% improvement. Replacing the 1oo1 SOV with the 2oo4D SOVs (SILstroke) eliminated dangerous SOV failures and increased the SIL to 2.50, an 85% improvement. In addition, SILstroke virtually eliminates spurious trips of the process due to an SOV failure, or from conducting the PST of the valve.

For the case of Extending the Proof (Full Stroke) Test Interval, the Base Case utilized a one (1) year Proof Test (PT) Interval. Conducting a PST of the Ball Valve extended the PT Interval to 3.24 years. Replacing the 1oo1 SOV with the 2oo4D SOVs (SILstroke) eliminated dangerous SOV failures and increased the PT Interval to 5.91 years, an increase of nearly 600%. In addition, SILstroke virtually eliminates spurious trips of the process due to an SOV failure, or from conducting the PST of the valve.

Conclusions

The PST of critical process and safety valves yields significant improvement in the safety performance of these devices. The PST device should be fully fault tolerant (both air supply and exhaust), fail safe and on-line repairable without disabling or by-passing the SIF. Implementing the PST device should not cause spurious process trips, a decrease in the SIL of the SIF, or violate process safety time constraints. The ideal PST device should contain internal diagnostics, and be capable of verifying its fault-free operation prior to performing the PST of the valve.

Installing the 2oo4D SILstroke device can satisfy all of the above requirements, while virtually eliminating both dangerous failures and spurious trips of the process due to SOV failures, or from conducting the PST of the valve.

Both high safety availability and operational availability (no spurious trips due to the PST device) are important factors to consider when implementing PST. The virtual elimination of both costly dangerous failures and spurious trips due to SOV failures, while extending the Proof (Full Stroke) Test Interval or increasing the safety performance (SIL), provides significant economic benefits; and makes an investment in the SILstroke 2oo4D device very easy to rationalize.