NON-SIS IPL TESTING GUIDELINES

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ABSTRACT

The widespread adoption of the IEC/ISA 61511 standard for safety instrumented systems along with the utilization of Layer of Protection Analysis (LOPA) has focused a lot of attention on assuring the mechanical integrity of instrumented safeguards in the process industries. Regulations in most industrialized countries now require the implementation of mechanical integrity programs that include identification of safety critical instrumentation and regular testing. While the approach for safety instrumented functions, as per IEC/ISA 61511 is well established, similar testing requirements for non-SIS independent protection layers such as safety critical alarms and manual protective functions is not as well defined. This paper reviews the design guidelines for non-SIS IPLs and proposes an extension of those standards using IEC/IEC 61511 style analysis to determine the most appropriate testing intervals for those functions. In addition, the paper presents a table of “typical” test intervals for common instruments that will allow the discussed performance targets to be achieved.

1 Background

Layer of Protection Analysis (LOPA) is commonly used in the process industry to select Safety Integrity Levels (SILs) for Safety Instrumented Functions (SIFs) and to perform or supplement other process hazards analysis studies whose objective is to determine if an appropriate level of safety has been achieved for various process hazards. A key concept of LOPA is the Independent Protection Layer (IPL), which provides a robust safeguard against the realization of the consequences of a hazard. The effectiveness of an IPL is considered on a semi-quantitative basis and utilized to determine the SIL target when conducting a LOPA for SIL selection, or if tolerable risk levels have been achieved when LOPA is used as part of a Process Hazard Analysis (PHA). Whenever a safeguard is given credit as an IPL during a LOPA it gives a de facto classification as a safety critical device. In the United States, the Process Safety Management (PSM) regulation (OSHA 29 CFR 1910.119) dictates that all safety critical equipment must be inspected and tested following recognized and generally accepted good engineering practices but does not define how often maintenance and testing should occur.

Best practice for determining the required testing and maintenance frequencies for SIFs is well defined and commonly accepted. The process is based on the ISA 61511 standard (formerly ISA 84.00.01), and other ISA guidance documents, specifically the ISA 84.00.02 Technical Report. SIF performance can be calculated using standard formulae to determine SIL targets have been achieved. These equations are dependent on the failure rate and testing frequency of the equipment. This paper explains how the same methodology utilized for Safety Instrumented Systems (SIS) can be employed to determine the required test interval of non-SIS equipment that is considered safety critical, albeit with a minor variation to the analysis.

In order to utilize a quantitative approach to establish performance targets for non-SIS safety critical equipment, the first step should be the definition of a performance target for the equipment. A common problem in this approach is that safety critical equipment items often only form part of a protective function, and unlike SIF, may not be comprised of a sensor, logic solver, and final element. As a result, the non-SIS safety critical equipment should only be given a fraction of the standard budget for Average Probability of Failure on Demand (PFDavg). Using a combination of the definition of an IPL and the concept of “partial” PFDavg budgets, a quantitative performance target is set for the safety critical equipment’s performance. Once the performance target is established, the standard methodology can be applied and a test interval can be defined. This paper explains how to adapt the methods recommended in ISA technical reports for SIS to determine the testing frequency of non-SIS safety critical equipment. This paper also provides examples this approach for common equipment.

2 Importance of Testing Non-SIS IPLs

PSM practices ensure the mechanical integrity of all safety critical equipment, or “engineered safeguards”. Ensuring mechanical integrity requires classifying safety critical equipment as such, and then defining and executing maintenance and testing programs to ensure the equipment functions as required on an on-going basis. This program should be consistent with manufacturers’ recommendations, good engineering practices, and prior operating experience. While mechanical integrity best practices for SIS are well established and typically consistent with ISA 61511, mechanical integrity programs for non-SIS safety critical equipment is not as well defined, and often neglected – to the detriment of overall process safety.

Instrumentation that is considered safety critical equipment extends far beyond SIS. Some examples of non-SIS safety critical instrumentation include alarms, emergency block valves, relief valves, remote operated valves, rupture disks, and check valves. Each of these categories of instrumented safeguard have established standards and other guidance that define how and when they should be employed, but frequently the basis for determining testing frequency is lacking. For instance, ISA 18 and API 553 guide in the selection, installation and maintenance of alarms and emergency block valves (in oil and gas and refining), respectively. Unfortunately these industry practices contain only vague guidelines for testing of the instrumentation that they define.

The IEC/ISA 61511 standard has established an industry recognized method for calculating test intervals based on PFDavg for equipment in the SIS. The same basic technique can be applied to any device to determine how often it needs to be tested, after a quantitative performance target has been assigned.

3 Establishing Performance Criteria

In order to establish a mechanical integrity program utilizing an approach similar to IEC/ISA 61511, performance criteria should be set. In keeping with that standard, the performance criteria should be defined in terms of PFDavg. The most appropriate method for establishing that performance target is utilizing the definition of an Independent Protection Layer, due to its pervasive use in the process industries.

IPL are effectively assigned a PFDavg during a LOPA because each IPL is given a one order-of-magnitude credit (i.e. $PFD_{IPL} = 0.1$) for effectiveness. This effectiveness assumes that the IPL will have at least a 90% probability of preventing a hazardous occurrence. IEC/ISA 61511 assigns a SIL to a function which defines the allowable PFDavg of the equipment. A similar approach for verifying SIS equipment has met a SIL target can apply for the non-SIS instrumented safeguards.

The complication with non-SIS instrumented safeguards is that these safeguards often do not form a complete function consisting of detection (sensor), decision (logic solver), and action (final element) as would be found in the SIS. For instance, an alarm would only form the detection portion of an IPL, whereas an emergency block valve would only form the action portion. Since these instrumented safeguards do not comprise the “entire IPL” their performance criteria should reflect that situation and only allow a portion of the PFDavg budget to be allocated to that equipment.

Best practice of equipment vendors and certification bodies that review and approve of safety critical equipment have long employed a rule of thumb that apportions the “PFDavg Budget” among the sensor, logic solver, and final element subsystems of a SIF. This rule of thumb can similarly be applied to non-SIS instrumented safeguards. The PFDavg budget distribution typically used in industry is:

Sensor Subsystem:	35%
Logic Solver Subsystem:	15%
Final Element Subsystem:	50%

Therefore, the PFDavg budget or a sensor would be assigned as $PFD_{sensor} = 0.1 \times 0.35 = 0.035$. Similarly, the PFDavg budget for an emergency block valve would be assigned as $PFD_{final\ element} = 0.1 \times 0.5 = 0.05$. Other non-SIS instrumented safeguards such as check valves, rupture discs and relief valves that perform the entire function can be assigned the entire 0.1 PFDavg budget. The adjusted values give a reasonable PFDavg to use as the basis for determining the test interval of a non-SIS instrumented safeguard.

4 Verifying Achievement of Performance Criteria

ISA TR 84.00.02 contains simplified equations that demonstrate the relationship between PFD, equipment failure rate (λ), and the test interval (TI). The simplex equation for a single component with no redundancy (i.e.,. 1oo1 voting scheme) for calculating PFDavg is shown below

$$PFD_{avg} = \frac{\lambda \times TI}{2}$$

This equation should be rewritten to include only the dangerous failure rate since a safe failure would be detected immediately as spurious operation of equipment and does not contribute to the probability of failure on demand.

$$PFD_{avg} = \frac{\lambda_D \times TI}{2}$$

The dangerous failure rate will differ between devices. The maximum test interval that will still allow the target PFDavg to be achieved can be calculated with the above equation. Examples of application of this concept follow.

Pneumatic Pressure Switch

$$PFD_{sensor} = \frac{\lambda_D \times TI}{2} = \frac{3.91E-6\ per\ hour \times 8760\ Hrs}{2} = 0.0171$$

In this case the derived PFD_{sensor} is less than 0.035, thus a twelve month test interval is acceptable. Note that sensor could include a human-interface device such as a selector switch, push button, etc. This calculation can be used to determine PFDavg for this human interface.

Air Operated Ball Valve

$$PFD_{final\ element} = \frac{\lambda_D \times TI}{2} = \frac{1.2E-6\ per\ hour \times 8760\ Hrs}{2} = 0.0053$$

It is important to note here that all of the equipment that is employed in the instrumented safeguard should be considered when determining the failure rate used in the calculation. For instance, for an emergency block valve consideration includes not only the valve, but the actuator and solenoid valve.

In this case the derived $PFD_{\text{final element}}$ is less than 0.05, thus a twelve month test interval is acceptable.

5 Table of Performance for Typical Instruments

The authors have prepared a table of common equipment and performed PFDavg calculations to allow determination of acceptable test interval through a simple look-up table. This will aid users in employing this approach for determining acceptable test intervals for non-SIS instrumented safeguards. The following tables list some common equipment and possible test intervals. An "X" in the column of a given test interval indicates that the test interval is acceptable. Although the tables provide an estimate of the possible testing intervals for various components, users are strongly encouraged to develop their own tables based on their actual plant conditions and relevant equipment failure rates.

Table 1 - Sensors

		Test Interval (Months)				
Equipment Type	**λ_D (in hours)**	**12**	**24**	**36**	**48**	**60**
Current Transmitter	3.32E-06	X	X	-	-	-
Flame Scanner – Burner	3.00E-06	X	X	-	-	-
Flow Switch	3.20E-06	X	X	-	-	-
Flow Transmitter – Coriolis Meter – High Trip	2.96E-06	X	X	-	-	-
Flow Transmitter – Coriolis Meter – Low Trip	1.85E-06	X	X	X	X	-
Flow Transmitter – Magnetostrictive Meter – High Trip	2.64E-06	X	X	X	-	-
Flow Transmitter – Magnetostrictive Meter – Low Trip	1.65E-06	X	X	X	X	-
Flow Transmitter – Vortex Shedding – High Trip	2.80E-06	X	X	-	-	-
Flow Transmitter – Vortex Shedding – Low Trip	1.75E-06	X	X	X	X	-
Level Sensor – Capacitance	2.00E-06	X	X	X	-	-
Level Switch – Float/Displacer	2.00E-06	X	X	X	-	-
Level Switch – Piezo-Electric – High Trip	4.20E-07	X	X	X	X	X
Level Switch – Piezo-Electric – Low Trip	1.98E-07	X	X	X	X	X
Level Switch – Pneumatic	4.50E-07	X	X	X	X	X
Level Transmitter – Displacement – High Trip	6.30E-06	X	-	-	-	-
Level Transmitter – Displacement – Low Trip	2.80E-06	X	X	-	-	-
Level Transmitter – Magnetostrictive – High Trip	9.00E-07	X	X	X	X	X

Level Transmitter – Magnetostrictive – Low Trip	9.00E-07	X	X	X	X	X
Level Transmitter – Radar – High Trip	6.00E-07	X	X	X	X	X
Level Transmitter – Radar – Low Trip	4.80E-07	X	X	X	X	X
Pneumatic Pressure Switch	3.91E-06	X	X	-	-	-
Pneumatic Relay with Pilot	8.00E-07	X	X	X	X	X
Pressure Switch	3.84E-06	X	X	-	-	-
Pressure Transmitter – High Trip	1.35E-06	X	X	X	X	X
Pressure Transmitter – Low Trip	7.50E-07	X	X	X	X	X
Proximity Switch	1.50E-07	X	X	X	X	X
Push Button	3.75E-07	X	X	X	X	X
RTD	9.02E-09	X	X	X	X	X
Speed Transmitter	1.54E-06	X	X	X	X	X
Temperature Switch	2.40E-06	X	X	X	-	-
Temperature Transmitter – High Trip	3.50E-06	X	X	-	-	-
Temperature Transmitter – Low Trip	2.50E-06	X	X	X	-	-
Thermocouple – High Trip	1.20E-06	X	X	X	X	X
Thermocouple – Low Trip	6.00E-08	X	X	X	X	X
Turbine Meter – High Trip	1.46E-05	-	-	-	-	-
Turbine Meter – Low Trip	1.50E-06	X	X	X	X	X

Table 2 – Final Elements

		Test Interval (Months)				
Equipment Type	**λ_D (in hours)**	**12**	**24**	**36**	**48**	**60**
Air Operated Ball Valve	1.20E-06	X	X	X	X	X
Air Operated Butterfly Valve	1.35E-06	X	X	X	X	X
Air Operated Gate Valve	1.20E-06	X	X	X	X	X
Air Operated Globe Valve	1.13E-06	X	X	X	X	X
Hydraulic Operated Ball Valve	1.35E-06	X	X	X	X	X
Hydraulic Operated Slide Valve	2.50E-06	X	X	X	X	-
Motor Operated Valve	4.50E-06	X	X	-	-	-
Motor Starter Circuit/Contactor	3.00E-07	X	X	X	X	X
Stack Damper (Fired Heaters)	2.70E-06	X	X	X	X	-
Trip and Throttle Valve	2.32E-06	X	X	X	X	-

Note: No test interval tables have been provided for relief devices. The recommended test intervals are sufficiently defined in their application standards (e.g., API 510 clause 6.6.2.2 … pressure relieving devices in typical process services should not exceed: a. Five years for typical process services …)

6 Conclusions

Process Safety Management practices require all safety critical equipment to be tested at some interval that does not exceed the recommendations of recognized and generally accepted good engineering practices. Use of the approaches in IEC/ISA 61511 can be applied to a wide range of instrumented safeguards after a performance target is assigned to the equipment. The methods and equations in ISA TR 84.00.02 can be applied to determine an acceptable testing frequency. To facilitate adoption of this approach through the process industries, the authors have prepared a list of equipment and satisfactory test intervals.

7 References

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