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EMERGENCY SHUTDOWN VALVE RELIABILITY FUNCTION TEST BY AUTOMATED PARTIAL STROKE TESTING SYSTEM

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Graphical abstract

Abstract

Partial stroke testing (PST) is a technique that is regularly practiced in oil and gas industries to test the emergency shutdown (ESD) valve by closing a certain percentage of the valve position and stop any flow through the pipeline. Generally, it only functions when there is an emergency occurring in the production system. When the ESD valve remains in one position for a long period, there is a risk and potential of fail on demand which is, the ESD valve fail to operate during the emergency shutdown. This testing can reveal approximately 75% of unrevealed failures in valves. It can also provide predictive maintenance data that can contribute to the extension of the preventive maintenance for the ESD valve. The objectives of this paper are to design, simulate, build and test the performance of the automated PST system based on PLC. Four guidelines and methodology are used in this work. First, understanding the operation of the PST system. Then, the utilization of the capability of MATLAB-Simulink software as the simulation tool for the PST design system. Next, designing the PST automated system based on PLC design and lastly, testing the performance of the PST design system using lab scale PST system prototype that has been built. Results of the project shows that the PST system is successfully designed and simulated via MATLAB-Simulink and the PLC programming is working in the correct order as performed on the prototype.

Keywords: PST, ESD, PST automated system, PST based on PLC, performance of PST

1.0 INTRODUCTION

Emergency Shutdown Valve (ESD) only functions when there is an emergency occurring in the production system, the valve should close and stop the flow of any substance through the pipeline. Full function test for ESD valve will require plant shutdown and it is difficult to be tested online for many companies. In this project, the concept and theories of Partial Stroke Testing (PST) are studied and designed base on PLC. PST is important to perform in order to predict the status of the ESD valve. PST via PLC can reduce the production downtime and the repair cost of ESD valve [1]. ESD is difficult to test online by vendor as most of the heavy industrial processes require stable connection in order to carry out the online testing which will result to the increase in production cost [2]. When the ESD valve remains in one position for a long period, there is a risk and potential of fail on demand which is, the ESD valve fail to operate during the emergency shutdown [3]. The ESD valve needs to perform Partial Stroke Testing (PST) in order to predict the status of the ESD valve and to increase the Partial Stroke Testing (PST) intervals that will improve the Probability of Failure on Demands (PFD) [4]. The methodology of this project are, understanding the operation of the PST system. Second, reviewing the literature on the Partial Stroke Testing (PST) and Programmable Logic Controller (PLC) will. Thirdly, by using MATLAB/Simulink software, the Partial Stroke Testing (PST) system and Programmable Logic Controller (PLC) are designed and developed. Next, by using the same software (MATLAB/Simulink), the Partial Stroke Testing (PST) system and Programmable Logic Controller (PLC) are simulated. After that, the Partial Stroke Testing (PST) prototype are built. Then, the characterization of Partial Stroke Testing (PST) is tested based on Programmable Logic Controller (PLC). Lastly, the results obtained are analyzed.

2.0 AUTOMATED PARTIAL STROKE TESTING SYSTEM

2.1 Safety Instrumented System (SIS)

In one process, a safety system is designed to function upon dangerous process and abnormalities in the process, which is to protect people, environment and material assets [5]. A safety instrumented system (SIS) consists of detectors, logic solvers and actuating items [6]. ESD is an example of the actuating items. The main function of a safety instrumented system (SIS) is when a predefined process abnormalities occur, the abnormalities shall be detected by the SIS sensors and actuating items should be activated (fail to function) and should not activate spuriously, without the present of any process abnormalities (spurious trip).

Most of the SIS are passive system, which is only activated when specified process abnormalities are detected. Function testing should be conducted to reveal any hidden failures and to verify the condition of the system, which still able to perform the required functions.

Failure classification of SIS is divided into two, which are Dangerous (D) and Safe Failures (S) [7]. The Dangerous (D) failure classification is also divided into two, which are Dangerous Undetected (DU) and Dangerous Detected (DD). Dangerous Undetected (DU) is only revealed by testing or when a demand occurs, meanwhile the Dangerous Detected (DD) is detected immediately [8].

2.2 Emergency Shutdown Valve (ESD)

An emergency shutdown valve is installed in a pipeline that feeds gas or liquid and etcetera to the production system. When there is an emergency occurring in the production system, the valve should close and stop the flow of any substances through the pipeline [9]. The valve is air operated gate valve. The actual open or close function is performed by sliding a rectangular gate. The gate valve is moved by the air piston which is connected to the gate by the stem. The gate valve has a fail-safe actuator. The valve is opened and kept open by air control pressure on the piston. The fail-safe function is achieved by a steel spring that is compressed by the air pressure. The valve is automatically closed by the spring force when the air pressure is released.

2.3 Partial Stroke Testing (PST)

Function test sometimes is not practicable to conduct because it is not technically feasible, time consuming and the test itself can lead to unacceptable hazards [10, 11]. An ESD valve is installed in a gas pipeline that is connected to the production system, which should close and stop the gas flow when an emergency is detected. In a normal condition, the ESD valve is in open position.

PST is a technique to test the emergency shutdown valve by starting to close the valve that can prove the health condition of the actuator and sense the movement by position switch or by observing the changes of the pressure [12] and then continuing the closure of the valve. This testing can reveals approximately 75% of unrevealed failures in valves.

2.4 Probability of Failure On Demands (PFD)

The safety unavailability, $\bar{A}(t)$ of the emergency shutdown valve in the first test interval $[0, \tau]$ is,

$\bar{A}(t)$ = Pr (a dangerous undetected (DU) failure has occurred at, or before, time t)

$$= \Pr(T \leq t)$$
$$= F(t) \quad (1)$$

If a demand for the emergency shutdown occurs at time t, the safety unavailability $\bar{A}(t)$ denotes the probability that the emergency shutdown valve will fail to respond adequately to the demand [13]. The safety unavailability $\bar{A}(t)$ is therefore often called the probability of failure on demand (PFD) at time t [14, 15].

It is sufficient to know the long run average value of PFD, without referring to the time t.

$$\text{PFD} = \frac{1}{\tau}\int_0^{\tau} \bar{A}(t)dt$$
$$= \frac{1}{\tau}\int_0^{\tau} F(t)dt \quad (2)$$

Let $R(t)$ denotes the survivor function of the item with respect to DU (dangerous undetected) failure. Since, $R(t) = 1 - F(t)$,

$$\text{PFD} = 1 - \frac{1}{\tau}\int_0^{\tau} R(t)dt \quad (3)$$

If the ESD valve has constant failure rate λDU, the survivor function of the ESD valve is $R(t) = e^{-\lambda DU\tau}$ and the PFD is,

$$\text{PFD} = 1 - \frac{1}{\tau}\int_0^{\tau} R(t)dt = 1 - 1 - \frac{1}{\tau}\int_0^{\tau} e^{-\lambda DU\tau}dt$$

$$\text{PFD} = 1 - \frac{1}{\lambda DU\tau}(1 - e^{-\lambda DU\tau}) \quad (4)$$

If we replace e-$\lambda DU\tau$ by its Maclaurins series, we will get,

$$\text{PFD} = 1 - \frac{1}{\lambda DU\tau}\left(\lambda DU\tau - \frac{(\lambda DU\tau)^2}{2} + \frac{(\lambda DU\tau)^3}{3!} - \frac{(\lambda DU\tau)^4}{4!} + \cdots\right)$$
$$\text{PFD} = 1 - \left(1 - \frac{\lambda du\tau}{2} + \frac{(\lambda DU\tau)^2}{3!} - \frac{(\lambda DU\tau)^3}{4!} + \cdots\right)$$

When $\lambda DU\tau$ is small, then,

$$\text{PFD} \approx \frac{\lambda DU\tau}{2} \quad (5)$$

3.0 DESIGN SPECIFICATIONS

Design specification of Partial Stroke Testing (PST) shown in Figure 1.

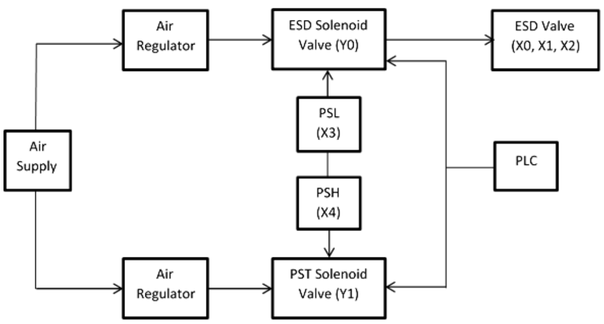

Figure 1 Block diagram for partial stroke testing

Air is a medium of input supply to two numbers of air regulators in the Partial Stroke Testing (PST) System. One regulator is connected to an ESD solenoid valve and the other regulator is connected to the PST solenoid valve. The regulators' function is to control the pressure of the air supply to the ESD and PST solenoid valve. The pressure switch low (PSL) and pressure switch high (PSH) are responsible to observe the changes of the pressure during the Partial Stroke Testing (PST). In order to detect the locations of the gate of the ESD valve, a position sensor is installed which will show XO for 100% in open position, XI for 90% in open position and X2 for 80% in open position. This automated system is based on PLC control. The partial stroke test is initiated manually by using switch button.

3.1 Design Process Flow

The PST is initiated by pressing a manual switch button. After the manual switch button is pressed, the location sensor will confirm the location of the gate of the valve is 100% opened position (X0). Then PST solenoid valve (Y1) will be energized. The PSL (X3) and PSH (X4) will confirm the changes in pressure of air supply. Next, the ESD solenoid valve (Y0) will be de-energized. The partial stroke test timer will start counting the time of the test. After the position sensor has confirmed that the gate of the valve is 90% opened position (X1), the ESD solenoid valve (Y0) will be energized and the PST solenoid valve (Y1) will be de-energized. If the valve is at 80% opened position (X2), partial stroke test will be cancelled and the ESD solenoid valve (Y0) will be energized, PST solenoid valve (Y1) will be de-energized and then the valve will return to the 100% opened position (X0). Design process flow of Partial Stroke Testing (PST) is shown in Figure 2.

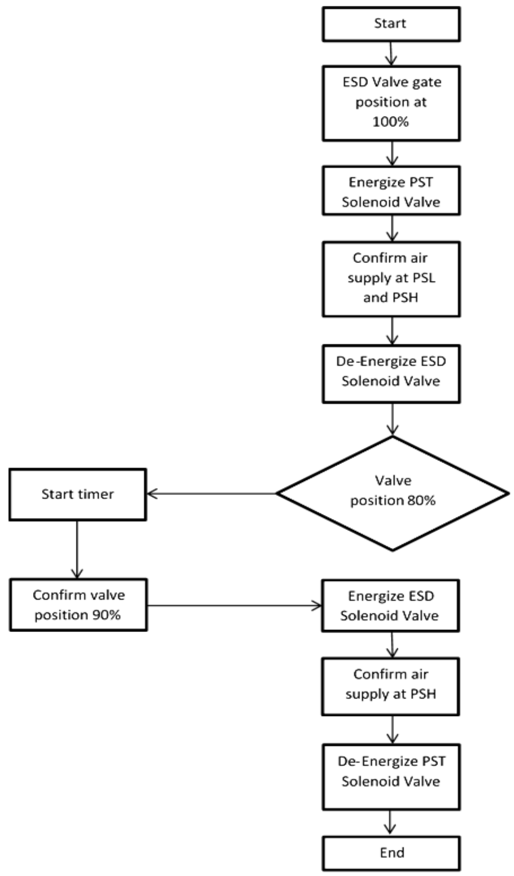

Figure 2 Process flow for partial stroke testing

3.2 Matlab-Simulink Model Of The Partial Stroke Testing System

The PLC controlled process is simulated in a MATLAB/Simulink block named 'PST Logic Control'. This block's outputs (PST SOV, ESD SOV, "PASS" and "FAIL") are connected to a scope, in order to obtain the test results. The block 'PST Logic Control' is the keystone of the proposed methodology. It will emulate the cycle of PLC operation. Figure 3 shows the PLC operation and PST process interaction. Meanwhile, Figure 4 shows the model of controlled PST in the MATLAB-Simulink.

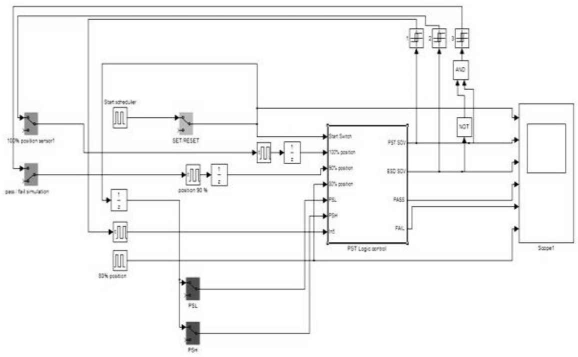

Figure 3 PLC Operations and PST Process Interaction

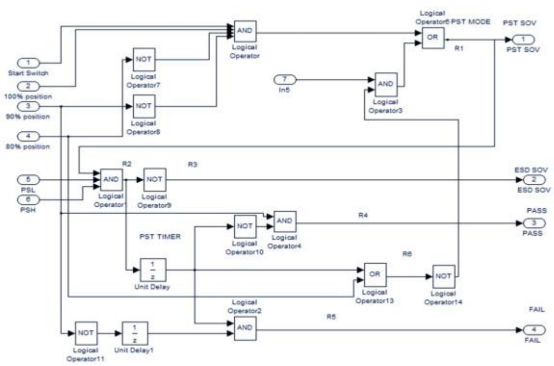

Figure 4 PLC Operations and PST Process Interaction

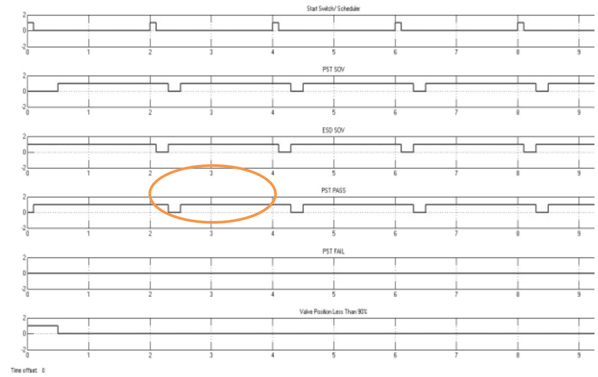

Figure 5 Results of Partial Stroke Testing (PST) System is PASS

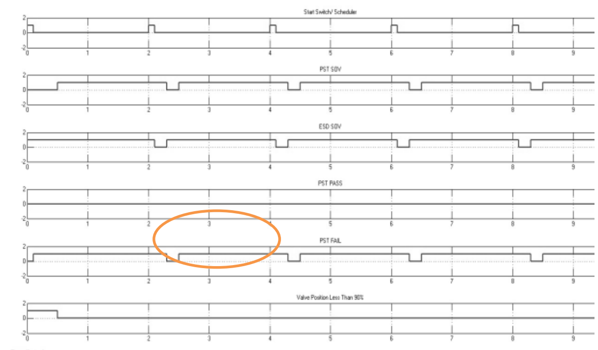

Figure 6 Results of Partial Stroke Testing (PST) System is FAIL

4.0 RESULTS AND DISCUSSION

The results and analysis for the performance of the PST system is based on the PLC. The simulation results show that the PST is 'PASS' when the PST SOV is energized and ESD SOV is de-energized as shown in the Figure 5. Furthermore, the simulation results also show that the PST is 'FAIL' when the PST SOV is de-energized and ESD SOV energized as shown in the Figure 6. In this simulation, dummy input signal is used to generate the corresponding output after going through the designed system.

Figure 7 shows the devices and connection of the prototype design. When the power supply is connected to the prototype, the PLC program will check the contact of the magnetic reed switch in order to confirm the 90% opened position of the air pneumatic cylinder is in a good condition. Then, in the normal operation, the selector switch is selected to the "ESD" mode. Next, the start push button is pressed in order to initiate the function of the prototype for the normal operation. After that, the red indicator light for "ESD" will be on and the ESD solenoid valve will be energized with the normal operation pressure, which is 0.4MPascal. The normal operation pressure is displayed at the pressure switch display.

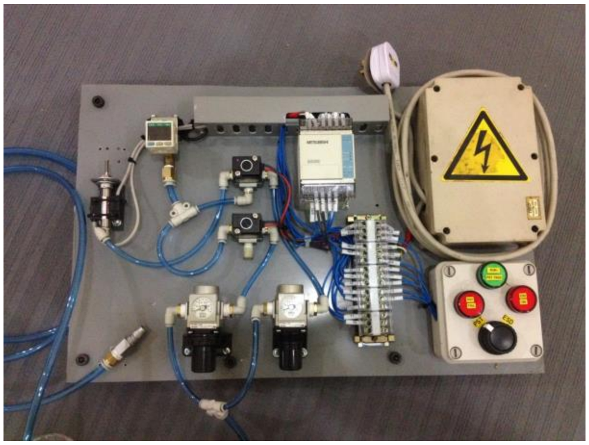

Figure 7 Project prototype

In order to perform the PST, the selector switch changed from "ESD" mode to the "PST" mode. Then the ESD solenoid valve will be de-energized and the PST solenoid valve will be energized. The PST solenoid valve will be energized with the PST operation pressure on 0.3MPascal. Pressure switch will display the PST operation pressure reading. Next, the magnetic reed switch will detect the position of the air pneumatic cylinder which is 90% opened, the green indicator light will be on to indicate the PST is "PASS".

5.0 CONCLUSION

PST system is designed on the MATLAB-Simulink software for simulation. The simulation results show that this PST system is implemented based on PLC. The challenges of completing this project was the development of the PLC programming and the interfacing between the PLC programming and the prototype hardware. The writing of the PLC programming takes a systematic procedure from defining the input and output devices to the internal relays development. The PLC programming is one of the important key for the success of the project. After the PLC programming is developed, a lot of hardware testing is conducted in order to ensure the function of each devices are correct and more importantly, the results of the PLC programming are produced correctly. Finally, the PST prototype is successfully operated automatically based on PLC.

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