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Automated pressure transmitter for calibration and testing system

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Abstract
Pressure is one of the common parameters in Process Control whereby the periodvic calibration need to be done. Calibration is an important element in the measurement process instrumentation readings. Works calibration will be run periodically according to a pre-set schedule depends on how critical readings in need of the processes involved. If it is critical, works calibration will be run more frequently and vice versa, if readings are in need is for monitoring purposes only. Works calibration for pressure transmitter will be executed in two ways, namely in house and field calibration. Currently for both methods, the calibration will be run manually by a service engineer. The method used for supplying air pressure to the pressure transmitter is by using manual hand pump. The reading and data from the transmitter is presented the digital manometer. The calibration report is then generated manually by the engineer. The instrument for the calibration is particularly a pressure transmitter. For the calibration, at least two transmitters will be used. One pressure transmitter must be a Master Standard Unit (MSU), and the other(s) will be Unit under Test (UUT). For this paper the manual method is replaced by automatic control by utilising electrical and electronic equipment that is controlled by PID controller.

Keywords: pressure transmitter, PID controller, automatic calibration

1. Introduction

Calibration is the most important element that needs to be done to ensure that measurement undertaken by an instrument is located within the authorized range which refers to the technical specifications issued by the factory. In the processing industry, such as oil and gas, petrochemicals, oleo-chemicals and others, measurement parameters such as flow, pressure, level and temperature are very important to ensure that chemical process react optimally. To ensure the reading of the process instrument that is in use is at a pre-set accuracy, works such as regular and periodic calibration shall be held. Service engineers will perform on the pressure transmitter test for Unit under Test (UUT) individually during calibration and data will be taken manually. For example for pressure transmitter, calibration works can be done with in-house calibration and field calibration. This work will take time and the accuracy of the readings taken will depend on the efficiency of service engineers.

The methodology is by using continuous control by feedback control method. The actuators are control valves, and for the data acquisition DAQ modules will be used. Therefore, to make it automated, Proportional, Integral and Derivative (PID) control scheme will be used. Performance pressure transmitter in the test will be measured in terms of its ability to produce an accurate reading and repeatability of where it is still in the range of error is allowed.

This proposed project will focus on producing a system that is capable of calibrating several pressure transmitter unit or (UUT) at a time with calibration report with uncertainty and error count will automatically generated. With this, we will be able to assess the robustness and reliability of pressure transmitter that produced by a variety of well-known manufacturers such as Yokogawa, Rosemount, E + H, and many others.

Fig 1: Pressure transmitter installed in an industrial process plant

2. Literature review

Calibration shall use appropriate methods and procedures for all tests and calibrations within its scope according the International Standard for General requirements for the competence of testing and calibration laboratories, ISO 17025. These include sampling, handling, transport, storage, and preparation of items to be tested and calibrated and where appropriate estimated of the measurement uncertainties as well as statistical techniques for analysis of test and calibration data [1].

Pressure is the force exerted by a gas or liquid on a surface. The SI unit of pressure measurement is the Pascal (Pa). Other common units are N/m2, Torr, psi and bar [2].

Gauge pressure shall be used for the calibration whereby it is referred to when the pressure is measured with reference to the atmospheric pressure as the basis then the measurement is called the gauge pressure. The relationship between absolute, gauge and vacuum measurements can be observed in figure 2.

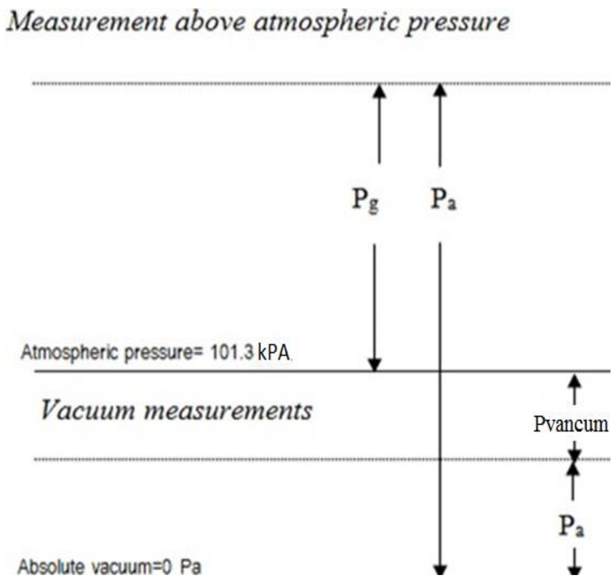

Fig 2: Relationship between absolute, gauge and vacuum measurements

Gauge pressure is defined when the pressure is measured with reference to the atmospheric pressure as the basis then the measurement is called the gauge pressure.

Absolute pressure is defined when we measure a pressure in a system with perfect vacuum or absolute zero as the basis then we call the value of the pressure as the absolute pressure. Vacuum gauges meanwhile are used when the pressure being measured has a value less atmospheric pressure. Vacuum pressure may be expressed as absolute pressure or vacuum units. Differential pressure on the other hand signifies the difference in pressure between two points.

Determination of resolution of Unit under Test (UUT) is that the resolution of an instrument is the smallest value of the variable that can be differentiated by using this instrument. In the case of the pressure gauge that is an analog instrument the resolution will define the smallest change in pressure that will cause a readable change in the position of the needle. In the case of the digital instruments, the resolution will refer to the change in the input required to move the least significant digit in the output by one [3].

Uncertainty Evaluation consists of uncertainty of measurements. Uncertainty of measurement is the doubt that exists about the result of any measurement. By quantifying the possible spread of measurements, we can say how confident we are about the result. The uncertainty derives from the measuring device and from the skill of the person doing the measuring [3]. The Figure 3 shows the workflow of the calibration procedure.

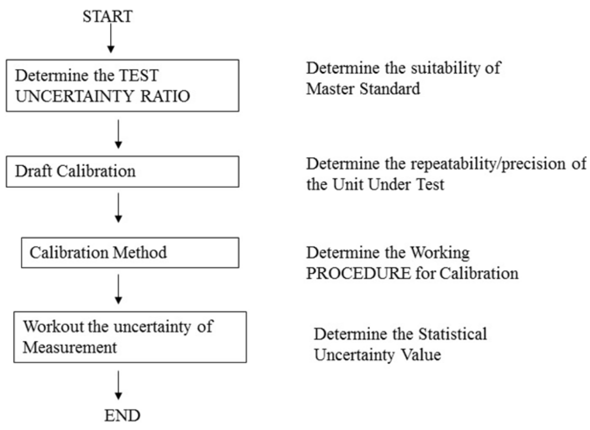

Fig 3: Calibration Procedure

Hysteresis is the property of instrument, wherein at a particular value the output of the instrument when the variable is increasing is not the same as the output of the instrument at the identical value of the input when the variable is decreasing. The results are plotted with the MSU reading in the x-axis and the UUT reading both for the increasing and decreasing directions in the y-axis. As commonly understood the electronic pressure transmitters have virtually no hysteresis error. With analog gauges there is a tendency to display hysteresis as the movement has mechanical parts [3].

PID Controller Scheme is chosen for the control method. The inputs from the pressure transmitter and output for the control valve of the system are real-valued variables. The real-valued variables go through a tuning method which is applying Ziegler-Nichols (ZN) tuning to optimise the output [4].

Control valve is the Final Control Element (FCE) of the closed-loop control. Globe valve type is one of the most widely used control valves in process control. Advantages that are considered for globe valve are that it can withstand high differential pressures, no leakage, and disassembles easily for maintenance. Furthermore it has wide range of sizes, pressure ratings, and flow characteristics. A typical globe valve has a stem that is adjusted linearly (up and down) to change the position of the plug. As the plug changes, the area for flow between the plug and seat (opening) changes. Many different seat and plug designs are available to achieve desired relationships between the stem position and flow rate. The standard plug must oppose the pressure drop across the valve, which is acceptable for small pressure drops. For large pressure drops, a balanced globe valve is used to enable a valve with small force to open and close the plug [5].

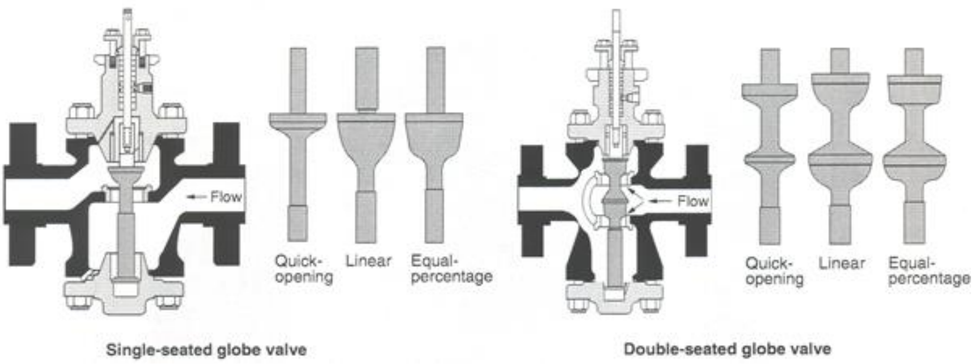

Fig 4: Globe valve crossectional view

Data acquisition (DAQ) modules are the hardware to be used for the integration between the software and hardware. The DAQ modules (plug-in or USB type) typically include one or more A/D converters (ADCs), D/A converters (DACs), analog and digital I/O ports, and counter/timer circuits. These components interface the computer to real-world analog, digital, and TIO signals. Analog signal conditioning peripherals amplify, linearize, isolate, and filter the signal so that the signal can be properly digitized [6].

3. Comparison of manual vs automatic method

The current method implemented (manual method)

Service engineers will use the hand pump to generate pressure on the need and the reading will be referred to the Master instrument Standard Unit (MSU).

The test instrument is a Unit under Test (UUT) and reading will be compared with reference to the MSU unit.

MSU units in use must be certified through the reading of the calibration process by the ruling body of SIRIM if in Malaysia. This calibration work will be done one by one as can be referred to Figure 5. In addition, if the range of pressure that is read by the UUT high, service engineers will need more energy to pump in an effort to generate higher pressures.

For the calibration report, the accuracy of which is derived depends on the accuracy and precision of a service engineer before taking readings when doing calibration work. The earnings report will include the generator manually to uncertainty and error counts.

Fig 5: Manual calibration work in progress.

Manual calibration has been done in industry for pressure transmitter. Hand valve is shut-off before tubing is inserted at the Pressure transmitter. Then the procedure of manual calibration commence by manually pumping the air pressure to increase pressure to the transmitter and reducing pressure by releasing the pressure knob of the pump. The value of the reading is present by a digital manometer and then the report will be produced manually the calibration engineer.

The current method is found to be very time consuming if a handful of pressure transmitter need to be calibrated. The proposed method has the capability to do several calibration of UUT at a time. The pressure supplied will follow the set value (SV) of the 5 points calibration method automatically by using PID Control. The pressure will be regulated by using a control valve. By this automatic method, the Uncertainty Error due to repeatability of the experiment can be reduced. The automatic method has the possibility to reduce hysteresis of the calibration reading. The increase and decrease of the pressure is controlled by using PID Control in which will reduce overshoot of pressure from the Set Value of the calibration.

a) Manual calibration process

1. Air pressure is pumped manually by using hand pump whereby used to supply pressure to the Pressure Transmitter.
2. The set value for calibration is adjusted manually by releasing the pumped air to reduce the pressure.
3. The data is presented at a digital manometer, and the manually recorded by the calibration engineer.
4. The calibration report is then produced by the calibration engineer.

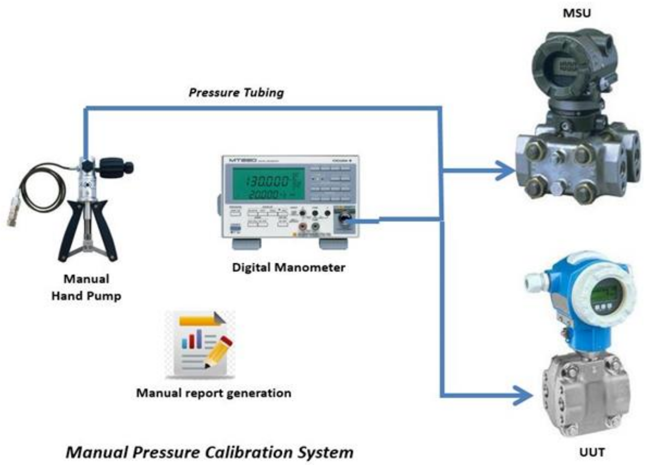

Fig 6: Current Manual Pressure Calibration System

b) The proposed automatic calibration process

1. Hand pump will be replaced by mini compressor to generate air pressure to the system.
2. Manual adjustment of the pressure at the hand pump will be replaced by control valve.
3. The Unit Under Test (UUT) can be more than one calibrated at a time for the calibration process
4. The reading and data from the pressure transmitter will be presented at the PC Graphical User Interface (GUI), on the PC and the data is stored.
5. The calibration report is then generated

4. Methodology

a) Calibration setup and procedure

Study will be carry out to understand standard operating procedure (SOP) for calibration job refer to ISO17025 standard to ensure that the system will be develop comply all regulation guideline. Another part need to be consider is in order to develop an automatic pressure transmitter calibration and testing system, studying the fundamental theory of PID control scheme with the ZN tuning method for a control valve application which is pressure will be control based on desired 5 point calibration method. Technical specification for all equipment that related to the system such as mini compressor, control valve, data acquisition module (DAQ) and pressure transmitter need to be identify. Study also will be carry out to identify the suitable mechanism design for an automatic pressure transmitter calibration and testing system to replace the conventional method.

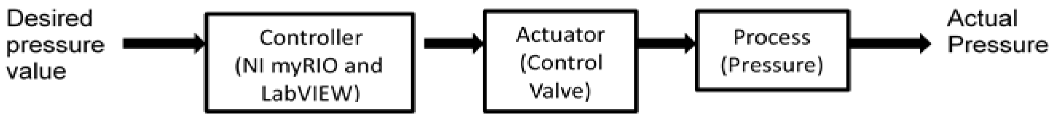

Fig 7: Open loop system of the pressure process

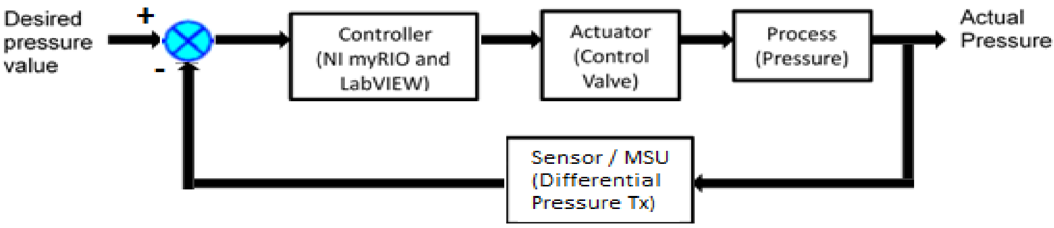

Fig 8: Closed loop system of the pressure process

b) Hardware and system development

An automatic pressure transmitter calibration and testing system will consists of several important part such as pressure generator, controller and reference instrument unit. Mini compressor will generate the air pressure supply needed in the system while data acquisition module (DAQ) will be act as a controller. When perform a calibration job, Master Standard Unit (MSU) pressure transmitter reading become a reference while unit that we perform a calibration we call it as a Unit Under Test (UUT). This system will be able to perform a calibration and testing job for multi-unit of UUT at one time even range of the UUT are different. All an intelligent system will be embedded into a data acquisition module (DAQ). The DAQ used is My RIO by National Instrument and the Software is Lab VIEW. DAQ will control the control valve operation to achieve the desired pressure value refer to the 5 point calibration method. At the same time, calibration and testing report will be generate automatically and all important data required in the report such as uncertainty calculation and percentage of error will be calculate. The system is a SISO system as the input is from the pressure reference set point and the output is related to the valve opening percentage to control the actual pressure.

Fig 9: MSU and UUT setup

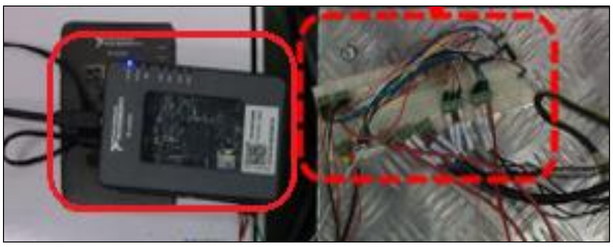

Fig 10: DAQ module and input-output circuit

c) Programming development

Here, the software used is Lab View whereby consists of Graphical User Interface (GUI) also will be develop to monitor the calibration and testing job. An automatic calibration and testing report generation system also will be developing at this stage. Proportional, Integral and Derivative Control Scheme is used for the controller part.

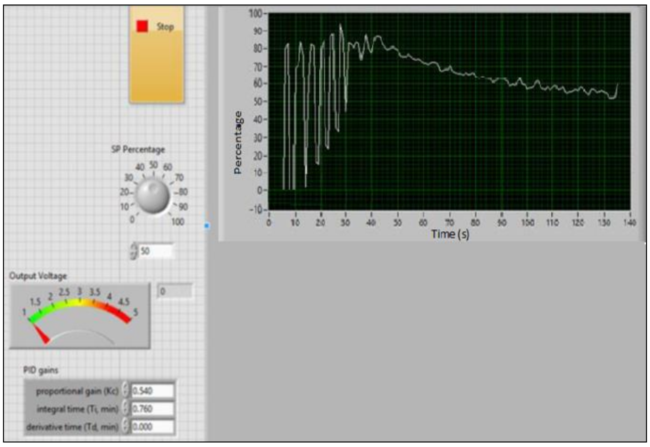

Fig 11: Graphical User Interface (GUI) of Lab View

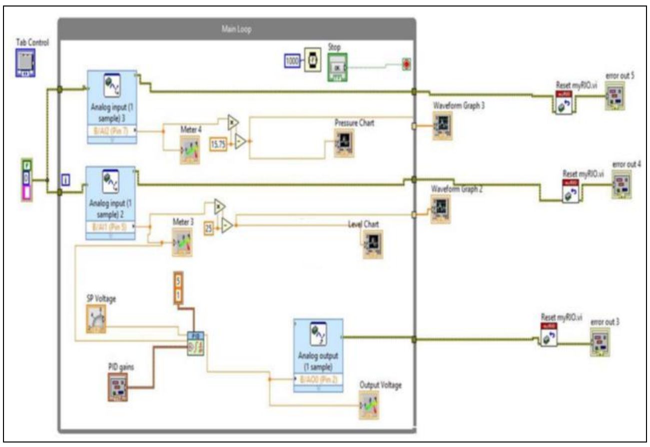

Fig 12: Lab View modular programming

d) Test Run

The data obtained from the experiments are analyzed and identified. An actual result will be analyzed based on response time, steady state error, overshoot and settling time for desired pressure value refer to the 5 point calibration method. An automatic generated uncertainty and percentage of error calculation also will be analyzed compared to the manual calculation. Improvement will be done to obtain an optimize result.

5. Results and Discussions

a) Trial and error from auto tuning

A set of default value P=1 and I=1 of the PI Controller is used for the first responds trial. The set value is adjusted to be 50%. The result as shown in the graph in Figure 13. There is a bit lag of around 4 seconds before the sensor value show spikes up and down until the 40 seconds. After 40 seconds, the value become stable. But the hysteresis is around 20%, which is still large to be considered as successful to be settling time. Furthermore, the target of 2 minutes to reach final value cannot be achieved.

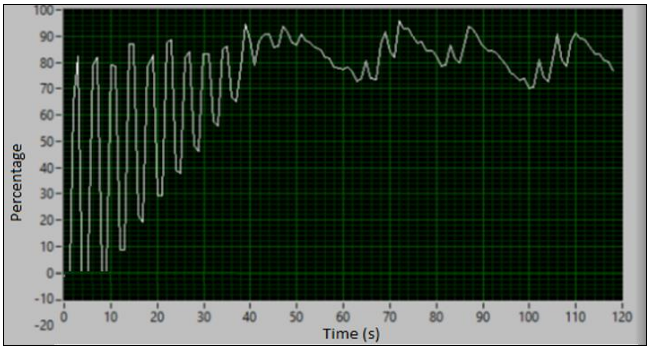

Fig 13: Pressure response by using default value of auto tuning

Second trial value is adjusted to P=0.54 and I=0.76. The response graph becomes less aggressive than the previous result as shown in Figure 14. The graph shows that the final value can be obtained around 133 seconds. It is acceptable for the final value, but the initial response is too aggressive. This will create a long term effect that could shorten the life span of the control valves. Thus a well-known Ziegler-Nichols Open Loop Method for tuning can be utilized for this process which involves test and result table.

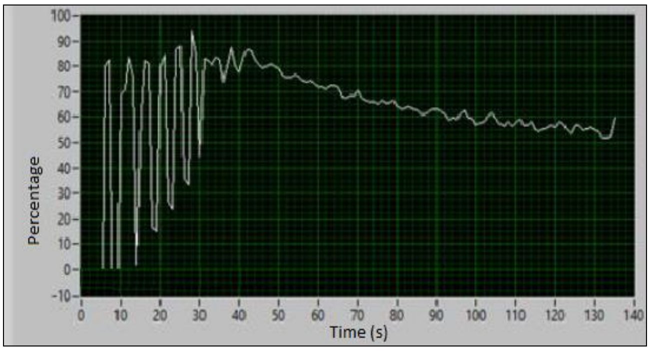

Fig 14: Pressure response by using auto tuning

b) Open loop test using ZN method

An open loop test was implemented to obtain the value of Proportional and Integral value via ZN Open Loop Method.
As the pressure is increased to 100% range of the chosen process, time is taken to obtain the Dead Time, T and Compensating Time, τ.

- Gain = Output/Input = 100% / 50% = 2
  $T = t_1 - t_0 = 7 - 0 = 7$ sec
  $\tau = t_2 - t_1 = 85 - 7 = 78$ sec
- PI value obtained from ZN table calculation
  $K_c = 0.9\ \tau / K_pT = 0.9(39) / 2(3.5) = 5$
  $T_i = 3.3T = 3.3(3.5) = 11.55 / 60 = 0.190$ min
- PI value used in control
  P = 5 and I = 0.190

The pressure response shows lag or dead time of 7 seconds and compensating time of 78 seconds. Therefore, after using ZN table, resulting in the value of P=5 and I=0.19 is being obtained. This result is the basis of the reference value of Proportional and Integral value for the actual tuning response.

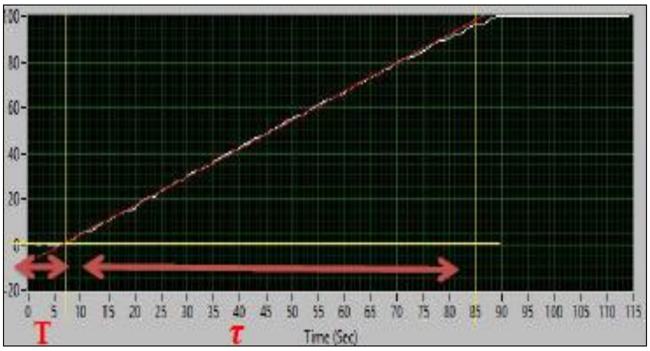

Fig 15: Acquiring dead time and compensating time values using ZN open loop test.

Referring to pressure response graph in Figure 16, the set value is set to 50% with value of used for P=6 and I=0.2. The reference of the value is obtained from the ZN Tuning method. The transient response and the steady-state response is satisfactory. The transient response is dramatically improved to become much stable compared to the trial and error methods. For the steady-state value also shows huge improvement as the settling time is obtained at 50 seconds when the value can be maintained at the set value of 50%.

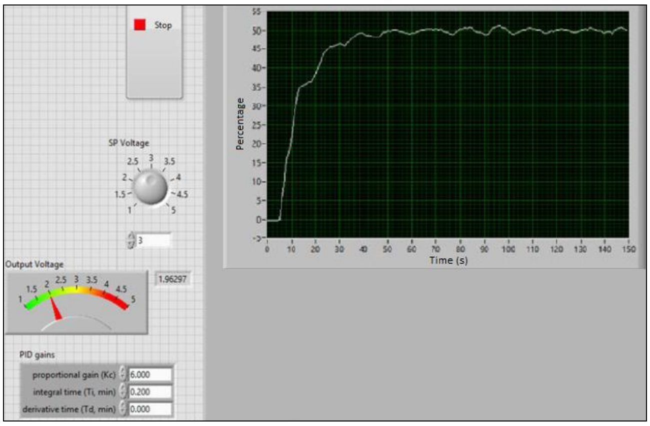

Fig 16: Pressure response after tuning is done

The overall result shows the rise time Tr of 22s, settling time, Ts of 50s, with overshoot less than 2%, and hysteresis of only 4%. Therefore, the target set earlier of the automatic tuning and adjustment to the set value of 2 minutes or less is successfully obtained.

c) Five-points calibration data using ZN tuning method

An automatic detection system for five-point pressure transmitter calibration was developed. The three repeated measurement was recorded automatically from the pressure transmitter, while the increment of desired five-point pressure value automatically calculated by the system. Five-point calibration data for three repeated measurement show in Table 1 and Table 2 show calculated mean and percentage of error.

Table 1: Five-point Calibration of Pressure Transmitter

Point (%)	MSU (bar)	MSU (mA)	UUT_1 (bar)	UUT_2 (bar)	UUT_3 (bar)
0	0.00	4.00	0.01	0.00	0.01
25	1.00	8.00	1.03	1.01	1.02
50	2.00	12.00	2.03	2.03	2.04
75	3.00	16.00	3.04	3.02	3.03
100	4.00	20.00	4.02	4.03	4.01

Table 2: Mean & Error (%) of Pressure Transmitter

Point (%)	Mean (bar)	Error (%)
0	0.007	0.700
25	1.020	2.000
50	2.033	1.667
75	3.030	1.000
100	4.020	0.500

Automatic pressure transmitter calibration system can be conduct in parallel session with maximum 5 unit of pressure transmitter simultaneously. Table 3 as below show a time consuming comparison between automatic and manual calibration method start from five-point calibration measurement, data capture and calculation for mean and percentage of error. It shows that, an automatic system could reduce time consuming in pressure transmitter calibration works with an intelligent calibration report generation system. In real application during plant shutdown maintenance works, this system could become great tool in order to complete big amount of pressure transmitter calibration especially in large scale of petrochemical plant. This system also could improve in term of measurement reliability and repeatability of calibration works.

Table 3: Comparison Time Consuming Automatic and Manual Calibration

Number of Pressure Transmitter (Unit)	Automatic Calibration (seconds)	Manual Calibration (seconds)
1	118	155
2	122	325
3	122	492
4	120	656
5	123	819

6. Conclusions

As a conclusion, by using automated pressure transmitter calibration, time consumption for UUT calibration is reduced comparing to manual method. Calibration time can be significantly further reduced when more than one UUT calibration are done in parallel with each other. It is proven as advantage of the system as the pressure values maintained within acceptable mean & error percentage the for the five-point calibration.

For the control, PID controller is utilised for the automated pressure calibration. In order to improve the PID auto-tuning control, Ziegler-Nichols (ZN) Open Loop tuning method is used for the pressure control optimization.

7. Acknowledgement

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