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AUTOMATED SYSTEM FOR FIRE PUMP PERFORMANCE TESTING

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บทคัดย่อ

มาตรฐานระบบป้องกันอัคคีภัยในอาคารถูกบังคับจากรัฐบาล มาตรฐานสากลที่ใช้คือ มาตรฐาน National Fire Protection Association (NFPA) โดยมาตรฐาน NFPA 20 และ NFPA 25 ระบุการใช้เครื่องสูบน้ำดับเพลิงในระบบ เนื่องจากเครื่องสูบน้ำดับเพลิงเป็นอุปกรณ์ที่ไม่ได้ใช้งานประจำ จึงเป็นเหตุให้สมรรถภาพของเครื่องสูบน้ำทำงานต่ำกว่ามาตรฐานได้ เพื่อให้เครื่องสูบน้ำคงสภาพการทำงานที่ดีได้ มาตรฐาน NFPA บังคับให้ทุกอาคารต้องทำการทดสอบประสิทธิภาพเครื่องสูบน้ำดับเพลิงเป็นประจำทุกปี เนื่องด้วยการขาดประสบการณ์ของผู้ที่ทำการทดสอบและการขาดเครื่องมือวัด เป็นผลให้กระบวนการทดสอบเครื่องสูบน้ำดับเพลิงใช้เวลานานเพื่อให้ได้ผลทดสอบสมรรถภาพของเครื่องสูบน้ำ บทความนี้ได้เสนอระบบอัตโนมัติสำหรับการทดสอบประสิทธิภาพเครื่องสูบน้ำดับเพลิง โดยระบบได้ถูกสร้างและทดสอบสำหรับใช้ในห้องปฏิบัติการ ระบบที่ได้นำเสนอนี้ได้แสดงการทดสอบที่ใช้เวลาน้อยลง ได้ผลการทดสอบที่เที่ยงตรงมากขึ้น ส่งผลและทำให้สามารถทำการทดสอบเครื่องสูบน้ำในอาคารได้บ่อยกว่าที่ต้องการ

ABSTRACT

The standard fire protection in buildings is regulated by the government. The internationally used standard is the National Fire Protection Association (NFPA). The standard NFPA 20 and NFPA 25 indicated the use of fire pump in the system. Since the fire pump is not regularly used, therefore the pump performance may not be up to the working standard. In order to keep the pump to be in good condition, the NFPA required every building to perform their pumps testing periodically. Due to inexperience personals and lack of instrument, the fire pump testing procedure took a considerable long time to obtain the performance testing result. This paper presented an automated fire pump performance testing system. A laboratory-scale system was constructed and test. The presented system shown to improve the testing time, accurate of testing result and permit the building to perform the test more frequent than required.

KEYWORDS: Fire Pump Testing, Fire Pump Components, Fire Protection, Automation.

1. Introduction

Thailand undergoes the continually economic increasing. It brings more building constructions; these are medium-sized building, high-rise building, business complex, factory building and assembly occupancy. These buildings, old and new, are regulated by the law in order to protect life and property. Thai law requires the installation of fire extinguisher systems; the systems include fire alarm, fire hydrant and fire sprinkler. All fire protection systems consist of fire alarm system, and they are divided into two groups: action and no action. The one with fire extinguishing action is widely used among industrial plants and medium and large commercial buildings and residences. If the fire pump is out of order, no water is immediately feed to suppress the fire; hence, the fire pump plays the most important role in the fire extinguisher systems. For this reason, the fire pump requires regular testing, inspection and maintenance; so that when there is fire in the building, it is able to response and operates under its performance requirement. The pump performances are the water pressure and the volumetric flow rate. Each parameter has to have a high enough value for delivering the water to the fire suppression system of the belonging building. The selected fire pump must be designed according to engineering principles. It need to be built and assembled from high-quality, durable materials. The fire pump testing standard practice in Thailand follows the National Fire Protection Association (NFPA) and Engineering Institute of Thailand Under H.M. the King's Patronage or EIT. The NFPA 20, Standard for the Installation of Stationary Pumps for Fire Protection, is the standard that describes types of fire pump, associated equipment, and fire pump installation [1]. The NFPA 25, Standard for the Inspection, Testing and Maintenance of Water-Based Fire Protection Systems, is for the fire protection systems that use water; it describes testing, inspection and maintenance of the system [2, 3]. The EIT standard follows most of the NFPA codes and standards. The chapter 5 of EIT Fire Protection Standard and Fire Suppression includes fire pump and its installation. A problem commonly found during the fire pump performance testing under NFPA 25 is the complication in the process; this is the procedure for setting the test parameters and conditions, as well as data recording. Since the testing is not a daily operation, therefore it requires an experienced engineer to perform the testing. Difficulties of fire pump performance testing and error of the test results have been found in buildings with inexperience of the person in charge of the operation.

2. Fire PumpSystem

2.1 Fire Pump Configuration

The basic configuration of a fire pump system is shown in Figure 1 [4]. This diagram is the modification from Figure A6.3.1 (a) in NFPA 20-2016. The diagram showed not only the pumping system but also the testing system for the fire pump performance evaluation; with additional fire pump testing components such as valve IV, V, VI and flow meter. The fire pump is a machine that feed the water to the water sprinkler system and hydrant system. The hydrant system is equipment inside the building; they are fire sprinklers, fire hoses and hydrant heads.

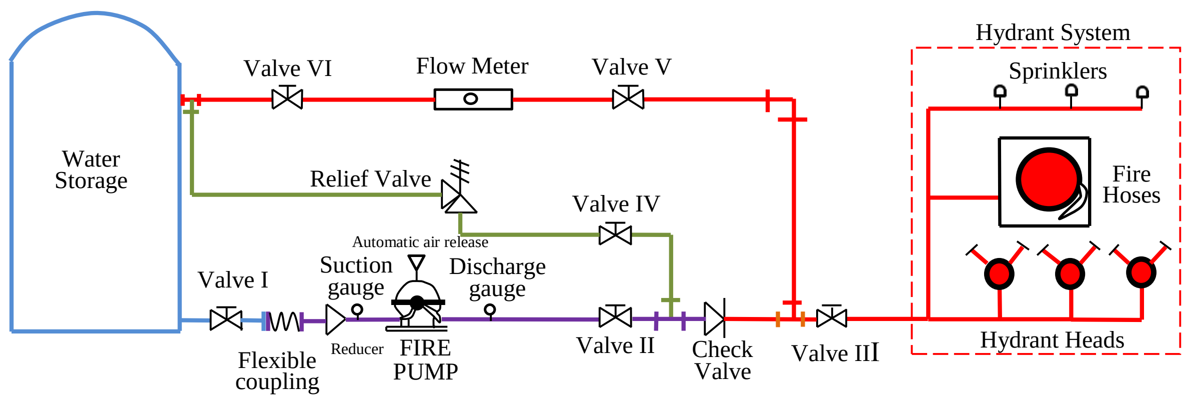

Figure 1 A fire protection system configured with a fire-pump performance testing system.

In high-rise buildings and industrial plants, the fire pump system requires high value for both water pressure and flow rate. The objective of the evaluation is the checking of the working condition of the system to assurance that it will be work properly with reliability, thus ensuring the supplying of water in a fire emergency. When one or more fire sprinklers are exposed to heat above the design temperature, the water pressure in the sprinkler system drops, it activates the fire pump to start the operation [5]. The water flow from the water storage through valve I, fire pump, valve II, check valve, valve III and to the hydrant system, respectively; as shown in Figure 1. The flexible coupling is used for minimizing the vibration and alignment of pipes.

A relief valve is a pressure relief valve (PRV) used for preventing over pressure which is generated by the fire pump system. It is necessary for protecting the system components which can be damaged by the high pressure. The water flow from the pump via valve II, valve IV, through PRV and return to the water storage (see Figure 1).

Since the fire pump testing evaluation cannot perform by using the hydrant system of the building, a water recirculation piping is installed [6, 7]. This pipe line allows the water to return to the tank; by letting the water to bypass the valve III, and allowing it to go through valve V and valve VI, respectively (see Figure 1). When testing the fire pump, valve III is closed and the water flow is regulated by a control valve, which is the valve VI. Notice that, during the normal operation, valve III is open while valve V is closed.

The valves I to V are outside screw and yoke (OS & Y or OSY) gate valves. The functions of OSY valve are opening or closing via the gate, for controlling the water flow. This valve type has the screw outside the case, which is always obvious whether the valve is closed or open. This is its advantage for visual inspection of the valve position.

2.2 Fire Pump Specification

The specifications for fire pump performance testing can be evaluated according to the NFPA 20. The test results need to be confined to the graph of Figure 2. The graph has the flow rate (q) in the horizontal axis and pressure (p) in the vertical axis; both are expressed in percentage. This graph indicated the condition when the fire pump operates at 0% flow rate; the outlet pressure (churn pressure) has to be less than 140% of rated pressure. When the flow is 150% of the rated flow rate; the outlet pressure has to be higher than 65% of rated pressure. If the result of the pump testing curve (*p* vs *q*) is inside the shaded area of the graph in Figure 2, the pump considers being in a good working condition [1].

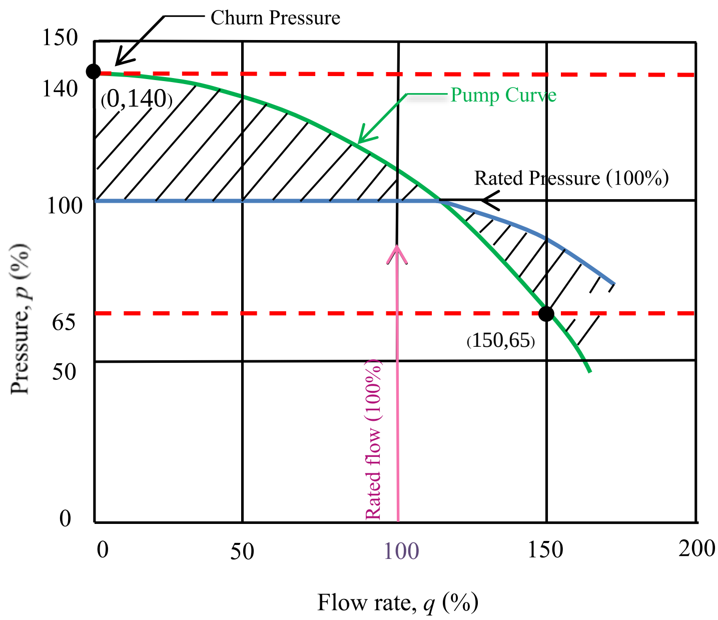

Figure 2 Fire pump performance curve according to NFPA 20.

3. Survey of Fire Pump Testing System

In order to develop the automated system for fire pump testing, we surveyed buildings and factories for gathering the technical and practical problems during the testing of each site. The survey was done during the period from February 2016 to August 2017; for the total of 30 sites in Central and Eastern Thailand. Technically, it was found that the recirculation pipe or testing pipe were not properly installed; these are small diameter pipe (20%), short length of the pipe line (67%) and no testing pipe line (10%). In practice, it was found that: 83% had difficulties in setting the flow rate and took more than 3 hours to get the test done, while 40% failed to set the flow up to the 150% of the rated flow rate. Figure 3 compare of the mentioned survey results. Most of the practical difficulties were caused by the technical improper installation of the recirculation pipe, and inexperience of the person whom performance the test.

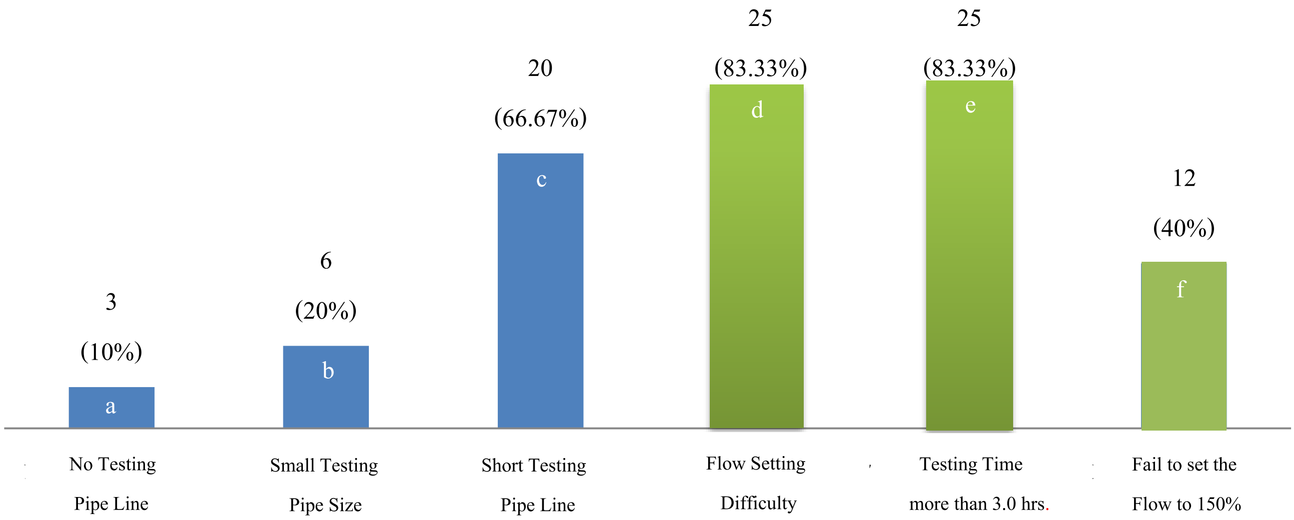

Figure 3 Technical (a to c) and practical (d to f) problems found from the survey of fire pump system from 30 buildings and factories. The upper number indicated the number of site, the numbers in parenthesis are percentages.

4. Experimental System

The proposed laboratory system for developing an automated testing procedure for fire pump performance evaluation is shown in Figure 4. The space requirement is 8.7 meters long, 2 meters wide and the height of 2.3 meters. The unit of the size and length of pipes are in millimeter (mm). The details of the components used in the system, testing procedure and automated system are explained in the following sections.

4.1 Fire Pump Configuration and Components

The detail of the fire pump and components used, as shown in Figure 4, are presented as follow.

4.1.1 Water Storage. Water storage used is a cylindrical water tank with the diameter of 1000 mm. The tank has the capacity of 1000 liters.

4.1.2 Suction Gauge. The suction gauge is a pressure gauge for indicating the inlet pressure of the pump.

4.1.3 Fire Pump. Fire pump used for the system has the maximum flow rate of 400 gpm (US gallon per minute). At the rated flow rate of 100 gpm, the water pressure is 65 psi (pound per square inch) or equivalents to the total dynamic head of 46 meters. The impeller of the pump has the diameter of 182 mm. It operates at the recommended speed of 2900 rpm (revolution per minute). The end-suction fire pump was selected and the pump is operated by an electric motor. Notice that the rated flow rate is 100 gpm; therefore the rated flow rate percentage of 100% equals to 100 gpm, and so on.

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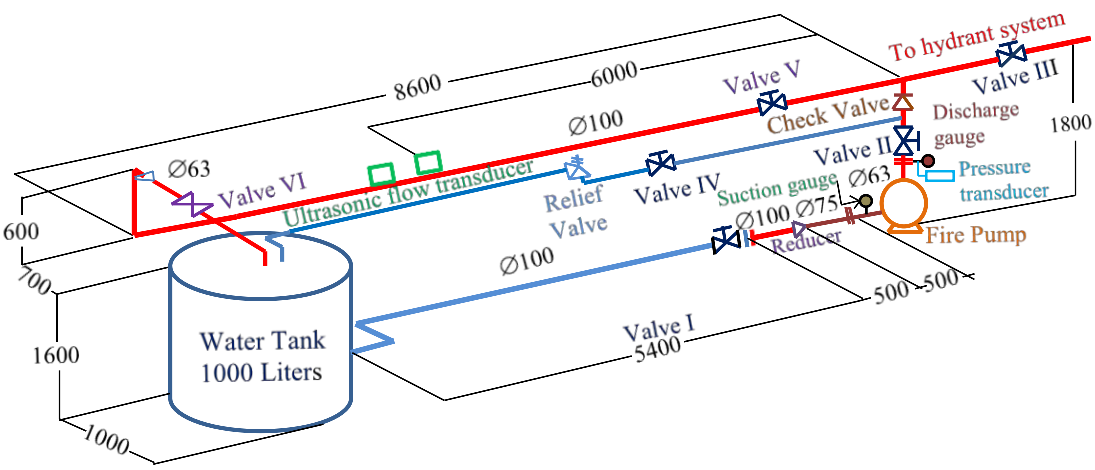

Figure 4 The 3-D layout diagram of the components (unit in mm).

4.1.4 Fire Pump Motor. The fire pump motor is the electric motor which drives the fire pump. The selected motor was a 50 Hz, 3-phase, 380 volts with the power of 11 kW at 2950 rpm.

4.1.5 Discharge Gauge. The discharge gauge is at the outlet of the pump. It is used for showing the pressure being supply to the hydrant system.

4.1.6 Valves. Valve I to V are OSY gate valves. They are manually operated.

4.1.7 Check valve. The check valve prevents back-flow in the fire pump.

4.1.8 Relief Valve. Relief valve is a pressure relief valve (PRV). The selected valve protects the fire protection system components when the pressure is higher than 100 psi.

4.1.9 Pipes. The piping use steel pipe with diameter of 100 mm. When the pipe is connected to the pump or valves with different diameter, reducers are used.

4.1.10 Valve VI. A servo control valve is used at the position of the valve VI. It is driven by a DC servomotor which needs supply voltage of 24 VDC. The motor is controlled by a controller which transmits the control signal; the signal has a range from 4 to 20 mA. The motor has the power of 40 watts and provides the maximum torque of 200 Nm. The control valve enables us to regulate the water flow rate (q) to any required values.

4.1.11 Hydrant System. Hydrant system is the fire protection system inside the building. For our laboratory system, it is not connect to the hydrant system; therefore the outlet of valve III has a pipeline return to the tank instead of the hydrant system. The valve III is closed during the performance testing.

4.2 Fire Pump Performance Testing Procedure

The fire pump testing according to NFPA 25 needs to perform at least once a year. The process of obtaining the result is summarized by the flow diagram of Figure 5a. The block diagram for the automatic testing system is shown in Figure 5b.

The required measuring data is the water pressure (*p*) at the specified setting of the flow rates (*q*). The NFPA 25 requires measuring the pressure at 0%, 100% and 150% of the rated flow. During the test, an engineer responsible for open and close the valves, indicated in Figure 1 and 4, in the sequence as shown in Figure 5a. The flow rate is manually set by using the valve VI, which needs to adjust the position of the valve opening in order to obtain the required flow rate.

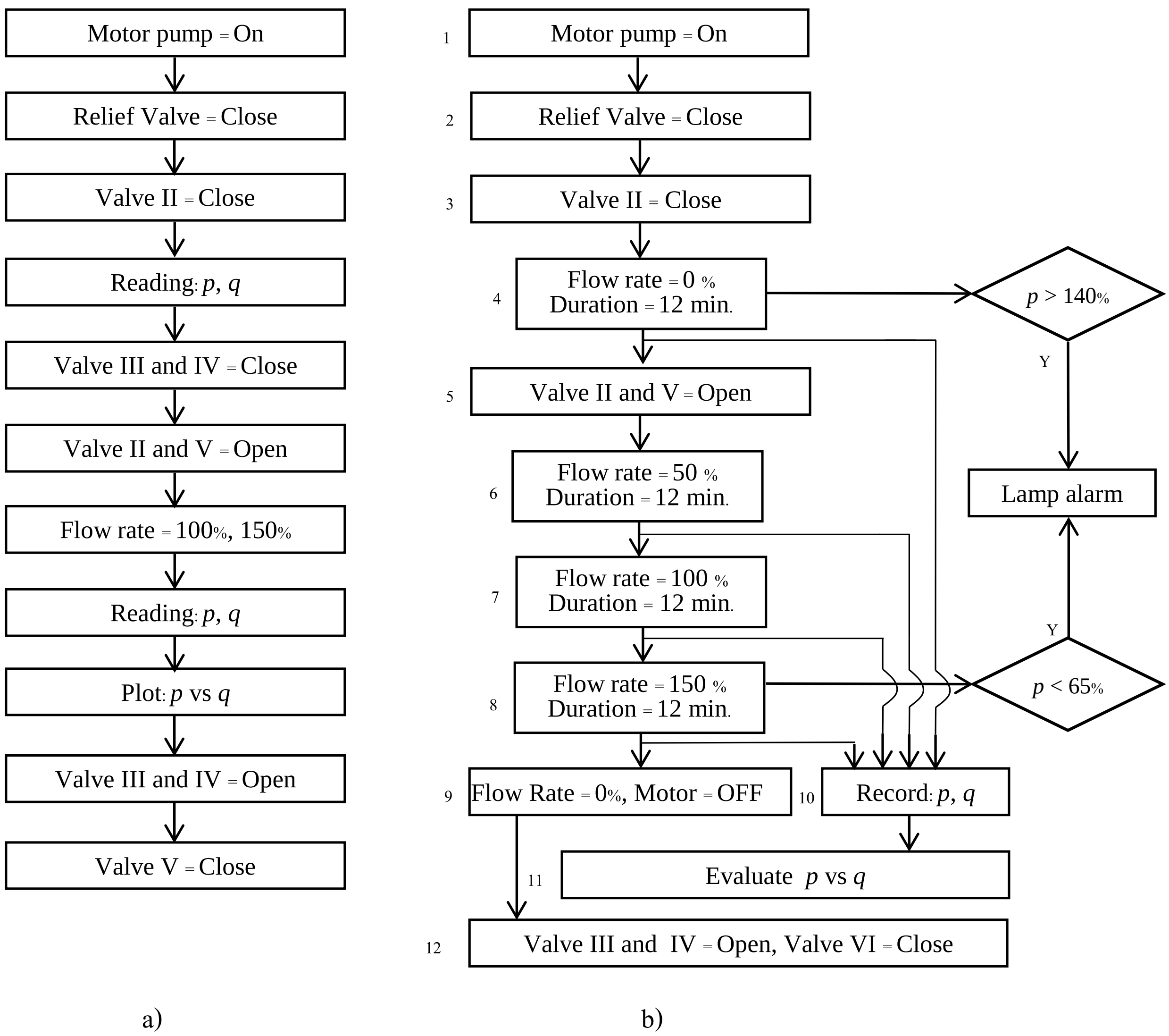

Figure 5 a) Flow Diagram of fire pump performance testing procedure, and b) Block diagram for the automated testing system.

Based on the graph of Figure 2, the measured value of p and q need to be in the indicated region. The process typically takes about 3 hours for the completeness of the evaluation. In order to minimize the time taken and maximize the accuracy of the reading. The block diagram of Figure 5b introduced a servo controlled valve for automatically setting of the flow rates and duration for reading the water pressure. The time sequences are controlled by the use of programmable logic controller or PLC. The data reading is done by applying pressure and flow sensors via an analog-to-digital (A/D) unit. The recoding and replay is stored in a SD RAM card. For a fully automated testing system, valve II to V can be replaced by solenoid valves.

4.3 Automated Testing System and Components

For automatic testing of the fire pump performance, measuring and control devices are applied to the system. The detail of the components, for control and measurement, are described below.

4.3.1 Control Valve. The control valve as described in section 4.1.10 is an electro-actuator valve and is called servo valve. Unlike the manually operated valve I to V, the control valve is electrically controlled. The actuator is a DC servomotor with a built-in closed loop control. The feedback block diagram for position and torque control of the valve is shown in Figure 6. The motor generates torque required for open or close its ball valve via a gear box with the gear ratio of K_G. The torque T is measuring by the transducer H_T. The position of the valve opening θ is feedback via the position transmitter H_P; it is compared with the position input signal R. The forward path gains of the controller are G_1 and G_2. This servo valve (Darhor Technology Co., Limited, model HL-20A) used DC servomotor which receives current command signal between 4 to 20 mA for controlling the flow rate.

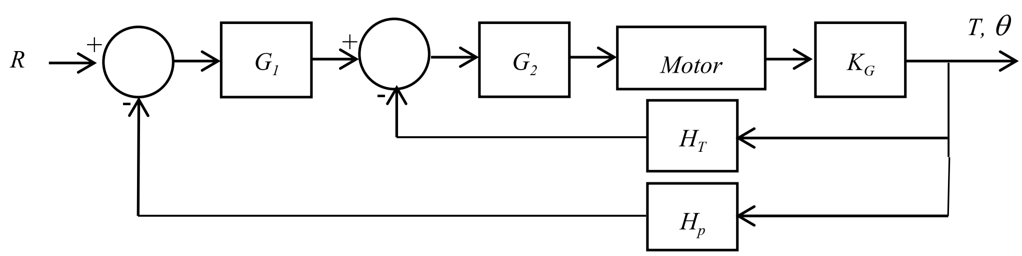

Figure 6 Closed loop control of the servo valve.

4.3.2 Flow Rate Transducer. The flow rate measurement was done by using an ultrasonic flow rate sensor (Shenzhen Hurricane Tech. Co., Ltd, model EUF162W) accuracy 1%. The transducer was attached, to the pipe, near the inlet of the control valve (valve VI) as shown in Figure 1 and 4. The flow rate signal was calibrated by a standard flow rate meter (Ultraflux, model UF801P) with the accuracy of 0.5%.

4.3.3 Pressure Transducer. The water pressure is measured by using a pressure transmitter (Danfrost, model: MBS3000). The output signal voltage is 0 to 10 VDC for the range of pressure from 0 to 10 bars (or 0 to 145.04 psi).

4.3.4 Programmable Controller. This controller is a programmable logic controller (PLC). It is used for sequential control of the testing process according to the block diagram in Figure 5b. The PLC was programmed the order and the corresponding time (flow rate duration testing time) of the operation from the block number 4, 6 to 9 of the diagram in Figure 5b. The flow rate duration testing time could be program to any time other than 12 minutes. The PLC unit was connected to the controller that controls the servo valve (Figure 7); also, interfaced with display or input and output unit, reading and processing the pressure and flow signal via the A/D unit. The PLC used for the testing was Mitsubishi, model FX5U-32M.

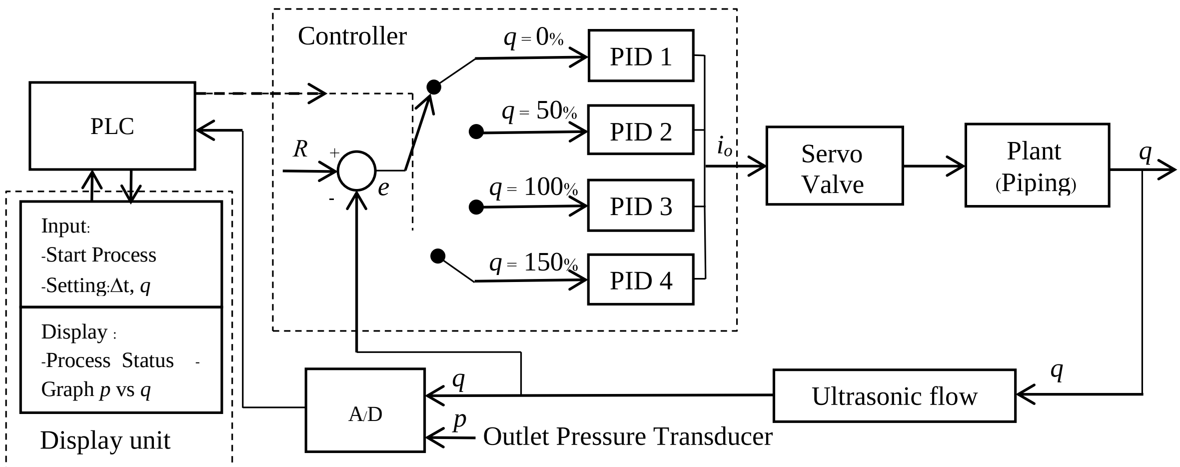

Figure 7 Interconnection of control components for the fire pump testing system.

4.3.5 Display Unit. The display unit employed in the system was Mitsubishi, model GOT2000. It was directly communicated with the PLC unit as shown in Figure 7. It served as an input and display unit; and used a touch-screen monitor for user interfaces. This unit was used for display and recording process data. The unit was configured so that the numerical data could be display real-time as texts or graphs. These numerical data could be transferred to a SD card. We also used this unit for initiating the testing process, setting values for upper and lower pressure limit and motor current limit.

4.3.6 Controller Unit. The control of the required flow rates was done by using a digital indicating controller (Azbil, model ADC36). This controller unit was configured four PID (proportional-integral-derivative) controllers, as shown in Figure 7. Each for the flow rate, as indicated in Figure 5b, was at 0%, 50%, 100%, 150%. The analog signal obtained from the ultrasonic flow transducer (as mentioned in section 4.3.2) was used as the feedback signal to the PID controllers; thus ensuring the flow rates were kept within the requirement. The output signal of the PID was the command for positioning the servo valve of section 4.3.1.

4.3.7 Analog-to-Digital Unit. This A/D unit was used to transform the analog signal to digital signal so that the data could be handled by computers. The primary analog signals were pressure and flow rate, the others consisted of the valve position of the servo valve, electrical current of the motor pump and any interested signals of the system. The selected A/D unit was a six-channel, Mitsubishi Electric model FX3U-4AD.

5. Result and Discussion

5.1 Flow Rate Accuracy

The ultrasonic transducer is compared with the standard flow meter for the accuracy of the reading. The instruments used are indicated in section 4.3.2. The comparison was performed at the water flow rate around 0, 25, 50, 100 and 150 gpm. The result was shown in Table 1. This tabulated data indicated the ultrasonic flow meter transducer read higher values than the standard. The low errors were at the low flow rates; the maximum error was at 101.56 gpm (7.818% error), but the error decrease at the flow rate of 152.86 gpm (6.764% error).

Table 1 The accuracy of the ultrasonic flow meter used in the system.

Reference : Standard flow meter (gpm)	Ultrasonic flow rate transducer (gpm)	Absolute error (gpm)	% Relative Absolute error
0	0	0	0
25.96	26.40	-0.44	1.695
50.06	52.60	-2.54	5.074
101.56	109.50	-7.94	7.818
152.86	163.20	-10.34	6.764

5.2 Automated Fire Pump Performance Testing Results

An example of the time recording data of a fire pump performance testing is shown in Figure 8. The graphs were from the six channels of the A/D with the sampling rate of 60 Hz. The test was performed with the flow rate duration testing time (Δt) of 12 minutes. The flow rates were at 0%, 50%, 100% and 150%; noted that the system had an additional flow rate at 50% - which was not required by NFPA 25. Observing that, the percentage of the flow rate of 50% corresponding to 50 gpm, as indicated in Section 4.1.3. The graphs were the flow rate q with the scale in gpm, water pressure p in psi, percentage valve opening position θ, motor pump electrical current i_p in Ampere (A), controlled current signal i_o in mA, and the error signal e to the PID controller in mA. The signals, i_o and e, were that taken at the location indicated in the block diagram of Figure 7. The number on the vertical scale of the graph was common for the six graphs, but different units. The tested pump showed to have an uniform pressure with the average pressure of 70 psi for the four tested flow rates. Notice that there was an over shoot of the valve position at the beginning of each changed of the flow rate. The over shoot was from the underdamped setting condition of the

PID controller. The graph indicated that the valve position was not constant due to the disturbance of the flow and thus the valve position was changing in order to regulate the constant flow. It was found that the location of the flow meter which was not near the outlet of the control valve caused the deviation of the flow rate due to the transportation lag of the feedback signal.

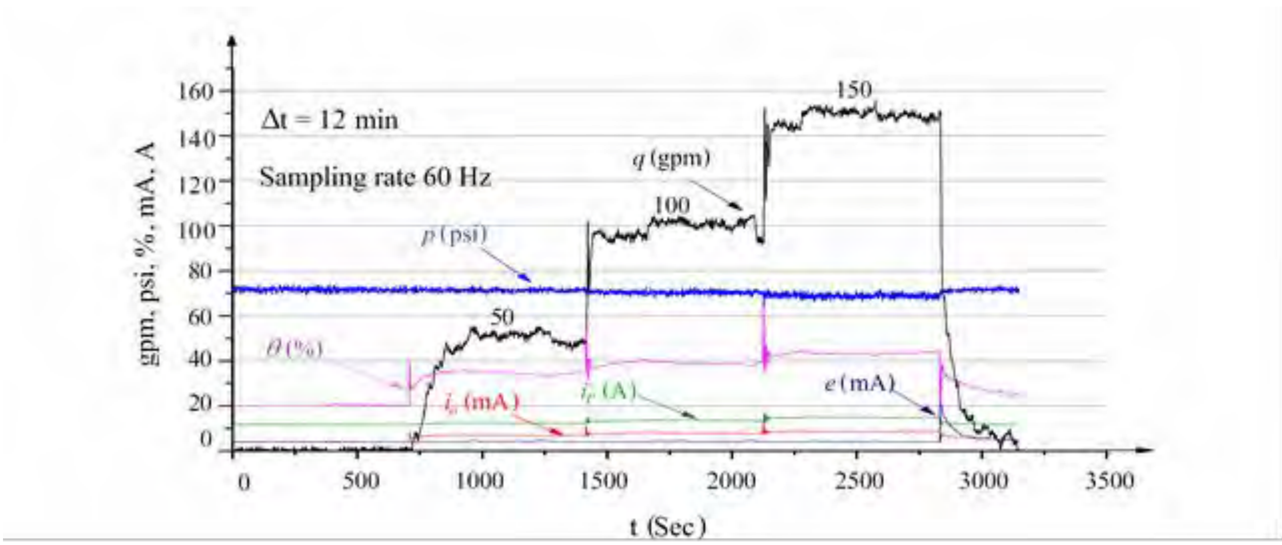

Figure 8 An example of time function graphs obtained from the automated fire pump performance testing system; the results obtained from four flow rates at 0, 50, 100 and 150 % of the rated values, and the flow duration time (Δt) of 12 minutes.

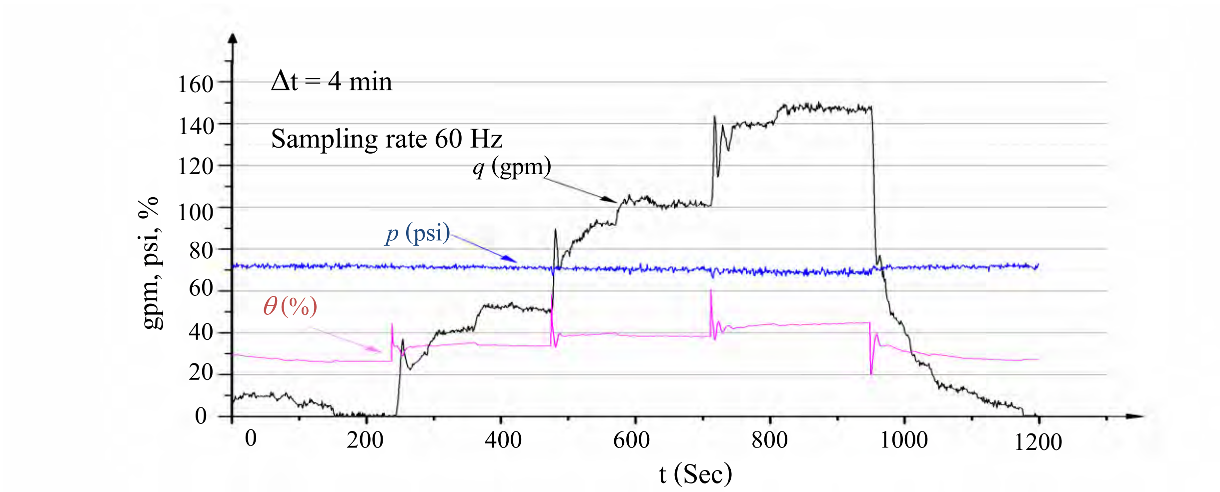

Figure 9 Fire pump performance testing showing only the pressure, flow rate and valve position for the flow rate duration time (Δt) of 4 minutes.

The fire pump performance testing results are for Δt = 12 min shown in Table 2 and Figure 10. These tabulated data and graph results are automatically generated and saved in SD card. The table compares the pressure (in psi) and the percentage of the flow rate and pressure, according to NFPA 20 and NFPA 25 (95%), of the tested pump at rated flow rate percentages (NFPA 20 required 3 points). Pressure 1 and pressure 2, in the second and third columns, are the tested data obtained on two different dates: 25 April 2017 and 18 January 2018, respectively. The graphs of *p* vs *q*, obtained from Table 2, are shown by having the pressure in psi in vertical axis and the percent flow rated from 0 to 150% in horizontal axis. Two horizontal lines of the corresponding 65% and 150% rated pressure are also plotted. This graph indicated that the tested pump satisfied the NFPA 20; therefore it was suitable for use as a fire pump. By comparing between the two tested pressure (pressure 1 and 2), it was also passed the testing standard under the criteria (95%) evaluation of the NFPA 25 standard.

Table 2 Compares the pressure (in psi and %) of the tested pump with NFPA 20 and NFPA 25.

Flow Rate %	Pressure 1 psi	Pressure 2 psi	Pressure (psi) NFPA20	Pressure (%) NFPA20	Pressure NFPA25 (95%)
Churn, 0%	72.92	72.50	105.00	150%	99.42%
50%	72.85	72.85			100.00%
100%	71.77	71.77			100.00%
150%	70.06	70.06	45.50	65%	100.00%

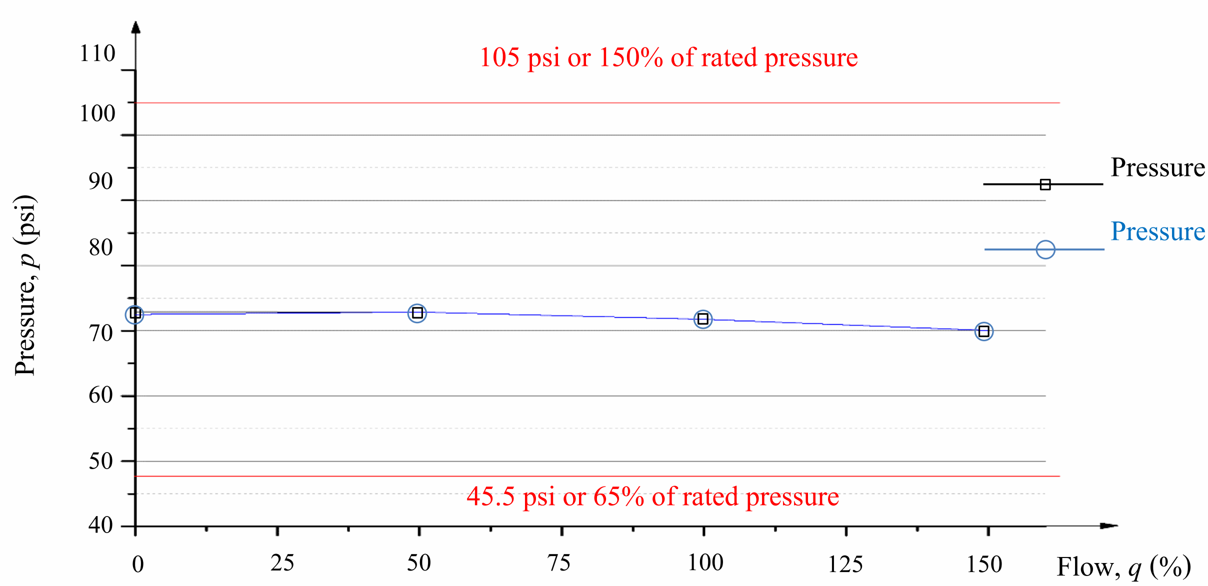

Figure 10 Graphical performance presentation of *p* vs *q* of the tested fire pump.

6. Conclusion

The proposed automated fire pump performance evaluation system was developed for the purposes of not only for training engineers about the testing process, but also being able to apply with any exiting fire pump system in buildings. The system developed from the pump driven by a 3-phase electrical motor. The motor pump operated at 2950 rpm which give water pressure of 65 psi at the rated flow rate of 100 gpm. The size of the pump used in this research considered to be small which capable for using with one inch fire hose in the radius of 30 meters. The system operation and setting was done by means of touch screen controller. It provided the ease of operation and reduced the testing time from 3 hours to 20 minutes (more or less - depended on the selected flow rate duration testing time). The results of the tested data can be stored in SD card and the data can be display as graphs of time function, which can be replayed on computers. This automated system proved to reduce the testing procedure and time; but the important of all is the reliability and accuracy of the result. These advantages were introduced by the use of servo valve and PLC.

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