

Smart Sensing for Variable Pressure of Oil Well Safety Valve Using Proportional Pressure Control valve

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Abstract

Protection of the oil pipelines which extracted from the wells was found to shut the well and prevent the leakage of oil when broken using safety valve. This valve is automatically activated by loss of pressure between the well and pipelines, which take the pressure, signal from hydraulic pressure sensor through pressure control valve which has constant or variable value but it is regulated manually. The manual regulatory process requires the presence of monitoring workers continuously near the wells which are always found in remote areas. In this paper, a smart system has been proposed that work with proportional pressure control valve and also electronic pressure sensor through Arduino controller, which is programmed in a way that satisfies the relationship between pressure loss and the real value of well's pressure that works at every moment and according to the condition of area. The system was designed to make sure it works by using simulation program (Automation Studio). A laboratory device was also built that simulates the system's work to ensure the performance and design of the system and as a result, a proportional relationship between sensor pressure on the pipeline and the well's pressure has been obtained by using the passage of the signal through Arduino controller which proved that it worked smartly. It has been concluded that the wells could be operated and protected smartly and remotely without presence of workers and monitors.

Nomenclature

$f_e(t)$	Solenoid force generated by coil current	N		the throttle opening in the valve which connects the pump outlet and the cylinder
$i(t)$	Coil current	Amp		
p_l	The working pressure(load pressure)	Pa	Q_r	The flow rate through the throttle opening connecting the cylinder and reservoir
P_s	The supply pressure	Pa		m^3/sec
Q_f	The flow rate through the oil passage into the internal feedback mechanism in the valve	m^3/sec	u_s	The overlap of spool
			u_0	The output voltage of the amplifier
Q_l	The flow rate through	m^3/sec		

x_e	The armature displacement	m
$x_e(t)$	Displacement of solenoid	m

Introduction

The specifications of oil wells in southern Iraq are working under different pressures at different time depending on the place and environments. They used safety valves located on the way of pipe line that transport the oil from well to storage tank. The required

pressure is adjusted manually. In this paper, the control system will modify such that the pressure is adjusted automatically using pressure sensors that are auto-sensitized without intervention of workers. The process of pressure measurement will transfer of the electronic signal to the control valve that works on proportional pressure. The block diagram of pressure control system is shown in Fig. 1 and the practical system is shown in Fig. 2

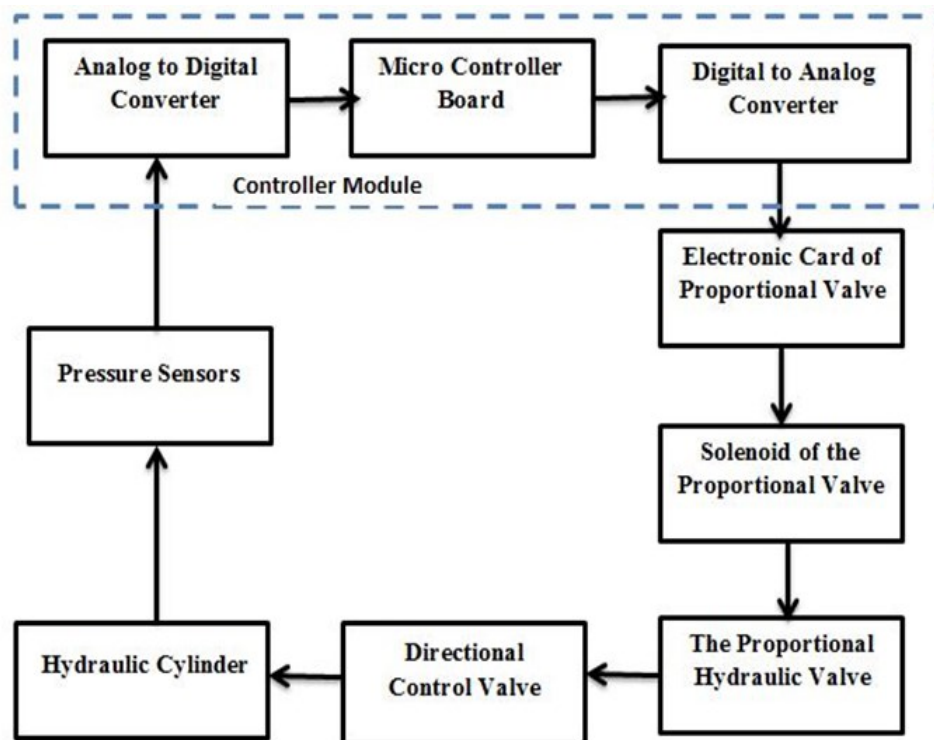


Figure (1) The block diagram of pressure control system

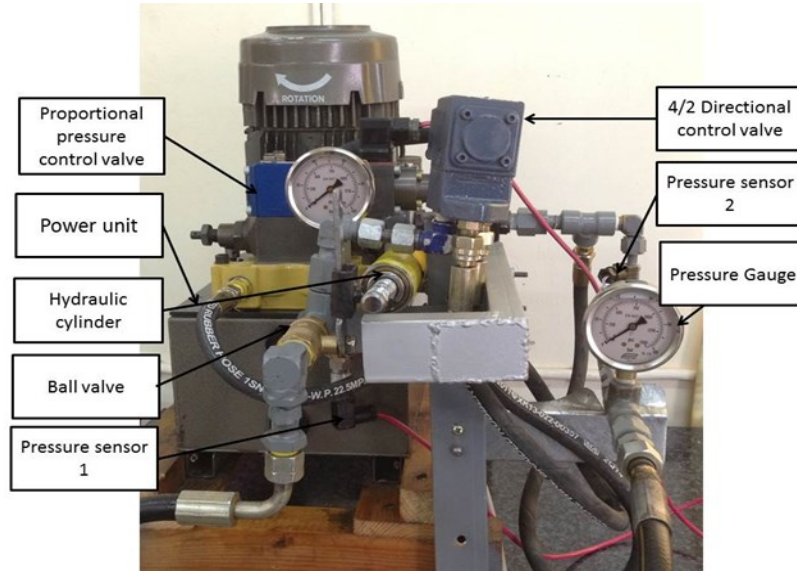


Figure (2) The electro-hydraulic closed loop system (EHCLS)

Proportional pressure control valve

The proportional pressure relief valves are directly operated by means of proportional solenoids. They are used for converting electrical input signals into a proportional pressure output signal [5]. These valves are used for limiting the pressure in a system [6]. The type of proportional pressure control valve used was DBEP6A06-13/45AG24K4M which is shown in Fig. 3. A proportional amplifier type VT-VSPA1K-1 [7] used to control the circuit of the proportional pressure relief valves. The proportional amplifier is shown in Fig. 4.



Figure (3) Proportional pressure relief valve type DBEP 6 A06-13/45AG24K4M

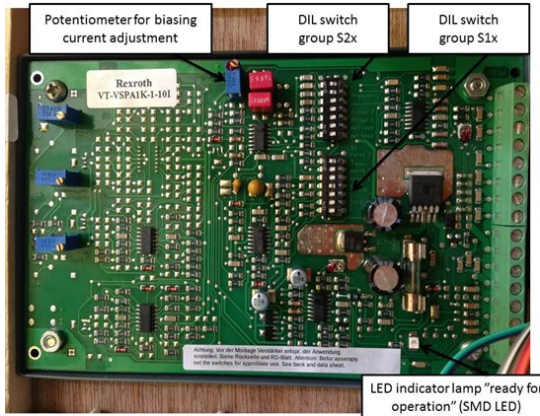


Figure (4) Proportional amplifier type VT-VSPA1K-1

Working principle of proportional valve controller

Proportional valve controller is a device that provides a control current to the coil of proportional valve. It can control the force or displacement of solenoid by this control current consequently change the opening of valve to achieve the aim of controlling the oil pressure or flow in hydraulic circuit. Solenoid force generated by the coil current is [4]:

$$f_e(t) = (i(t)N)^2 / (2R_g l(x_e)) \quad (1)$$

Where $f_e(t)$ solenoid force is generated by coil current; $i(t)$ is coil current; N is number of coil turns; R_g is air-gap reluctance; l is air gap length is a function of x_e . Linearization of Eq.(1) gives

$$f_e(t) = K_i i(t) + K_{x_e} x_e(t) \quad (2)$$

Where K_i is current-force gain of solenoid; K_{x_e} is displacement-force gain of solenoid; $x_e(t)$ is displacement of solenoid. The special structure design

of solenoid makes itself have a horizontal displacement-force characteristic, so $K_{x_e} \approx 0$, Therefore, Eq.(2) can be simplified to

$$f_e(t) = K_i i(t) \quad (3)$$

From Eq. (3) the solenoid force can be obtained which it is proportional to the coil current.

Mathematical model for the proportional pressure control valve

According to the working principle of the proportional pressure control valve, the mathematical model for the process it can establish. The valve is used together with the proportional solenoid and proportional amplifier [8]

1- The voltage equation of proportion solenoid coil circuit

The valve adopts the electromagnet which is a one-way trip controlling type, and the amplifier which is single-input and single-output DC one. The proportional solenoid control coil voltage is

$$u_0 = L \frac{di}{dt} + (R_c + r_p)I + K_b \frac{dx_e}{dt} \quad (4)$$

Where u_0 is the output voltage of the amplifier (V); L is the electrical inductance of a single coil (H); I is the electric current through the coil (A); R_c is the resistance of a single coil (Ω); r_p is the internal resistance of the amplifier (Ω); K_b is the motional EMF

coefficient(V.s/m); x_e is the armature displacement (m).

2-The thrust equation of an armature output

Proportional solenoid is the excitation power – mechanical conversion device with the displacement of the level – force characteristic, after power armature in a magnetic field is powered by the effect of the electromagnetic force and the electrical signal which is exported by the proportional control amplifier will be converted into a force or a displacement. Within the working stroke, the resulting electromagnetic force in Eq. (3)

3- The balance equation of the spool

In a stroke-controlled proportional solenoid, there are electromagnetic force, inertial force, friction force and fluid power, as well as the spring force on the spool, ignoring the hydraulic clamping force, then the force balance equation can be written as follow:-

$$F_m - p_l A_s = M_1 \frac{d^2 x_s}{dt^2} + B_1 \frac{dx_s}{dt} + K_1(x_{10} + x_s) + K_s(x_s - x_{v0}) \quad (5)$$

Where p_l is the working pressure (load pressure) (Pa); A_s is the section area of the spool (m²); M_1 is the equivalent mass of the spool (kg); B_1 is the integrated damping coefficient (N.s/m); K_1 is the return spring stiffness (N/m); K_s is the fluid dynamic stiffness coefficient (N/m); x_{10} is the pre-

compression of the spring (m); x_s is the spool displacement (m); x_{v0} is the opening volume form port A to port T (m).

4- The equation of the flow balance

The orifice flow of the control valve [3] (see Fig. 5)

$$Q_l = C_{d1} A(u_s + x_s) \sqrt{\frac{2}{\rho} (P_s - P_l)} \quad (6)$$

$$Q_r = C_{d2} A(u_s - x_s) \sqrt{\frac{2}{\rho} P_l} \quad (7)$$

$$Q_f = -A_s \frac{dx_s}{dt} \quad (8)$$

Where Q_l is the flow rate through the throttle opening in the valve which connects the pump outlet and the cylinder, Q_r is the flow rate through the throttle opening connecting the cylinder and reservoir, Q_f is the flow rate through the oil passage into the internal feedback mechanism in the valve, C_{d1} and C_{d2} are the discharge coefficients of the throttle openings in the valve; P_s is the supply pressure (Pa); ($A = \pi \cdot d_s^2$, d_s is the diameter of spool section (m)) is the area of the throttle openings(m²); ρ is the density (kg/m³); u_s is the overlap of spool (m).

If the pressure is too low in the controlled volume, the valve opens to supply pressure to fill up the volume until it reaches the target pressure. If the pressure is instead

too high, the valve opens to tank in order to reduce the pressure in the controlled volume. The controlled pressure is sensed by the valve and compared with the target pressure. The valve is therefore self-regulated. The target pressure is set by an electronic signal and corresponds to the force applied on the spool by a solenoid [2]. The valve that is

studied in this work is shown in Fig.5.

Electronic circuit with Arduino UNO Board

The circuit are designed and built experimentally by the researcher from electronic components. The block diagram of this circuit is shown in Fig. 6.

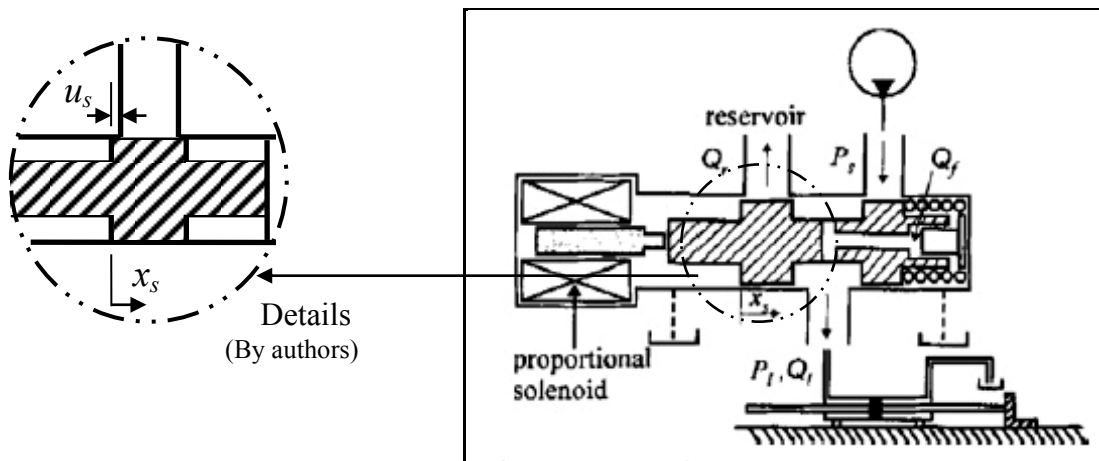


Figure (5) A schematic of the proportional pressure control valve [3]

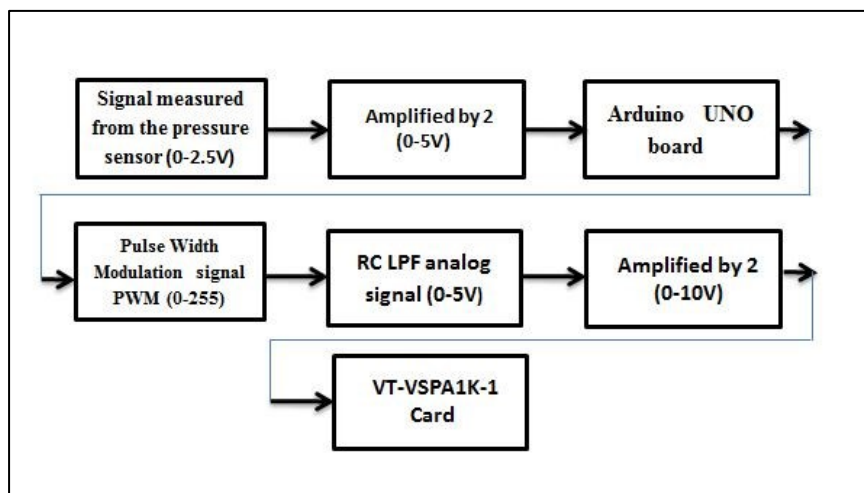


Figure (6) Block diagram of electronic circuit

Procedure of writing Arduino program for pressure sensor

1-Find calibration of proportional pressure control valve, the range of pressure is (0-25 bar). The results of calibration are listed in Table (1)

Table 1 Calibration of proportional pressure

Pressure [bar]	Voltage [volt]	Current [Amp.]
25	6	0.36
24	5	0.28
18	4	0.21
10	3	0.15
5	2.74	0.12
2	2	0.1
0	0	0

2- Reading pressure sensor 1 at (0 - 2-5-10-18-24-25 bar) in order to get relationship between pressure and voltage. The results of reading are listed in Table (2)

Table 2 Reading pressure sensor control valve

Pressure [bar]	Output voltage [4.9mv/unit]
25	995
24	881
18	698
10	456
5	280
2	198
0	0

3-Find the mathematical equation of proportional pressure control valve by using curve fitting tool package in MATLAB where the input is the

pressure from sensor reading in Table (2) and output is voltage of proportional control valve in Table (1) divided by 2. The Arduino program flow chart is shown in flow chart (1)

$$V = a1 * p^3 + a2 * p^2 + a3 * p + a4 \quad (9)$$

Where $a1 = 6.714 * 10^{-9}$, $a2 = -1.062 * 10^{-5}$, $a3 = 0.006945$ and $a4 = 0.0104$

Simulation analysis with Automation Studio

Automation Studio (AS) package was developed in (2003) by (FAMIC Technologies inc/Canada) to contain comprehensive libraries of hydraulic, pneumatic, ladder logic, and digital electronic symbols. This package is completely integrated software package that allows the user to design, simulate and animate circuits consisting of various automation technologies [1]. Smart sensing variable pressure of well petrol safety valve was built and simulated with this program. All components and parameters of the system have been selected and connected as in the actual system in the project work sheet as shown in Fig. 8

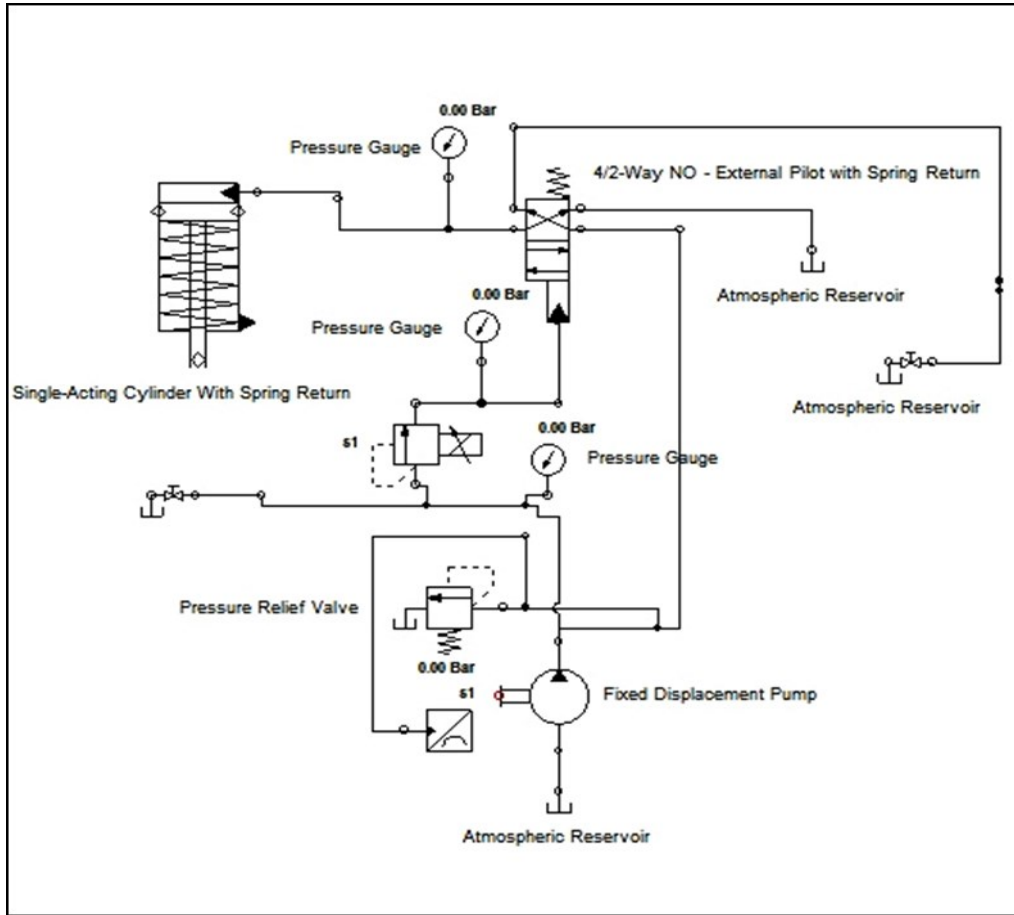


Figure (8) The project work sheet of simulation analysis

Results and Discussion

Simulation results using automation studio

Electro-hydraulic system has been built with automation studio package. Fig. 9 shows the linear speed of single-acting cylinder with spring return at different pressures. Fig. 10 shows input pressure to single-acting cylinder with spring return and Fig. 11 shows the measured data of pressure sensor at different pressure.

Experimental Results

In this section we list the results of calibration of proportional pressure control valve as shown in Fig. 12 and the behavior of pressure sensor. The experimental results were obtained from the test rig by using two pressure sensors, two cases are shown below. The two results were taken when there was no pressure drop in the hydraulic system and happen leakage in the this mean there is pressure drop, the leakage occurred when the shut-off valve

was opened. We explore these results obtained from MATLAB

software connected with Arduino board.

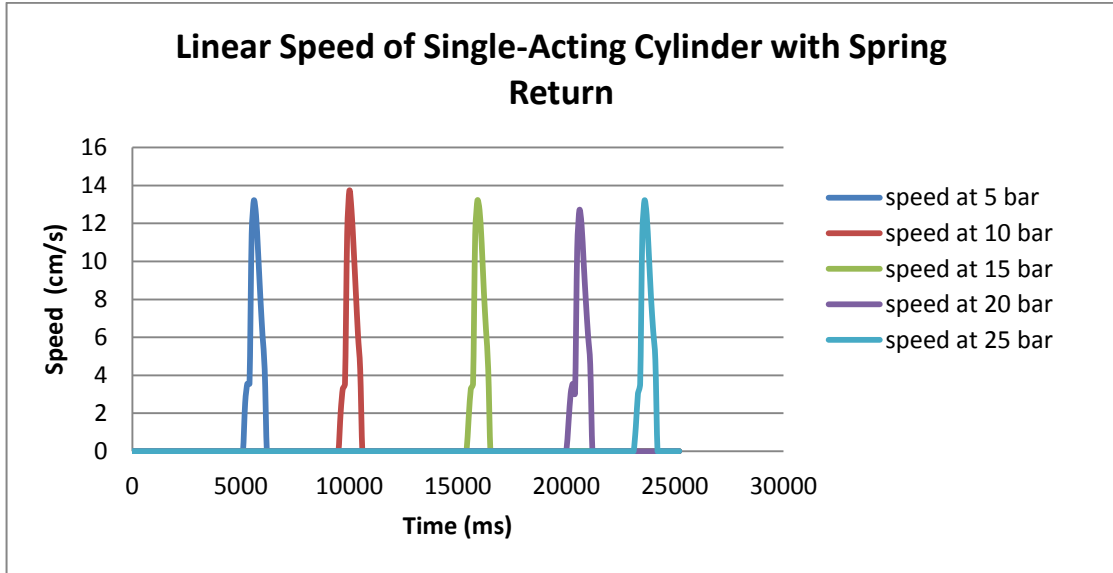


Figure (9) Linear speed of single-acting cylinder with spring return

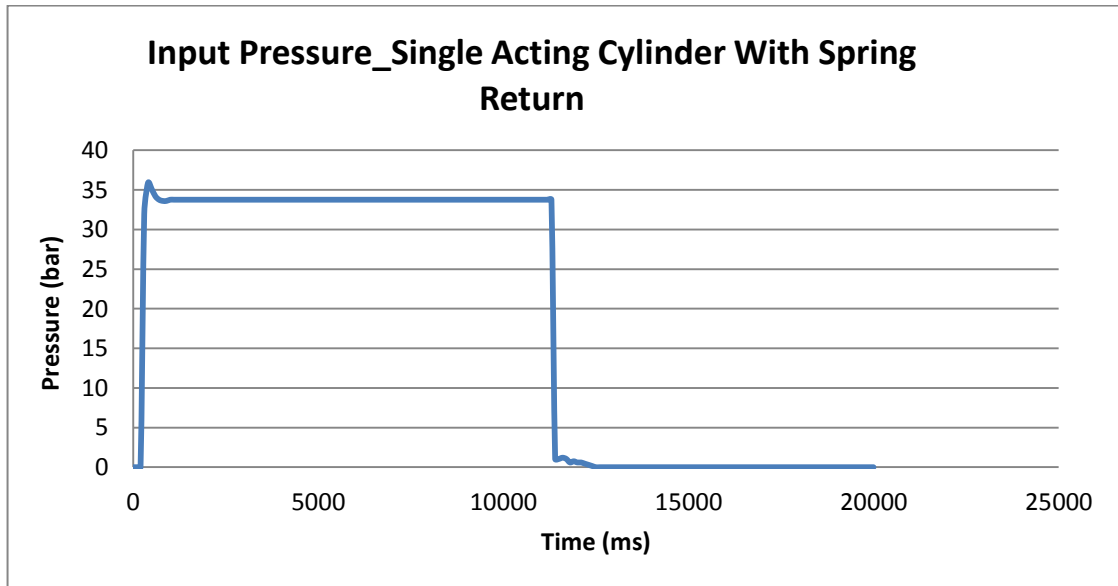


Figure (10) Input pressure of single-acting cylinder with spring return

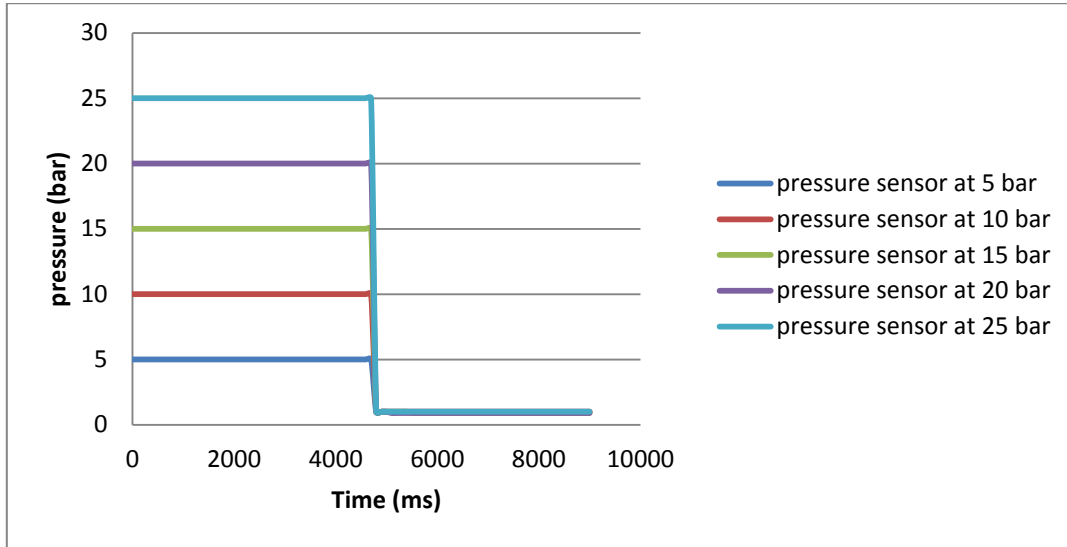


Figure (11) Measured data of pressure sensor at different pressure

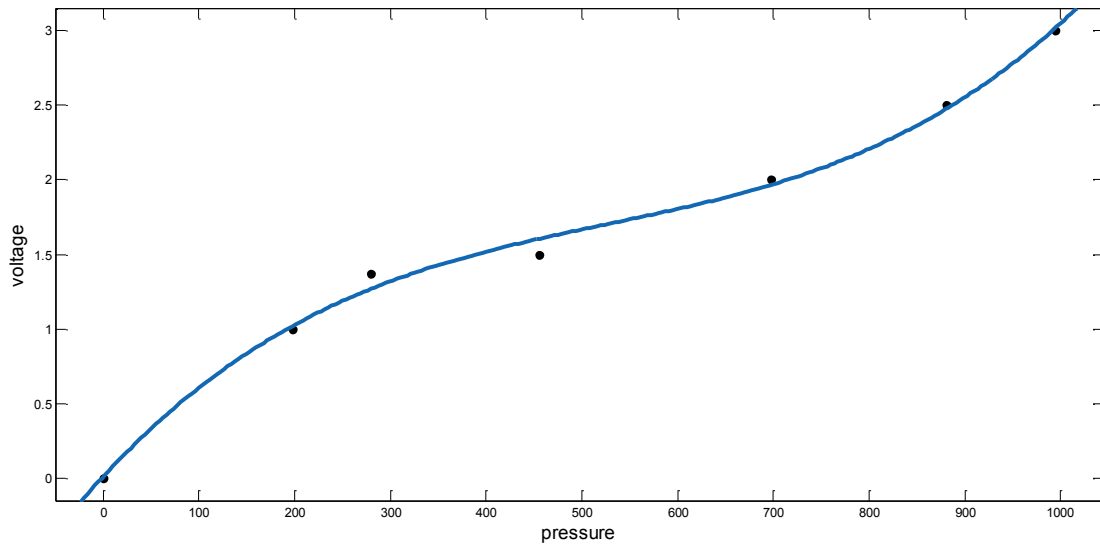


Figure (12) The calibration curve of proportional pressure control valve

Case one: no pressure drop in the hydraulic system

Fig. 13 shows behavior of the pressure sensor 1 at 5 bar with time.

The equation of pressure sensor is

$$f(t) = a_1 \cdot \exp(-((v-b_1)/c_1)^2) + a_2 \cdot \exp(-((v-b_2)/c_2)^2) + a_3 \cdot \exp(-((v-b_3)/c_3)^2) \quad (10)$$

Where

$$a_1 = 159.8, b_1 = 23.75, c_1 = 8.245, a_2 = 261.9, b_2 = 86.14, c_2 = 41.95, a_3 = 173.2, b_3 = 41.03, c_3 = 19.59$$

It shows that as time passes, the pressure fluctuates between values. To eliminate this fluctuation the average value is taken in the Arduino program.

Case two: pressure drop in the hydraulic system

Fig. 14 shows behavior of the pressure sensor at 20 bar with pressure drop.

Notice that when the oil leakage occurs the pressure will drop to (1 bar). Directly the sensor detects at very high response.

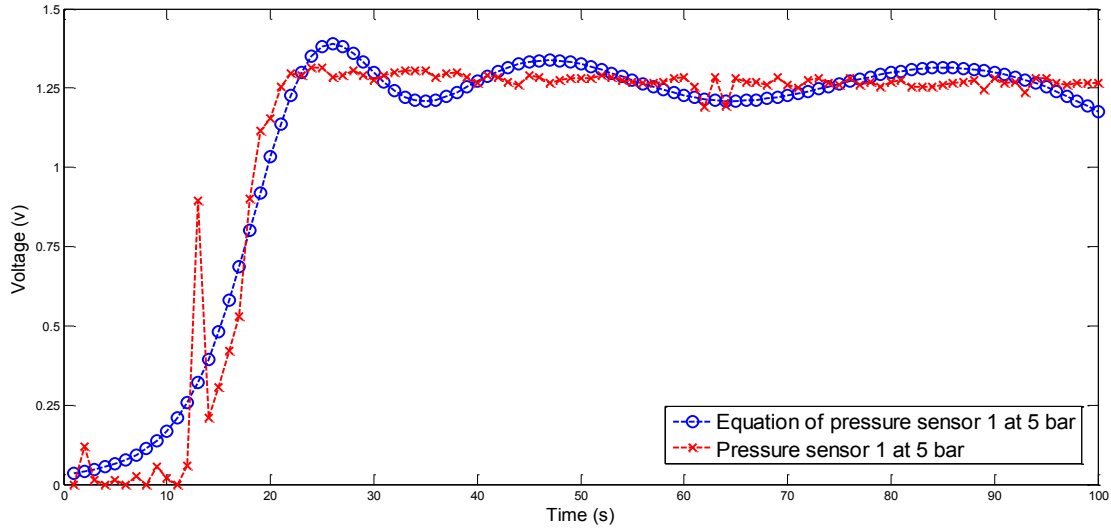


Figure (13) Behavior of pressure sensor at 5 bar (Refer to Eq. (10))

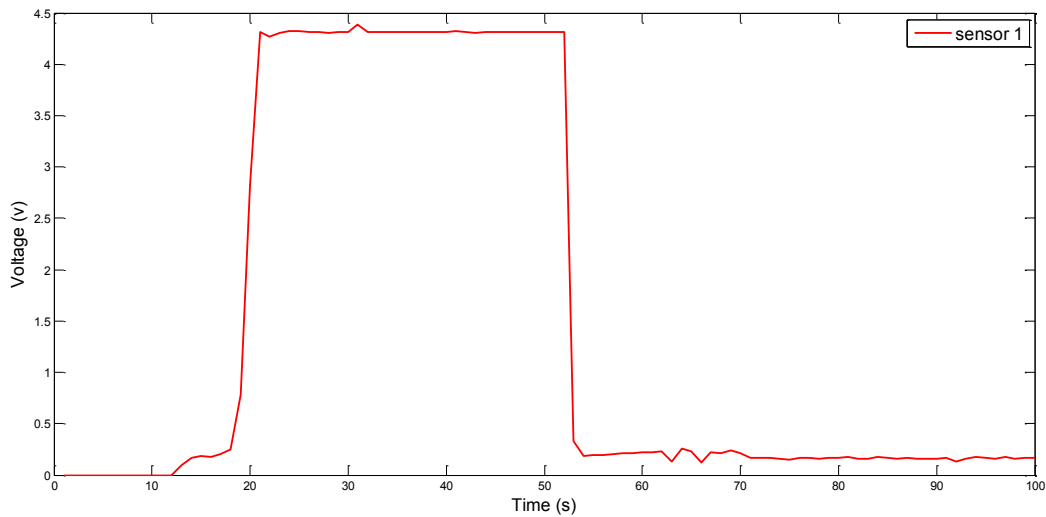
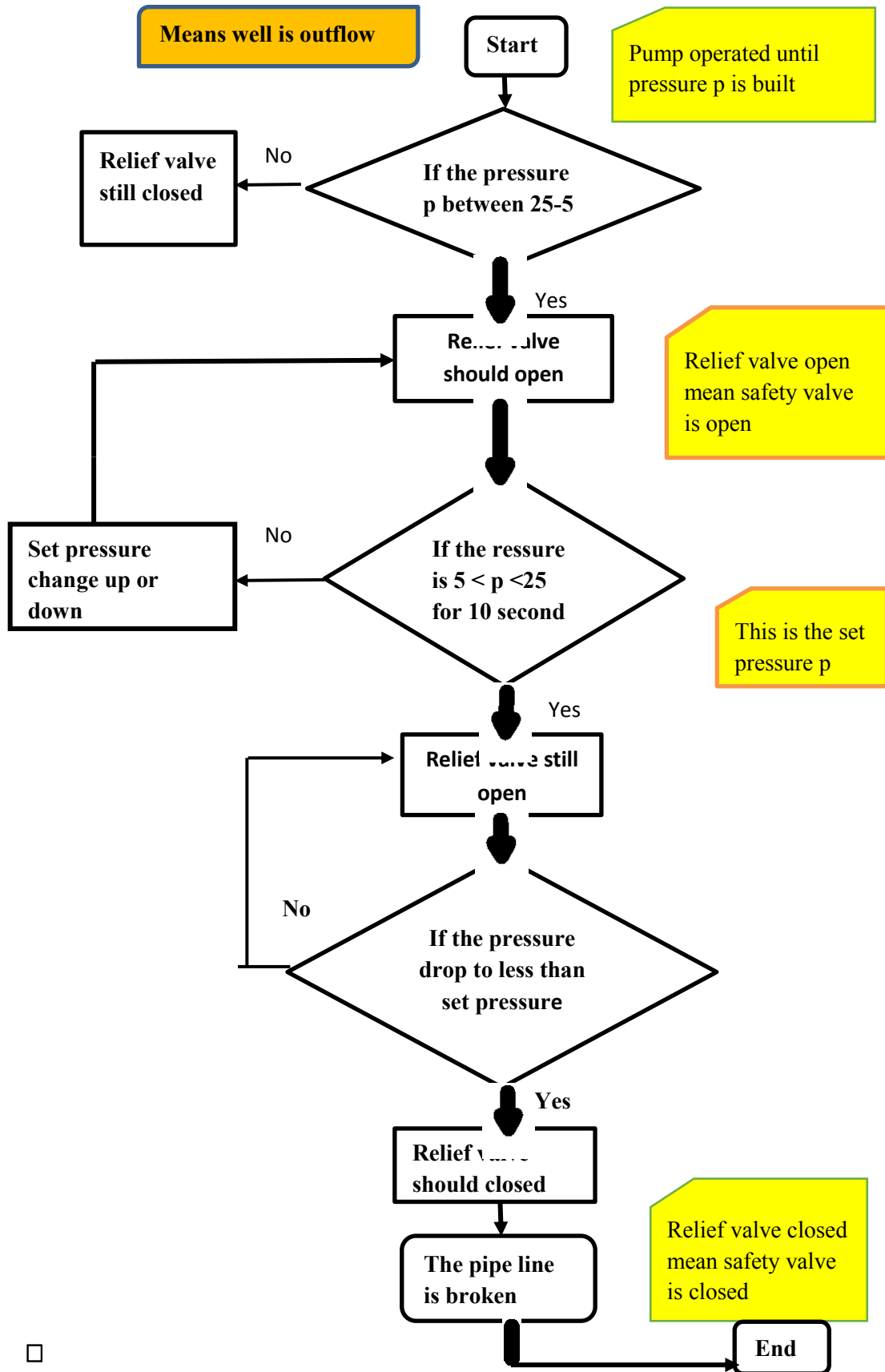


Figure (14) Behavior of pressure sensor at 20 bar with pressure drop



Flow chart (1) Arduino program flow chart

Conclusions

As a result of this study, the following conclusions are made

1- It can be made smart sensing of variable pressure for oil well safety valve using proportional pressure control valve, since the system takes instantaneous pressure as calibrated to be a set point, accordingly the proportional pressure control valve will depend on the value of setting. It is possible to apply this system on the surface safety valves for wells and oil transport pipelines.

2-In the case of the pressure source was change the pressure sensor will sense the new pressure and processing by the Arduino program that it was became the new setting automatically through proportional pressure control valve.

3-The (AS) package can be used as a simulation system for the design of hydraulic systems. It can deal with two types of users (professional and beginners). As well can be used to understand and study any hydraulic system.

References

1- Automation Studio (AS) user manual (2008) "Automation Studio

circuit design simulation software", Fluid Power and Automation Technologies, [http://www. automation](http://www.automation)

2-A. D. Amico, Pressure Control in Hydraulic Power Steering Systems, no. 1626. 2013.

3-K. Yang, I. Oh, and I. Lee, "Pressure Control of Hydraulic Servo System Using Proportional Control Valve," KSME Int. J., vol. Vol. 13, no. 3, pp. 229–239, 1999.

4-L. Q. Sen, B. Hong, and L. Jun, "Research on Embedded Electro-hydraulic Proportional Valve Controller," in 2009 Third International Symposium on Intelligent Information Technology Application, 2009, vol. 1, pp. 91–94.

5- Tonyan, Michael J.(1985) "Electronically Controlled Proportional Valves" by Marcel Dekker

6- Web site "Proportional Pressure Relief Valve Type DBEP Datasheet" Retrieved from

http://www.boschrexroth-us.com/country_units/america/united_states/sub_websites/brus_brh_i/en/products_ss/08_proportional_servo_valves/a_downloads/re29164_0203.pdf 2014/4/18

7- Web site "Rexroth Electrical Amplifier" Retrieved from http://www.boschrexroth-us.com/country_units/america/united_states/sub_websites/brus_brh_i/en/products_ss/03_electronics/a_downloads/re30111_2010-10.pdf 2014/4/18

8-Y. Guangwei and L. Muiyi, "Simulation research of proportional pressure-reducing valve," in *International Conference on Advanced Technology of Design and Manufacture (ATDM 2010)*, 2010, pp. 121–126

التحسس الذكي لتغير الضغط لصمام الحماية لبئر النفط باستخدام صمام سيطرة الضغط التناسبي

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الخلاصة

وجد صمام حماية أنابيب النفط المستخرج من الابار لغرض غلق البئر ومنع تسرب النفط عند حدوث كسر في الانبواب. وهذا الصمام يعمل تلقائياً عند التحسس بفقدان الضغط بين الانبواب والبئر والذي يأخذ اشارة الضغط من متحسس الضغط الهيدروليكي عبر صمام التحكم بالضغط الذي أما ان يكون ثابت القيمة أو من النوع متغير القيمة ولكن يتم تنظيمه يدوياً. عملية التنظيم اليدوي يتطلب تواجد عمال ومرافقين بشكل مستمر قرب البئر والذي دائماً يكون في مناطق بعيدة. في هذا البحث تم اقتراح منظومة ذكية تعمل مع صمام لتحكم بالضغط التناسبي وكذلك متحسس الضغط الالكتروني وذلك من برنامج عبر مسيطر مرمج اردينو الذي تم برمجته بشكل يحقق العلاقة بين فقدان الضغط وقيمة ضغط البئر الحقيقية الذي يعمل عليها كل لحظة وحسب متغيرات المنطقة والظروف. تم تصميم المنظومة والتأكد من عملها باستخدام برنامج المحاكاة (Automation studio) كذلك تم بناء جهاز مختبري يحاكي عمل المنظومة للتأكد من أداء عمل المنظومة والتصميم. وكنتيجة لذلك فقد تم الحصول على علاقة تناسبية بين ضغط المتحسس الموضوع على مسار الانبواب وضغط البئر من خلال مرور اشارة عبر المسيطر الاردينو والذي أثبت أنه يعمل بشكل ذكي . تم لاستنتاج انه بالإمكان عمل الابار وحمايتها بشكل ذكي وعن بعد دون تواجد عمال ومرافقين قرب البئر