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Performance of Proportional Directional Flow Control Valve in Rotational Hydraulic Movement

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Abstract— Fluid power control system is the technology that deals with the generation, control and transmission of forces, movement of mechanical element or system with the use of pressurized fluids in a confident system. This paper concentrates on static and dynamic performance of a rotational movement of hydraulic system under different operating conditions with connecting a proportional directional flow control valve (PDFCV). High technology is used for measuring and recording the experimental results which achieves accurate evaluations. Experiments have been conducted in case of no-load, 2003, 3093 and 4128 N load values. The performance under minimum and maximum loads is only reported. Supply pressure has been changed from 10 up to 50 bar. The effect of variation of pressure, load and flow rate values on the performance of the hydraulic system has been studied. It is concluded that increasing the load decreases the flow rate and speed of hydraulic motor, but increases the torque. In addition, increasing the supply pressure increases the flow rate.

Index Terms— Hydraulic systes, proportional directional flow control valve, dynamic performance, hydraulic motor.

1 Introduction

THE term fluid power refers to energy that is transmitted via a fluid under pressure and a main source of actuation used in diverse industrial applications where high level of dynamic motion and force requirements make it as the only choice among various methods. In 1906, oil began to replace water as a pressurized fluid in hydraulic systems. Akers and Lin [1], investigated the performance of control systems theoretically and experimentally considering different operating conditions, however with constant values for supply pressure. Some researchers studied the theoretical and experimental analysis of a coupled system proportional control valve and hydraulic cylinder as R. Amirante, et al. [2]. N. D. Manring and Greg R. Luecke [3] had analyzed hydrostatic transmission system consisting of variable displacement pump and a fixed displacement motor where the system is linearized and the stability range was presented. Ajit Kumar, J. Das and Santosh KR. Mishra [4], investigated the performance of a proportional valve controlling hydraulic motor in hydrostatic transmission system. Various leakage flow and torque losses of the bent-axis hydraulic motor were to be represented as motor parameters like pressure and flow rate. The corresponding losses coefficients were to be evaluated and validated experimentally. Various experiments have also been conducted extensively in order to determine optimum performance of the system. Andrzej Milecki and Dominik Rybarczyk [5], presented the design of proportional valve with a Permanent Magnet Synchronous Motor (PMSM). The proposed valve was described, and its history is briefly reviewed. Basic equations describing the valve were formulated and its simulation model was implemented in MATLAB-Simulink software. Sadak [6] studied the effect of connecting a proportional directional flow control valve on the system.

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2 Nomenclature

A_n	Nozzle flow area	[mm^2]
C_d	Discharge coefficient	[%]
p_s	Supply pressure	[bar]
p_{sa}	Actual value of supply pressure	[bar]
p_1, p_2	Motor inlet and outlet pressure value	[bar]
Δp	Pressure difference through valve opening	[bar]
Q	System flow rate	[mℓ/s]
Q_n	Flow rate through valve nozzles	[ℓ/min]
T	Temperature	[º C]
Ʈ	Calculated torque value	[N.m]
n	Speed of hydraulic motor	[rpm]
v	Command volts	[volt]
V_m	Hydraulic motor displacement	[cm^3/rev]
W	System load	[N]
θ	PDFCV opening percentage	[%]
ω	Angular frequency	[rad/sec]
ρ	Oil density	[kg/m^3]

2.1 Abbreviations

A, B	Working lines
p	Supply pressure line
T	Tank return line
PDFCV	Proportional directional flow control valve

3 Objective

This investigation presents a study of the effect of proportion-

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al directional flow control valve on the performance of a rotational hydraulic control system under different operating conditions.

4 Overview of the Experiment System Description

The experiment is conducted using the hydraulic control system shown in Fig. 1. The system has been designed in order to provide a rotational movement. The system contains a fluid power supply unit, a 4/3 proportional directional flow control valve, and hydraulic motor. Operating conditions; pressure and loading values are varied. Heating and cooling units are designed in order to keep system temperature constant. The output signals are recorded by 4 channel recorder/logger plus computer. Electrical signal is supplied to the proportional directional flow control valve from a DC power supply through electric switch. The switch was used to get the required forward and backward rotational movement of the rotor of the hydraulic motor**.**

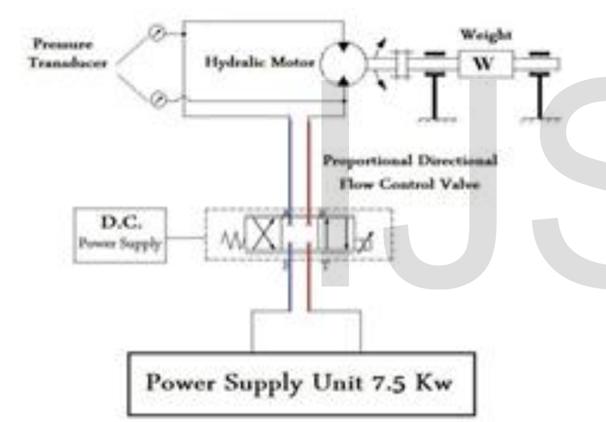

Fig. 1 Hydraulic circuit of fluid power control system

4.1 Calibration of Flow Rate through PDFCV

The flow rate of the system is calibrated using bucket and stop-watch technique. Measuring the output flow rate of the nozzles of PDFCV could be calculated according to Bernoulli equation (1). The results at different operating supply pressure are recorded then plotted in Fig. 2. A Schematic drawing of proportional directional flow control valve circuit is shown in Fig. 3.

$$Q_n = C_d A_n \sqrt{\Delta p / \rho} \qquad (1)$$

Where:
C_d = discharge coefficient.
A_n = nozzle flow area; [mm^2].
Δp = pressure difference through valve opening; [bar].
ρ = oil density; [kg/m^3].

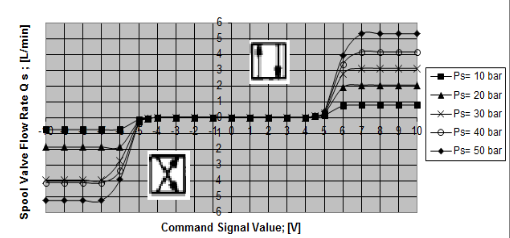

Fig. 2 Calibration curve of the flow rate versus the input electrical signal for PDFCV.

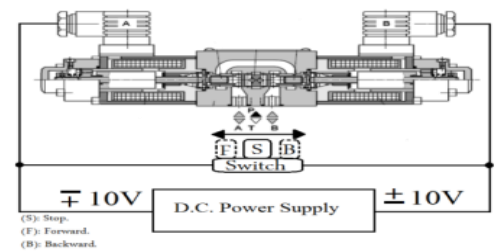

Fig. 3 Signal control of operating and opening of PDFCV.

5 Experimental Procedure

The experiments are conducted using the hydraulic fluid power control system shown in Fig. 1. Various test analysis and experimental evaluations are conducted in order to investigate the performance of the hydraulic motor connected to the proportional valve in the hydraulic control system.

The torque and speed of the rotor of the hydraulic motor, accordingly the flow rate, has been experimented under different values of operating variables. Practical experiments have been done under no-load. Then, the system has been loaded by 2003, 3093 and 4128 N. Supply pressure has been changed from 10 to 50 bar. All experiments are conducted at temperature value of 38°C.

6 Results

Firstly, the actual values of supply pressure (p_{sa}) in the fluid power control system with connecting proportional directional flow control valve in order to control the rotational movement of hydraulic motor, has been extracted from the experimental records and plotted in Fig. 3 for 100 % valve opening under free-load and for 4128 N load value. According to the analysis of system supply pressure, there is no significant change in the case of low pressure, but at high pressure values, there is slight change.

That is, the greater the value of the pressure and load significant change in the value of actual supply pressure is noticed.

Secondly in order to investigate the effect of load on system dynamics, it is necessary to calculate torque values from equations (2, 3, 4) under different load values at T=38°C.

$$Q = n \times V_m \qquad (2)$$
$$\omega = (2 \times \pi \times n)/60 \qquad (3)$$
$$T = (p_1 \times Q)/\omega \qquad (4)$$

Where;
Q flow rate of hydraulic motor

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n speed of rotor
V_m hydraulic motor displacement
ω angular frequency of rotor
p_1 inlet pressure to hydraulic motor
Ţ torque generated on hydraulic motor rotor

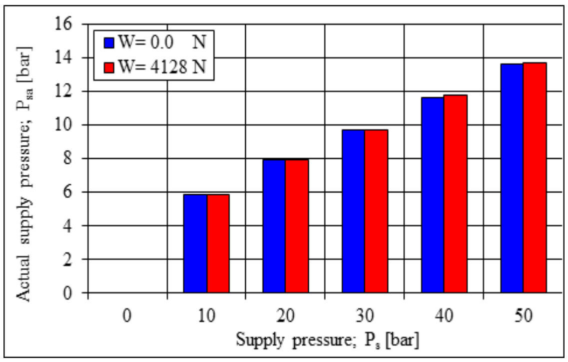

Fig. 3 Supply pressure analysis under free-load; W = 0.0 N and under 4128 N.

Experiments have been conducted in case of free-load, 2003 N, 3093 N and 4128 N. The minimum and maximum loads are only reported for different supply pressure values; p_s = 10, 20, 30, 40 and 50 bar. Results have been registered manually then plotted in Fig.4.

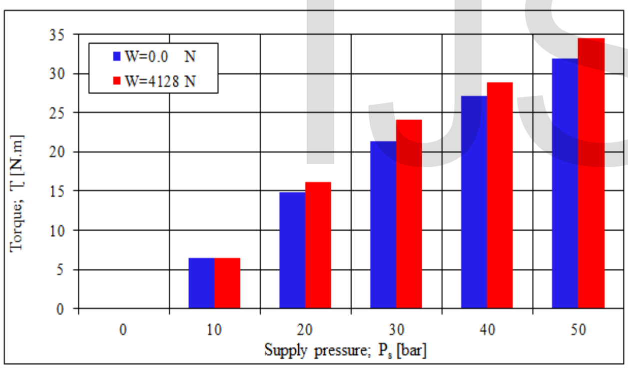

Fig. 4 Variation of torque versus supply pressure; p_s under free-load; W=0.0 N and W=4128 N.

Also, in order to investigate the effect of load on the speed; n and flow rate; Q, experiments have been conducted under the same conditions. Results have been registered manually then plotted in Figs. 5 and 6 respectively.

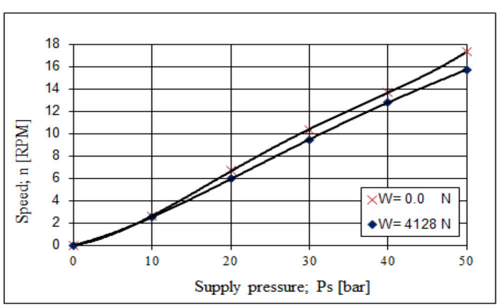

Fig. 5 Variation of speed; n versus supply pressure; ps under free-load; W=0.0 N and W=4128 N.

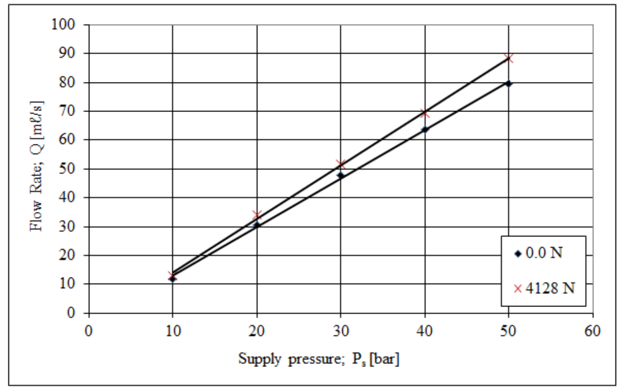

Fig. 6 Variation of flow rate; Q versus supply pressure; p_s under free-load; W=0.0 N and W=4128 N.

6 Evaluations and Discussions

The experimental results have been evaluated in order to investigate the effect of variation of operating conditions on system characteristics in case of connecting the proportional flow control valve.

System dynamic performance is represented by the effect of loading on system rotational movement according to torque generated on hydraulic motor rotor, speed and flow rate. Effects of loading on system dynamics are plotted in Figs. 7, 8 & 9 respectively.

The analysis indicates a maximum percentage of increasing torque value as 11.71 % with the increase of load at ps equal 30 bar. The minimum percentage is 0.93 % at 10 bar. On the contrary, increasing the load decreases the values of speed of rotor. The maximum decrease percentage is 10.71 % at p_s equal 30 bar and the minimum decrease percentage is 3.84 % at 10 bar. Fig. 9 shows that the flow rate decreases with increasing of load from free-load up to 4128 N. The maximum decrease percentage is 10.05 % at p_s equal to 10 bar, and the minimum decrease percentage is 5.025 % at 50 bar.

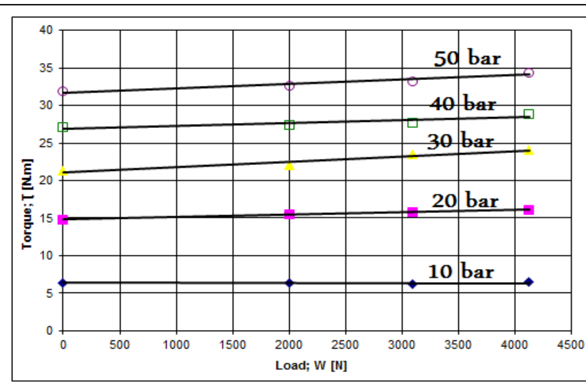

Fig 7 Variation of system torque; Ţ versus increasing of load up to 4128 N for different supply pressure values with PDFCV system

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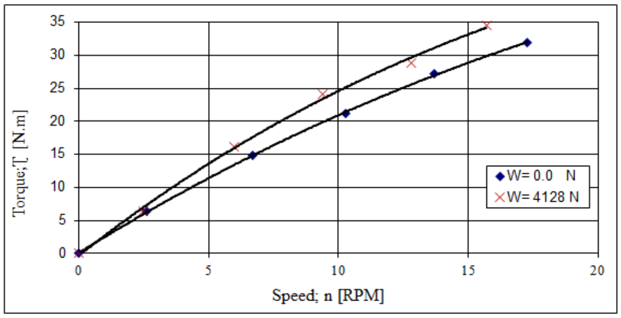

Fig. 8 Variation of rotor speed; n versus torque; Ʈ at different system loading

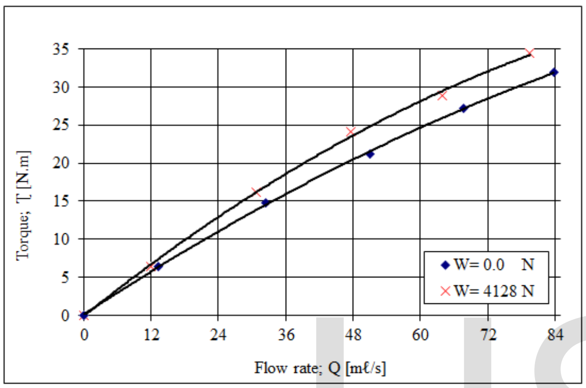

Fig. 9 Variation of generated torque; Ʈ versus flow rate; Q at different system loading

4 Conclusions

Studying the performance of mechanical fluid power control system with connecting a proportional directional flow control valve in rotational hydraulic movement system under different conditions, the following conclusions are achieved:

1- Using high technique for measuring and recording of system variables achieves accurate results.

2- System dynamic performance is represented by the effect of loading on system rotational movement, according to generated torque, on hydraulic motor rotor, speed and flow rate. It indicates increasing of torque values with the increase of load. On the contrary, increasing loading system decreases the values of speed of rotor, angular frequency; ω and flow rate; Q.

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