International Journal of Scientific & Engineering Research Volume 13, Issue 7, July-2022
ISSN 2229-5518

INVESTIGATION OF THE VALVE CONTROL PRESSURE AND CURRENT IN AN ELECTRO-PNEUMATIC CLUTCH ACTUATION SYSTEM

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Abstract

The linear movements of the piston in an actuation process are controlled by valves. The inlet valve ensures that pneumatic force is allowed in the actuation chamber resulting in the forward motions of the piston on one hand while clutch spring actions on the other hand pushes out air through the exhaust valve during the reverse motion of the piston. Both the opening of the inlet valve and the closing of the exhaust valve and vice versa at alternate cycles are functions of the valve control current. The valve controllers are accomplished by the electrical control unit. The electrical power required to open and close the inlet and outlet valves and the corresponding mechanical pressure for valves opening and closing are studied by empirical and analytical processes. The knowledge of these parameters is essential in the study of clutch actuation process in heavy duty vehicles. The investigation was done with a Mercedes Benz Actros Truck Model MP 2, 2031 actuator valve controller, whose spring was removed and subjected to test in a laboratory with mass spring and related apparatus. The spring thickness, coil width, number of turns and compressive forces under varying weights were determined and subjected to analysis. The result showed that the mechanical pressure on the valve spring is 191.529 bars while the electrical power and current demand of the valve controller are 1.96 watts and 82 milliamps respectively.

Key Words: Actuation, Controller, Electro-Pneumatic, Experiment, Pressure, Valve.

1.0 Introduction

In an electro-pneumatic clutch actuation system, the pneumatic input that initiates linear movement of the piston in an actuator is controlled by a valve (Barma & Huba, 2015). The reverse or backward motion of the piston as a result of clutch spring actions pushes out air through the exhaust valve. Both the opening of the inlet and the closing of the exhaust valves respectively and vice versa are also controlled sequentially. These valves controllers are accomplished by means of an electrical module popularly referred to as an electrical control unit (Langjord & Tor, 2011). The electrical control module is saddled with the responsibility of controlling the valves during actuation process. The electrical control signal can be turned on

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by either an on/off switch, magnetic solenoid/relays, proportional controllers or by other conventional electrical circuit control methods. The function of the ECU is to control the inlet/supply and outlet/exhaust valves and hence allow air flow to and from the actuator chamber of the pneumatic system. The pneumatic system is made up of a compressor, a supply/inlet valve and the exhaust/outlet valve. The compressor is the source of the pressurised air. The supply/inlet valve is the orifice through which pressurized air is supplied into the actuator while the exhaust/outlet valve provides an avenue through which a retuning air as a result of reverse motion of the actuator piston due to spring action is let off the system. The actuator is a chamber or cylinder like object which is used to enclose the piston rod and spring. Figs. 1 and 2 are the valve controllers.

Fig. 1: Valve in chamber

Fig. 2: Valve controller

In order to establish the amount of electrical power needed to accomplish this task of the control valve, it becomes important to determine the amount of pressure exerted by electrical control unit in switching or pushing up the control valve for the opening of the supply valve/port line and closing or pushing down the control valve to open the exhaust valve/port line and vice versa during clutch actuation. Thus, the valve controller is pushed up or down for the inlet and outlet pneumatic channels to be on and off alternately in response to clutch engagements and disengagements needs during actuation processes (Johnston & Johnson 2012). The knowledge of the valve control pressure and current in an electro-pneumatic clutch actuation system is essential in the study of clutch actuation process in heavy duty vehicles. Often, it is not easy to determine the electro-mechanical force and power to accomplish this control task by direct measurement. Experimental approach provides a way out.

2.0: Methods.

Empirical research design method was adopted. Experiment was carried out on an actuation chamber of Mercedes Benz Actros Truck model MP 2, 2031 truck.

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1. Meter Rule was used to measure free lengths of the Valve Control Coil or Spring and displacements in the free lengths of the coils as weights or loads of twenty grams are added incrementally.
2. Mass Spring Balance System was used to measure the control valve spring compression with respect to applied force or weight. This weight or force approximated to the force required to fully open and collapse the valves springs inlet and outlet pressures as it is done during actuation process.
3. Venire Callipers were also used for the measurement of the diameter and thickness of the control valve coil.

In this manner, data for Control Valve Parameters were obtained through measurement and tabulated in table 1.

Table 1: Measured parameters

S/N	Parameters	Readings
1	Valve coil diameter (D)	1.435cm
2	Valve wire diameter or thickness (d)	0.165cm
3	Control valve diameter or port (Dc)	2.865cm
4	Valve coil free length (L_f)	1.94cm
5	Number of coils in the Valve (N)	5
6	Control Valve voltage (V_{CV})	24V

The pictorial views of the experimental set up are shown in Figures 3.

Fig. 3: Pictorial views of the experimental set up.

3.0: Experimental Design, analysis and results.

The data obtained in the mass spring experiment is fundamental in the analysis that will yield the derived parameters. The data is shown in table 2.

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Table 2:The mass/spring compression of Valve coil experiment.

Force/weight (N)	Free Length, L_f (cm)	Length Variations, L_i (cm)	L_f-L_i (cm)
0	1.94	1.94	0
20	1.94	1.82	0.12
40	1.94	1.63	0.31
60	1.94	1.46	0.48
80	1.94	1.25	0.69

Column 1 and 4 are used to plot the graph of figure 3. The graph is also critical to the subsequent analysis that follows which will ultimately lead to the derivation of the required parameters.

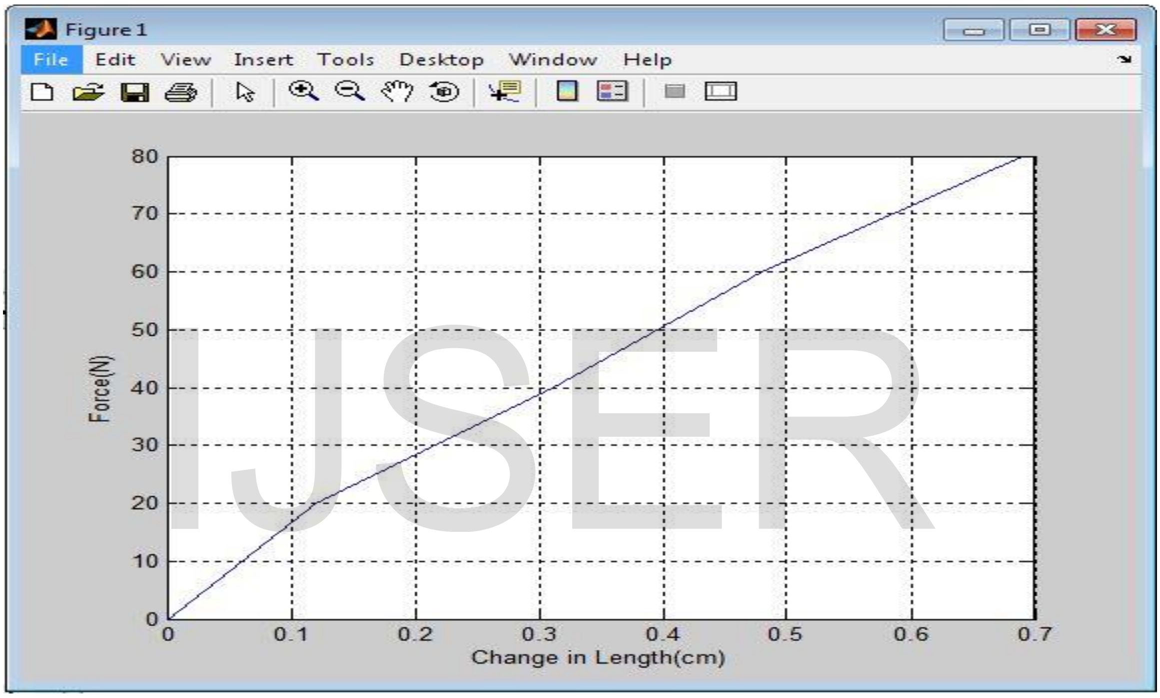

Fig. 4: Graph of Force/weight (N) and change in length {L_f-L_i} (cm).

According to Budynas and Nisbett (2011), Solid length of spring (Ls) is defined as

$$\boldsymbol{Ls} = d(N+1) \quad (1)$$

Where d) is Valve wire diameter or thickness

Substituting, $Ls = 0.165\ (5+1) = 0.99cm$

Maximum deflection, (Δ_L) *is defined as*

$$\Delta_L = L_f - L_s \quad (2)$$

Substituting, $\Delta_L = 1.94 - 0.99 = 0.95cm$

The graph of fig. 4 shows the relationship between force applied on the control valve coil and resultant change in length which the valve coil undergoes during switching the valves to control the inlet and outlet ports for supplying pneumatic pressure and exhaust same at the relevant

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periods. The maximum force required to compress the spring is relevant in knowing the force, pressure and power requirements of the valve controller.

From the graph (fig. 4), the slop of line AB was determined where A= $(x_1, y_1) = (0.4, 51)$ $and\ B = (x_2, y_2) = (0.3, 38)$.

By applying the mechanics of spring materials standard analysis for springs under tensile or compressive stresses (Budynas and Nisbett, 2011),

Spring Rate $k = \frac{\Delta W1}{\Delta L1} = \frac{\Delta W2}{\Delta L2}$ (3)

Or $w_2 = k\Delta L_2$ (4)

$k = \frac{\Delta W2}{\Delta L2} = Slope\ of\ line\ AB$ (5)

$Slope\ of\ line\ AB = \frac{51-38}{(0.4-0.3)X10^{-2}} = \frac{13\ x\ 10000}{0.1} = 1300\ x\ 10^3 N/m$.

Maximum force to deflect and collapse the spring w_2 or Wvc max.

w_2 = Wvc max= $K\Delta L$ (6)

$K\Delta Ls = 1300\ x\ 10^3 N/m\ x\ 0.0095m = 12.35\ x\ 10^3 N$

Diameter of the control valve or port (Dc) = 2.865cm

Pressure on the valve control or port,

Pc= $\frac{Force}{Area}$ (7)

Pc $= \frac{12.35\ x\ 10^3}{\frac{\Pi Dc^2}{4}} = \frac{\frac{12.35\ x\ 10^3 x4x10000}{\Pi x2.865x2.865}N}{m^2} = \frac{\frac{49.4\ x\ 10^7}{25.790243}N}{m^2} = \frac{1.91529\ x\ 10^7 N}{m^2}$=$191.529\ x\ 10^5 N/m^2 =$ 191.529 bars.

For a mechanical system, Energy (E) or work done (W) by the valve as it opens and closes is defined by force (F) multiplied by linear distance(ΔL) or force(F) multiplied by speed (s) and time(t).

Mathematically, $E = W = Fd = F\ x\ s\ x\ t$ (8)

Given $Force\ (F) = 12.35\ x\ 10^3 N\ and$

Maximum deflection of Valve spring, $\Delta L = 0.95\ x\ 10^{-2} m$

Substituting we have

$E = 12.35\ x\ 10^3 N\ x\ 0.95cm = 12.35\ x\ 10^3 N\ x\ 0.95\ x\ 10^{-2} m = 117.325Nm.$

Power (P) = $\frac{E}{t} = \frac{117.325}{6o} Nms^{-1} = 1.96\ watts.$

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For an electrical system, Energy (E) or work done(W) by the valve controller in switching on and off of the valve is the same as the mechanical energy. The power dissipated is the same as 1.96 $watts$.

The standard current and voltage rating of the truck's battery is 75 ampere/hour and 24 volts respectively. Thus,

the electrical current $I = \frac{P}{V}$ (9)

$I = \frac{1.96}{24} = 0.082\ Amper\ or\ 82\ milliampers.$

Hence the battery current ignites the solenoid or relays which increases the power to the required level that turns on the controller.

The derived parameters are presented in table 3

Table 3: Derived parameters

S/N	Parameters	Readings
1	Valve coil solid length (Ls)	0.99cm
2	Valve coil maximum deflection (Δ_L)	0.95cm
3	Control Valve pressure (V_{CP})	191.529 bars
4	Control Valve current (V_{CI})	82 milliamps
5	Control Valve power (V_{CP})	1.96$watts$

4.0 Conclusion

The study of the valve control parameter of an electro-pneumatic clutch actuation system via experimentation and analysis were aimed at understanding the physical dynamics of the actuation process. It reveals both the measured and derived parameters. The study showed that the Valve coil diameter (D) was 1.435cm while the Valve wire diameter or thickness (d) and Valve coil free length (L_f) were 0.165cm and 1.94cm. It also showed that the Valve coil solid length(Ls) and valve coil maximum deflection (ΔL) were 0.99cm and 0.95cm too. Control Valve diameter and resulting pressure (V_{CP}) gave 2.865cm and 191.529 bars respectively. The study also produced the Control Valve current (V_{CI}) as 82milliamp while Control Valve voltage (V_{CV}) and power (V_{CP}) were 24 volts and 1.96 watts respectively. These data are essential for the electrical control module to effectively perform the control functions of opening and closing the valves for adequate actuation process of an electro-pneumatic clutch actuation system especially in a heavy-duty truck.

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ISSN 2229-5518

5.0 Acknowledgement

I wish to acknowledge the critical contributions of the Management and Staff of Tetralog Nigeria Limited Enugu, for permitting me to use their factory and providing the test truck, Mercedes Benz Actros Truck model MP 2,2031 for the field research. In this respect, my special thanks go to the Managing Director, Engr. Onuora Nnabugo and His team of Staff including the Service Manager- Engr. E. Obielika, the Assistance Service Manager Engr. D. Gitau and the Training Manager – Mr. C. Nwinyi. My gratitude goes to the field staff; made up of Mr. J. Nwachukwu, Mr. M. Ogbonna and several others for their humility and untiring commitment to this project. Worthy of mention here too are the contributions of Engr. G. U. Ezeatu of ANAMMCO Enugu and Engr. Amasha Olakunle of Innoson Industries Limited, Enugu. Engr. Dr. J. Osibe, Engr. O. Nwoke, and Mr. R. Iduma, all staff of Akanu Ibiam Federal Polytechnic Unwana, for allowing me to use their Strength of Materials Laboratory for the study. My colleagues; Engr. Dr. I.U. Mbabuike, Engr. A.E. Abioye, Mr. J. E. Arua, and Mr. N. Onwuka deserve my thanks for their criticisms and support too.

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