EFFECT OF HYDRAULIC ACCUMULATOR ON THE SYSTEM PARAMETERS OF AN OPEN LOOP TRANSMISSION SYSTEM

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Abstract

This paper denouements the study of operating parameters of a hydraulic transmission system with and without the application of hydraulic accumulator. In this respect, the hydraulic system, designed in the open circuit mode, consists of the fixed displacement hydraulic pump which gives pressured fluid to the hydro-motor and charges the accumulator as well. The load on the motor is controlled hydraulically by coupling the motor with the loading pump, which discharges the fluid through the Pressure Relief Valve (PRV). The pressure decay of the accumulator in the hydraulic system has been analysed and the parameters affecting the pressure decay has been sorted out. The effect of pressure damping in the hydraulic system has also been investigated for different sizes of accumulators under different loading conditions. The proposed hydraulic system is modelled using MATLAB-SimHydraulics software. The study concludes with the identification of some major operating parameters which affects the performance of the Bladder type Accumulator.

1. Introduction

Hydraulically driven systems are a drive or transmission system that uses pressurized hydraulic fluid to drive hydraulic machinery. The open circuit and closed circuit hydrostatic transmission system have now became a subject for analysis based on its performance and suitability in Heavy Earth Moving Machineries (HEMM) industries. Hydrostatic Transmission Systems are considered to be the most efficient energy saving system now-a-days. Their response to system performance is very fast and precise. Efficiency of the main power source can be improved by HST system. Also, the HST system is energy regenerative and under partial loading conditions, the system is highly efficient. A hydraulic accumulator can be added to the HST circuit to improve the efficiency of the system in low-speed, high-torque situations. The accumulator can also be used to recover the kinetic energy without making the fluid flow reversion.

In all fluid power applications as Hydrostatic Transmission (HST) system, pumps are used to generate the required power to run the hydraulic motor in a hydraulic system [1]. The pumps deliver this power in a pulsation of fluid flow. The piston pump, as commonly used for higher pressures, tends to produce pulsation detrimental to a high pressure system [2]. The periodical pulsations of liquid dynamically damage the elements in the hydraulic system and reduce the service life causing significant sound sources [3]. The amplitudes of pressure pulses in the hydraulic circuit can be reduced by using accumulator of appropriate capacity with properly located in the system otherwise if the amplitudes of pulsating pressure increase remarkably; it may lead to the system failure. Accumulators act pulsation absorbers and surge absorber caused by rapid operation or sudden opening and closing of valves in a hydraulic circuit [4].

Nomenclature

\(V_f\) : Volume of fluid flow in accumulator
\(P_f\) : Fluid pressure in accumulator
\(P_1\) : Initial Pre-charge pressure of accumulator
\(P_2\) : Maximum system pressure of hydraulic system
\(P_3\) : Minimum working pressure of hydraulic system
\(V_1\) : Initial volume of gas in hydraulic accumulator
\(V_2\) : Volume of gas during fully charged(compression)condition of hydraulic accumulator
\(V_3\) : Volume of gas during discharge(expansion)condition of hydraulic accumulator
\(\Delta V\) : Change in velocity
\(a\) : Speed of sound
\(\beta\) : Bulk modulus of fluid
\(\rho\) : Fluid density
\(\gamma\) : Isentropic coefficient
Hydraulic accumulator stores the energy of the fluid by compressing the spring used in piston type accumulator or gas in bladder type accumulator. The gas accumulators are mostly used in mobile equipment where an elastic diaphragm separates gas and fluid working environment. The accumulators use nitrogen to keep the hydraulic fluid pressurized. When the fluid is flow into an accumulator, the nitrogen ($N_2$) inside the accumulator is compressed by reducing its volume.

The accumulators are based on the principle that gas is more compressible than mineral oil, used in the hydraulic system. Energy is stored by the volume of the hydraulic fluid that compresses the gas under pressure. If the fluid is released, it will flow out quickly, under the pressure of the expanding gas. The rate at which the compression and expansion of the gas takes place affects the gas state – which is defined by volume, pressure and temperature [5].

A hydraulic system is considered energy saving if it will have the following capabilities. First, it must improve the efficiency of the power source of the system or next, it must be a regenerative system to recover energy during degeneration or while the load is lowered. An energy saving HST system using accumulator was investigated through analysis and modelling [6].

### 2. Physical model of hydraulic system

The present study deals with the surge absorbing characteristics of a hydraulic accumulator. For this purpose, an open loop hydraulic system is considered which has some basic hydraulic components as shown in fig. 1. The hydrostatic system consists the variable speed electric motor (1) which gives variable mechanical power to the variable displacement pump (2). The pump gives pressured flow to the hydraulic motor (5) through the check valve (3). An accumulator (4) is used at the suitable location of the system, where availability of surge is maximum. To generate fluctuating load to the hydraulic system, a loading pump (6) is mechanically connected with the hydro-motor; the loading pump gives flow to the PRV (7). The load at the motor is adjusted by adjusting the set pressure of the PRV.

The hydraulic accumulator is installed in between them to absorb pressure pulsation and shock. Also, it stores potential energy from the surge, which will be used during emergency condition. The surge in the system may come from the pulsating flow or the fluctuating load [7]. For instance, with a five cylinder piston pump there will be five pulsations per revolution which is unimportant. However, an external disturbance is introduced in the system, through the electric motor, to generate the surge in the present system. Accumulator positioned upstream of the pump acts as a pulsation damper.

![Fig. 1. Physical system of open-loop hydraulic accumulator](image)

The main theme of this paper is to find out the suitable size of accumulator which will give less pulsation as pulsation cannot be removed by 100% but can be filter to negligible level. The amount of pulsation absorb is also a function of pre-charge pressure.

The specifications of the components used in the simulation of the Hydrostatic System (HST) system are tabulated in the table shown below:

<table>
<thead>
<tr>
<th>Component parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement of hydraulic pump</td>
<td>19.8</td>
<td>Cc/rev</td>
</tr>
<tr>
<td>Displacement of hydraulic motor</td>
<td>12.0</td>
<td>Cc/rev</td>
</tr>
<tr>
<td>Displacement of loading pump</td>
<td>11.0</td>
<td>Cc/rev</td>
</tr>
<tr>
<td>Valve pressure setting</td>
<td>50.0</td>
<td>Bar</td>
</tr>
</tbody>
</table>

### 3. Principle of operation

The bladder type accumulator consists of a synthetic polymer rubber bladder like chloroprene, nitrile, etc. inside a metal (steel) shell. The bladder is filled with compressed gas. A poppet valve located at the discharge port closes the port when accumulator is completely discharged. This keeps the bladder from getting out into the system. The main advantage of bladder type accumulator is that it responds quickly for receiving and expelling oil flow of oil [8]. It has lighter weight, lower cost, and compactness. The gas usually nitrogen is pre-charged during empty of hydraulic fluid and it should never be less than $\frac{3}{4}$ th of the working pressure [9]. Nitrogen is used due to non-poisonous, not combustible and does not combine easily with other element i.e. inert. The initial pre-charge gas pressure $p_1$ is normally 90% of the minimum working pressure $P_3$ of the hydraulic system. This is to prevent the accumulator bladder constantly closing the anti-extrusion check valve. The maximum system pressure $P_2$ is the fluid pressure when the accumulator is fully charged. $P_2$ should not be greater than 3 times the minimum working pressure or the elastomeric material of the bladder may be damaged.
4. Modeling of accumulator

Accumulator is a storage vessel and have significant role in hydraulic system. When the system pressure is greater than pre-charge pressure than gas is compressed and oil is flow in accumulator. If the process of variation is slow it is considered as isothermal compression otherwise it can be considered as adiabatic.

\[ P V_1^γ = P V_2^γ \]  
\[ V_2 = V_1 \left( \frac{P_1}{P_2} \right)^{\frac{1}{γ}} \]  
Volume of fluid flow in accumulator, 
\[ V_f = V_1 - V_2 \]  
\[ V_f = V_1 \left[ 1 - \left( \frac{P_1}{P_2} \right)^{\frac{1}{γ}} \right] \]  
Fluid flow rate in accumulator,
\[ Q = \dot{V}_f = 0.714 V_1 P_1^{0.714} P_2^{-1.714} \dot{P}_2 \]  
Assumption: Hydraulic accumulator works as quasi balanced process. Then,
\[ \dot{V}_f = 0.714 V_1 P_1^{0.714} P_2^{-1.714} \dot{P}_f \]  
\[ Q = \dot{V}_f = \begin{cases} 0.714 V_1 P_1^{0.714} P_2^{-1.714} \dot{P}_f & \text{if } \frac{P_1}{P_2} < 1 \\ 0 & \text{otherwise} \end{cases} \]  

5. Simulation of hydraulic circuit

The proposed hydrostatic system is modeled in MATLAB with sim-hydraulics. The hydraulic system consists of basic components like hydraulic pump connected with a variable angular velocity source. The output of sine wave is given to variable angular velocity source to introduce the pressure surge in the system. A PRV is set across pump for system safety to relief excess pressure of system. The upstream pressure comes in the form of pulsation which is sensed by pressure sensor. A flow sensor is also installed to check flow ripple. The hydraulic motor is run by the pressurized fluid. The load on motor shaft can be varied by varying PRV setting of loading pump. Accumulator is installed between the pump and motor to absorb pressure pulsation. Simulation have been performed by taking consideration of various parameter such as pump displacement, motor displacement, volume of accumulator, PRV setting etc.
prepared to find out how much pulsation is reduced for a given accumulator capacity, pre-charged pressure and also to find out the time to which accumulator will be able to run the motor.

6. Results and discussion

The simulated system is run for variable speed of the pump drive. The surge absorbing characteristic of the accumulators are plotted and shown in the current section.

![Fig. 4. Reduction of pressure pulsation using accumulator of different capacity at 70 bar pre-charge pressure](image1)

![Fig. 5. Enlarge view of pressure pulsation using accumulator of different capacity at 70 bar pre-charge pressure](image2)

![Fig. 6. Reduction of pressure pulsation using accumulator of 10L capacity at different pre-charge pressure](image3)

Fig. 4 represents the pulsation absorptivity of the accumulators as function of its size. It is observed that the small capacity accumulator absorbs the surge quickly while a time lag is observed as the size of the accumulator is increased. The enlarged view of the surge characteristic is shown in fig. (5). Study on the surge characteristic as function of pre-charge pressure

![Fig. 7. Reduction of pressure pulsation using accumulator of 20L capacity at different pre-charge pressure](image4)

![Fig. 8. Speed decay of motor with different capacity accumulator when discharge in emergency condition at 50 bar loading pressure](image5)

![Fig. 9. Speed decay of motor with different capacity accumulator when discharge in emergency condition at 60 bar loading pressure](image6)

The pressure surge characteristics in the hydraulic system with and without accumulators are shown above. It is observed that keeping the system pressure at 75 bar, the pre-charge pressure plays a vital role in surge-damping characteristic of the system. It is observed that lesser pre-charge pressure increases the time lag due to flow of fluid in the accumulator and much higher pre-charge pressure reduces the capacity to absorb the shock. It is found that if we are keeping accumulator at 80 bar pre-charge pressure and pulsation is around 84 bar then pressure pulsation is absorbed by accumulator in between 80-84 bar. Also, the discharge characteristics of the accumulator are shown in figs. (8) and (9), which indicates the response and energy storing capacity of the different accumulators at different pressures.
loading. It is found that when accumulator is discharged during emergency condition it runs the motor. The motor speed decrease with more rapidly in 10L accumulator compared to 20L accumulator and also the time to which it run the motor is also less in 10 L accumulator as shown in fig.8. Also as the pressure setting of PRV i.e. loading pressure increases the motor running speed decreases with increase in time to which motor runs as shown in fig.(9).

7. Conclusion

From the study carried out, it is obvious that the small size accumulator shows the quicker response in minimizing the pressure surge as compared to the large size accumulators. However, the energy stored and the discharge characteristic of large size accumulator is much better as compared to the smaller accumulator. It is clear from the above results that accumulators in the circuit absorb pressure surge within the circuit with certain limitations. Hence, the determination of the size of the accumulator for its multi-purpose use needs to be optimized. Also, the pre-charge pressure of the accumulator should be kept at the 90% of its discharge pressure. Hence to make the system stable and lifelong, the optimum sized accumulator should be used at optimum pre-charge pressure (near about system operating pressure). Also, in real system, we can choose the size of the accumulator by running the simulation program developed in this paper and by observing the surge absorbing characteristics of different size accumulators.

The future scope of this work will be to analyze the energy stored in the accumulator owing to pressure surge which needs both simulation and experimentation work, to be carried out.

Acknowledgements

The authors are thankful to the representative of Parker Hannifin India Pvt. Ltd., Kolkata, for their help in fabricating the Test set up. Authors would like to acknowledge the staff members of the department for their help in carrying out the research work.

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