STEADY STATE PERFORMANCE ANALYSIS OF HYDROSTATIC TRANSMISSION SYSTEM (HST)

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Abstract: Starting from introduction of hydrostatic transmission system(HST), the open circuit and closed circuit hydrostatic transmission system becomes great subject for analysis of its performance and its suitability in HEMM industry. This paper denouements the analysis of open circuit and close circuit hydrostatic system for energy saving purpose. The comparison between both hydrostatic circuits has been presented with the help of performance analysis based on their efficiency. These analysis is performed on MATLAB-simulation. This paper extracts the idea of hydraulic system design without generating prototype set-up under various variable condition. This helps in analyzing at what point or condition system may fails and provides way to reduce it resulting high energy efficient system. This paper also discuss the basic functions of components used in the both HST circuit.

Keyword: HEMM, open circuit & closed circuit HST system.

Notation

\[D_m = \text{Motor displacement}, \quad \eta_m = \text{Motor speed}\]

\[P_m = \text{Pressure difference across the motor}, \quad T_m = \text{Theoretical output torque of motor}\]

\[R_L = \text{Load}, J_L = \text{Load inertia}\]

\[Q_p = \text{Actual flow rate through pump}, \quad \alpha_p = \text{Displacement angle of swashplate}\]

\[\eta_p = \text{Pump volumetric efficiency}, \quad \eta_v = \text{Motor volumetric efficiency}\]

I. INTRODUCTION

Hydrostatic transmission drives are widely used in HEMM and construction equipment for better control, low weight per unit power consumption, compactness. Generally these equipment requires Low Speed High Torque (LSHT) characteristics. It is necessary to have good low speed characteristics without using reduction gear unit and also have a high output torque throughout its range. In order to improve the performance of the LSHT, the detailed analysis of performance of such systems are essential to make them more suitable for present requirements. The typical efficiency for a hydraulic pump or motor is only 85%. The overall efficiency for a very simple pump-controlled hydraulic system under ideal operating conditions is about 70% [Cundiff, 2002]. It may differ for different circuit design and component used. It is providing a research field in hydraulic system design to a great extent.

HST is the conversion of mechanical energy to hydraulic energy using pump driven by a prime mover, supplies pressurized fluid to a utilization point, and its conversion back to mechanical energy by drive a hydraulic motor (fig.1), which in turn, drives a load connected to its shaft. Two parameters, torque (T) and speed (N), are converted to two different parameters, pressure (P) and flow (Q), using a pump. The two new parameters, P and Q are converted back to torque (T) and speed (N) using a hydraulic motor. The principal reason for converting to fluid power is the convenience in transferring energy to a new location. The pressurized fluid, defined by the P and Q Parameters, easily flows around corners and along irregular pathways before reaching the point where it is reconverted to T and N. The product of T and N is called mechanical energy and the product of P and Q is called hydraulic energy. The HST system can provide smooth change of output speed, output torque and hence output power according to the design requirements. If the displacement of the pump and the motor are fixed, the HST system simply acts as a gearbox to transmit power from the prime mover to the load. The majority of HST systems, however, use a variable-displacement pump and a fixed displacement motor or both pump and motor may be of variable displacement type so that, speed, torque or power can be suitably regulated.

Therefore, the performance analysis of hydrostatic drive is important to establish the design guidelines based on the operating parameters of the major components of the system. From the accurately predicted performance of the HST system, the best combination of available components can be selected without building a series of prototype to obtain
experimental data for comparison. The data regarding the characteristics of pump and motor, the major components of the system, are required to predict the overall performance of the HST system. The performance of the system depends on the operating parameters of the system such as pump speed, load torque and supply flow rate. The characteristics of various loss coefficients of pump and motor may be obtained experimentally. Using them for given load torque and pump speed, the efficiency of the hydrostatic drives can be predicted.

There are two types of hydraulic systems mainly used, discussed below:

II. OPEN CIRCUIT HYDRAULIC SYSTEM

The open circuit mainly consists of a hydraulic reservoir, pressure compensated variable displacement in-line piston pump, radial piston motor, proportional pressure relief valve. In this the output from the motor goes to the hydraulic reservoir. This experimentation was performed by Dasgupta K. et al [1], in which he analysed the performance of hydraulic system as function of load and torque.

![Fig.2. Schematic of a open circuit HST system](image)

The simple arrangement of open-circuit hydraulic system is shown in fig.2. In this circuit the electric motor work as a prime mover and drives the variable displacement pump. The fluid from the tank goes to the bidirectional motor through hydraulically actuated 4/3 directional control valve. A load (R_L) with load inertia (J_L) is coupled with motor shaft. The fluid from the outlet of motor directly goes to the tank. A pressure relief valve is also used for safety purpose. If the pressure at the inlet side of the motor exceeds or equals to the setting pressure of relief valve, the valve opens and all fluid goes to the tank through pressure relief valve to prevent the damaging of motor, otherwise valve remains closed as shown in the fig.2. Internal leakage is also shown in the arrangement of open circuit HST system.

III. CLOSE CIRCUIT HYDRAULIC SYSTEM

This circuit consists of a hydraulic tank, axial piston swash plate controlled variable pump and rest components are same as in open circuit hydraulic system. The simple arrangement of closed-circuit hydraulic system is given below:

![Fig.3. Schematic of a closed circuit HST system](image)

This hydraulic circuit consists of two circuit; one is main circuit and another one is charge or make-up circuit.

The main circuit consists of a prime mover, one bidirectional variable displacement pump, one bidirectional fixed displacement motor, four check valves, and load(R_L) with load inertia (J_L) and two pressure relief valves. The charge circuit consists a make-up pump.

The fluid in main circuit recirculates from main pump to motor and from motor to main pump. Both the main pump as well as the make-up pump are driven by a single prime mover. But generally the capacity of make-up pump is 20% the capacity of main pump. The make-up pump is used to replenish the reduction of fluid due to internal leakage and some fluid is removed time to time for cooling purpose.

Mathematical Calculation

Efficiency of motor is calculated as :

\[
\text{Volumetric efficiency, } \eta_v = \frac{\dot{m}_m}{Q_m} \quad \text{(1)}
\]

Torque or mechanical efficiency, \( \eta_m \) = \( \frac{\dot{m}_m P_m}{T_m} \quad \text{(2)} \)

Total efficiency of motor = \( \eta_v \times \eta_m \quad \text{(3)} \)

If angular velocity of the pump shaft is kept constant, the pump flow rate can be adjusted with variable displacement pump via the swash plate displacement angle and can be given as:

\[
Q_p = \alpha k_p \theta \quad \text{(4)}
\]

Assumption that pump volumetric efficiency does not depend on pump rotation angle.

Experimental Procedure

For calculating the motor efficiency of open circuit and close circuit system the following test setup model is created in Matlab and thereafter simulation is done. Calculation is done considering the value of parametric efficiency of motor (fig. 4). From the simulation result in MATLAB-Simulink of open-loop circuit for 20 N-m load, the efficiency of steady state performance analysis of hydrostatic transmission system (HST).
A hydraulic motor is found 0.7403% for a particular reading at a particular time. It varies depending upon flow, differential pressure across motor, rpm etc. It is shown in the graph comparing efficiency of open and closed loop hydraulic system. Based on the analysis, it was found that the hydrostatic drive considered in this analysis is suitable for high torque and low speed applications. The leakage of the pump and the motor is considered and it mainly depends on the clearances between the mating parts. These clearances may vary with the load and the speed of the motor and the hydrodynamic lubrication affecting its life, which are very difficult to measure under running conditions. Considering these effects, further refinement of the model may be made. The studies conducted here may be useful to the practicing engineers and it may also be helpful for the selection of similar machines.

Also, a simulation model for closed loop transmission system is designed (fig.5) and providing constant load and varying pump displacement from 0 to maximum the torque, pressure differential, rpm, flow rate is calculated. From these we have calculated the efficiency of hydraulic motor.

From the simulation result in MATLAB-Simulink of closed loop circuit for 20 N-m load, the efficiency of hydraulic motor is found 81.57% for a particular reading at a particular time. It also varies depending upon flow, differential pressure across motor, rpm etc. It is shown in the graph by comparing efficiency of open and closed loop hydraulic system.

Fig.4: Model for open loop circuit in MATLAB

Fig.5: Model for closed loop circuit in MATLAB
IV. ANALYSIS OF THE SYSTEM AND RESULTS

Comparison of both the HST system are shown in graphs below. fig(a): the motor efficiencies vs rpm, fig(b): motor efficiencies vs differential pressure across motor, and fig(c): motor efficiencies vs flow given below:

![Fig.a.motor efficiencies vs rpm](image)

![Fig.b.motor efficiencies vs differential pressure (Pa)](image)

![Fig.c.motor efficiencies vs flow (m³/s)](image)

CONCLUSION

It is found that the efficiency of a closed loop hydraulic system is more than that of an open loop system for same operating variable. It varies according to differential pressure, speed of motor, flow across motor. The differential pressure across motor increases as load on motor shaft increases. The pressure pulsation in system pressure can be greatly reduced by using accumulator. Accumulator provides the cushioning effect by absorbing the hydraulic shock loads.

The analysis made in this paper examines the effects of various parameters on the performance of hydrostatic transmission system and compared graphically. The comparison shown concludes that how the system parameters can be varied to enhance the performance of HST.

REFERENCES