Design and Analysis of Hydrostatic Transmission System

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Abstract. This study develops a hydraulic circuit to drive a conveying system dealing with heavy and delicate loads. Various safety circuits have been added in order to ensure stable working at high pressure and precise controlling. Here we have shown the calculation procedure based on an arbitrarily selected load. Also the circuit design and calculations of various components used is depicted along with the system simulation. The results show that the system is stable and efficient enough to transmit heavy loads by functioning of the circuit. By this information, one can be able to design their own hydrostatic circuits for various heavy loading conditions.

KEY WORDS: Hydraulic Circuits, Hydrostatic Transmission, Safety Circuit, Simulation.

1. Introduction

In today's fast moving industrialized world, there is a requirement to convey loads from one place to another within a plant without damaging the consignment. Failure of a material handling device could hamper human resources let alone cost the company for material loss. So, for any company stability and reliability of the material handling device is paramount. HST transmissions are used to transmit rotating mechanical power from one source to another without the use of gears. One such advantage of such a system is that the transfer of power can be accomplished on a variable basis i.e. infinite gear ratios[1]. Hydraulic Hybrid Vehicles (HHV's), which use hydro-pneumatic accumulators to store kinetic energy captured during braking and return energy to driveline during vehicle acceleration, reemerged only over the last few years as viable technology, especially in application of heavy vehicles[2]. the HST system proposed here targets transportation of colossal loads over a designated path with the help of a closed loop axial piston pump[3] and stabilizer circuits to provide protection...
during any kind of failure. Detailed calculations along with the analysis of performance of various components are discussed.

Stecki et al. (2005) compared various drive systems from conventional to hydraulic\cite{1}. They also replaced conventional internal combustion engines by Hydraulic Hybrids for commercial use and large passenger vehicles. They validated the results with the actual model. Van de Ven et al. (2008) developed a paper on a hydraulic hybrid vehicle drive train to improve the fuel efficiency of a passenger car\cite{2}. The developed hydro-mechanical drive train enables independent control of the torque at each wheel. The hydro-mechanical system demonstrates excellent fuel economy potential, yet requires development work in the area of pump/motors with high efficiency at low displacement fractions.

Sunny et al. (2014) replaced conventional gearbox transmission system with Hydrostatic Transmission (HST) system\cite{3}. The applications being considered are those of typical off-road vehicles such as forestry, construction site or mining & quarry vehicles. They showed a small-scale simulation of the performance comparison between the two transmission systems. Hatti (2015) developed a hydraulic hybrid vehicle drive train to improve the fuel efficiency of a passenger car. The invention enables independent wheel torque control\cite{4}. Manring et al. (1998) showed a study about developing dynamic equations by using Routh-Hurwitz criterion that describe the behavior of hydrostatic transmission systems using a variable displacement axial piston pump and fixed displacement motor\cite{5}.

The circuit developed can be used to carry heavy loads within industry premises which cannot be supported by cranes and other in-house machineries. The principle of hydrostatics is used in this system. In order to carry heavy loads, it is required to have well efficient system components; the system does not stall. Various safety components are also added to provide safety to the operators in cases of malfunction. The calculations for designing circuit were carried out by selecting an arbitrary load while component selection was done from standard company catalogues\cite{6,7}. The simulation was carried out by Automation Studio in order to check the stability of system. The system gains stability within 16.67 seconds.
2. Calculative Analysis

![Figure 2.1: Basic model](image)

As shown in fig. 2.1, basic concept of circuit has been selected. A block model if preferred to be known as it formed the basic ideology of the circuit.

As it can be perceived, this model is actually an eight-wheel vehicle with two tyres per unit. The pump will drive all motors by providing flow of oil to the motor units which will then drive the wheels for transporting the load on it. The accumulator and braking units were added in order to apply brakes as and when necessary.

The torque and speed of motor were set to 360700 N/m and 2.6525 rpm respectively.

2.1. Motor Calculations

The selection of motor has been done by considering Hägglunds as a motor catalogue standard. It was based on the torque required by motor[6].

Motor configurations:-

VIKING 64-16300
Displacement = 16300 cm³/rev

Required flow rate = \( \frac{\text{motor displacement} \times \text{motor RPM}}{231} \)

\[ = \frac{994.687 \times 2.6525}{231} \]

\[ = 11.421 \text{ GPM or } 43.233 \text{ LPM} \]
Pressure required

\[
\text{Torque} = \frac{\text{PSI} \times \text{Motor displacement}}{2\pi}
\]

\[
\text{PSI} = \frac{\text{Torque (inch pound) } \times 2\pi}{8 \times \text{motor displacement}}
\]

\[
= \frac{319264.007 \times 2\pi}{8 \times 994.687}
\]

\[
= 2519.47019 \text{ PSI}
\]

\[
= 173.71 \text{ bar}
\]

\[
\frac{\text{RPM} \times \text{Torque}}{5252} = \text{Horse power}
\]

\[
\text{Horse power} = \frac{2.6525 \times 360700}{5252}
\]

\[
= 182.1699 \text{ HP}
\]

2.2. Hydraulic Pump Calculations

Required flow = 8 \times 43.233

\[
= 345.864 \text{ LPM}
\]

\[
= 91.3676 \text{ GPM}
\]

From Bosch Rexroth pump catalogue\cite{7}.

Pump Specifications:-

Displacement = 355 \text{ cm}^3

Pump flow = 533 \text{ LPM at 1500 rpm}

2.3. Reservoir

The Reservoir has been taken to be of 630 liters made of S.S. 316 and according to Rexroth standards, it weighs 20 kgs.
3. Circuit design

Figure 3.1. *Pump circuit*

Figure 3.1 shows the basic pump circuit diagram. It can be noted from literatures that variable displacement axial piston pump is required for proper functioning of such a circuit. Also, the calculations done are in good agreement with literatures. This circuit is a closed loop pump. The shuttle valve is used to maintain pressure in both the pressure and return line. When pressure on one side increases, the shuttle valve moves to the opposite position to relief it to tank by pressure relief valve.

The two pressure relief valves attached above the shuttle valve were used for the same reason but provided as extra safety to relieve not in the tank but to the low-pressure line. These valves were set at a pressure above the circuit pressure by 20 bar above the circuit pressure and the shuttle valve was set at 10 bar above pressure reliefs as per thumb rule. The sandwich check valve-spring loaded check valve assembly was used to lubricate the axial piston pump via the boots pump which was contained inside the housing of the pump. Flushing valve has been set at 20 bar to allow cooling and flushing operations. A relief valve is also set by the boost pump to avoid damage to the main pump by sudden pressure changes. An inline filter was attached to the boost pump in order to reduce clogging and contamination.
Figure 3.2 Motor circuit

Figure 3.2 shows the motor circuit diagram. The hydraulically motor used is a radial piston fixed displacement motor because of the requirement of high torque and low speed. The motor circuit was paired into a group in order to reduce pipe usage and for ergonomically considerations. A ball valve which is manually operated has been provided at pump entry to motor in order to shut off the circuit from pump. The 4/2 electro-hydraulically operated DCV's were used for the reason clutching purposes. The solenoids are provided for operation and clutching.

Figure 3.3 Cooling circuit

Figure 3.3 shows a simple cooling circuit in which oil coming from flushing valve is fed to the radiator in order to cool and maintain the viscosity. If it is not provided, the viscosity of oil will reduce and when it will reduce below a certain level, it will create losses thus bringing the system to an impasse. If the pressure limit is surpassed, the relief valve will open, thus shutting the cooling circuit from the main circuit allowing pressure drop. In order to disconnect the circuit manually, ball valves were provided.
Figure 3.4 shows braking circuit consisting braking pump which is of fixed displacement type external gear pump. It is attached to the main pump by a manifold block. When pump starts, first accumulator gets charged and then if the brake is not applied, the oil is relieved to the tank via the pressure relief valve. While applying brakes, by activating the 4/2 electrically operated DCV, the oil flows through the orifice since meter in circuit has been provided in order to reduce jerks while braking. On releasing the brake, the oil will return through free flow from check valve; thus retracting the brake. The accumulator is provided to withstand water hammer, surges and rapid change in pressure.
4. Results and discussion

**Figure 4.1** Speed and Discharge vs Time characteristics of the circuit

**Figure 4.2** Power vs Time characteristics of the circuit

**Figure 4.3** Power and Torque vs Time relationship of the circuit
It can be seen from figure 4.1 that the flow first increases and then gets constant after a certain time. It comes to its stable condition after a meager 16.67 seconds. The circuit flow is constant at the operating hours. From figure 4.2, it can be concluded that the power consumption becomes a maximum while starting, when the motor has to overcome the inertial load. After surpassing the inertial forces, the system stabilizes at 200 HP and according to the calculations, the graphs conforms since the calculated torque is 183 HP. The reason for the harmonic behavior is that any hydrostatic system provides required amounts of power based on the resistance it is provided.

The system requires more power at the initial stage when it has to overcome inertia forces along with the load it has to transport. As the system comes in motion, the system faces lesser resistance hence, the power to the wheel motors also reduces based on the same hydrostatic principle. Due to this innate property of a hydrostatic systems of self-adjustment we got a harmonic power and torque characteristic. The graph of any fluid system is harmonic which conforms with Manring et al. (1998). Figure 4.3 shows the relationship of power consumption and torque required by the circuit which are identical.

5. Conclusion

The proposed research will help industries to move heavy loads in company’s premises without damaging goods; with high accuracy and precision control. Heavy shipment’s delicacy will be maintained and that will lead company to less material damage and safer environment to human resources. With our proposed design, one can create hydraulic circuit that will solve the problem of heavy machinery’s movement. The system can also be governed by using proportional valves in order to achieve a highly sensitive control of the system.

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