

MODULE-6 : HYDROSTATIC TRANSMISSION SYSTEMS

LECTURE-23: Basic concept of Hydro-Static Transmission (HST) Systems

1. INTRODUCTION

The need for large power transmissions in tight space and their control with exceedingly rapid response for military, industrial as well as modern applications (such as robotics) requires motors with very high 'Torque-to-Inertia' ratio. The fluid power units, which possess such characteristics with several orders of magnitude higher than what can be obtained from other conventional units (such as electric motor, hydro-kinetic units etc.), are still holding the top rank in the field of application in spite of their relatively high cost. The rapid and continuous growth in computer aided control systems (such as computer-Microprocessor interactive control system) has kept the researcher active in developing/improving the electronic and electro-hydraulic synchronous control units. On the other hand it has stretched the attention of fluid power engineers to improve the hydrostatic units and transmission systems to enable these to respond to modern control systems.

With a basic knowledge of fluid power and its control as well as that of hardware of conventional hydrostatic units, one can enter into basic design, analysis and application of Hydrostatic Transmissions (HST) systems.

2. HYDROSTATIC TRANSMISSION (HST)

The term 'Hydrostatic' is used in fluid power transmission due to the reason that hydrokinetic and hydrodynamic effects i.e. the fluid inertia effects can be by and large neglected in the design and analysis of such positive displacement units and transmission systems. A hydrostatic transmission is a special case of energy transmission system. (ETS), where the mechanical energy of the input drive shaft is converted into pressure energy in the nearly incompressible working fluid and then reconverted into mechanical energy at the output shaft. Essentially, an HST consists of a drive wherein the hydraulic energy input element is a 'pump' and the output element is a hydraulic 'motor'.

Usually HST pumps and motors are designed and matched to optimize energy transmission.

Why hydrostatic transmission ?

The primary job of any ETS is to :

- i) accept energy input from a source i.e., a prime mover with its own output characteristics.
- ii) transmit and modulate the energy within the ETS, and
- iii) deliver an energy output to the load, which has its own set of characteristics.

To fulfill its job, the ETS must have a set of characteristics which permit an optimum match between the prime mover and the load characteristics. An ideal ETS would produce the desired output at any speed irrespective of its input characteristics. But this is never achieved.

A gear type transmissions can provide ideal load torques only at a few points (where the number of points is equal to the number of speed ratio in gear box) over its speed range. By Manipulating HST system a closely approximated torque curve may be achieved.

The primary difference between an HST and a hydraulic system equipped with hydraulic pumps and motors is that an HST is a whole unit in which pump and motor are specifically matched to work together. Also, HST controls are designed to provide the specific functions to enable the transmission to perform specific tasks.

2.2. Various features of HST.

Hydrostatic transmissions offer many important operating features. They are :

- i) remain stalled and undamaged under full load at low power loss.
- ii) hold a preset speed accurately against driving or braking loads.
- ii) operate efficiently over a wide range of torque/speed ratios.
- iii) operate in reverse at controlled speed within design limits unaffected by output loads.
- iv) transmit high power per unit volume displacement with low inertia.
- v) does not creep at zero speed. But fine inching may be possible with a little complexity in hydraulic circuit.
- vi) provide faster response than any other type of transmission;
- vii) provide dynamic braking.
- viii) provide long life with a little careful maintenance (mainly contamination control).
- ix) provide flexible transmission lines.

2.3. Basic HST configuration.

Fig.I-1 summarizes the four basic HST configurations, and conforms with international control technology usage. The terms '*open circuit*' and '*closed circuit*' describe how the hydraulic lines in the conducting circuit are connected. In an open circuit the flow path of fluid is not continuous, being interrupted by the reservoir. In closed circuit flow path remains uninterrupted.

HST may be classified further into two different categories from the employed control point of view:

- i) *open loop* (ii) *close loop*

Open loop controls are usually manual or electric/hydraulic aided manual controls. But the closed loop controls include purely hydrostatic control to all modern control systems.

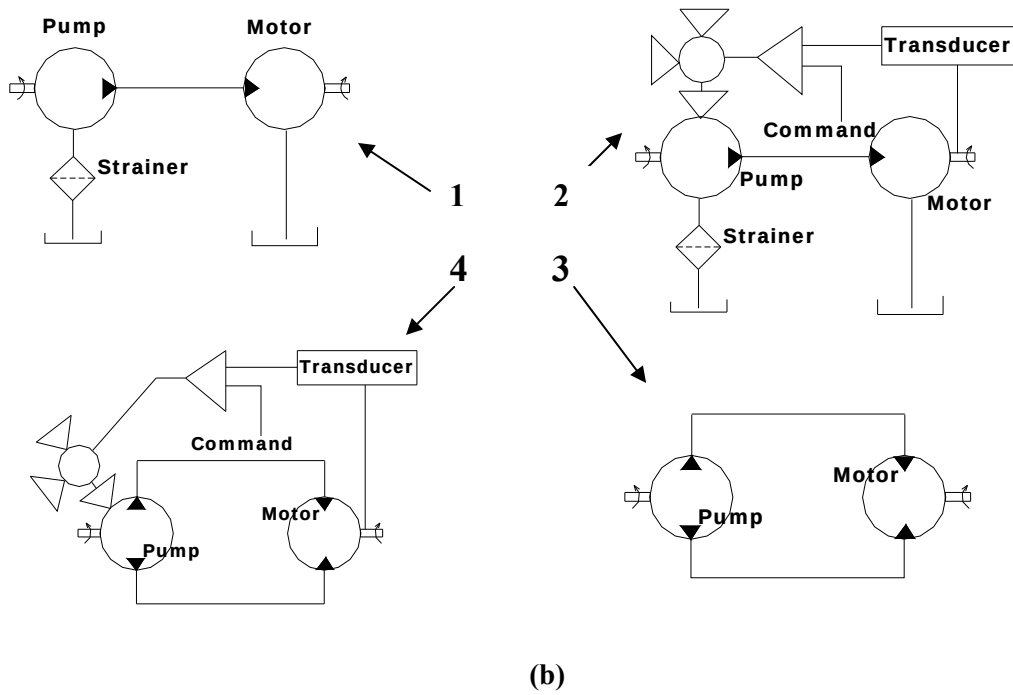
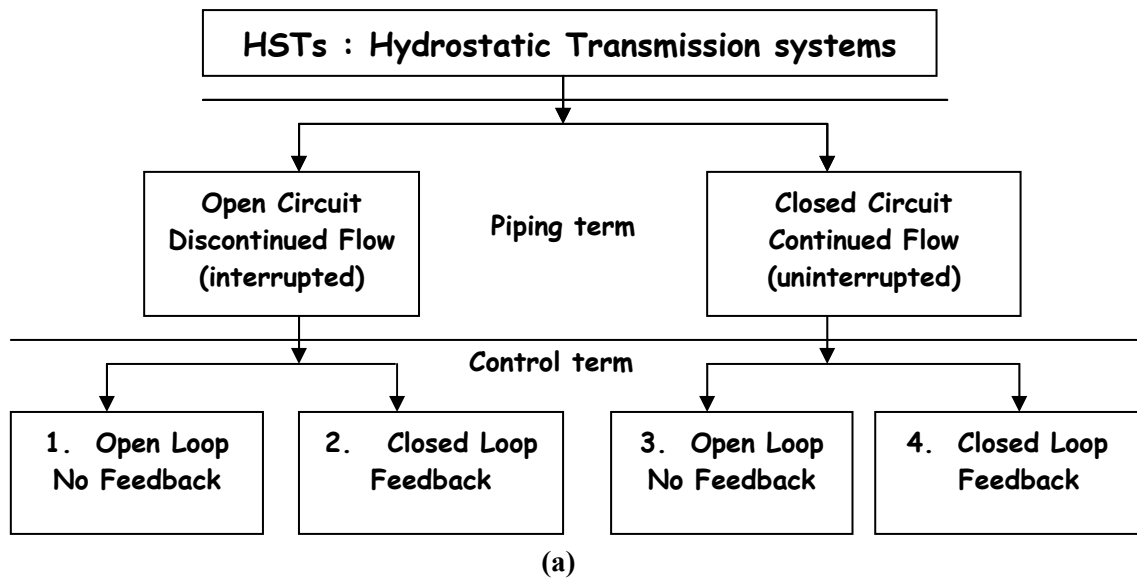


Fig. 6.23-1 : (a) Block diagram and (b) symbolic circuits summarizes four basic HST configuration.

2.4. Elements of HST system circuit.

A simple open circuit (Fig. 6.23-2) consists of the following major Elements:-

- i) Reservoir (ii) Suction strainer i.e., Filter (100-200 μ in general purpose oil hydraulic application), (iii) Pressure Relief valves (PRV) (single PRV can be used immediately after the pump), (iv) Pump (fixed or variable displacement), (v) Motor (fixed or variable displacement), (vi) Conduit (rigid or flexible) with connectors, (vii) Return line filter (10 to 25 m) and (viii) Control unit.

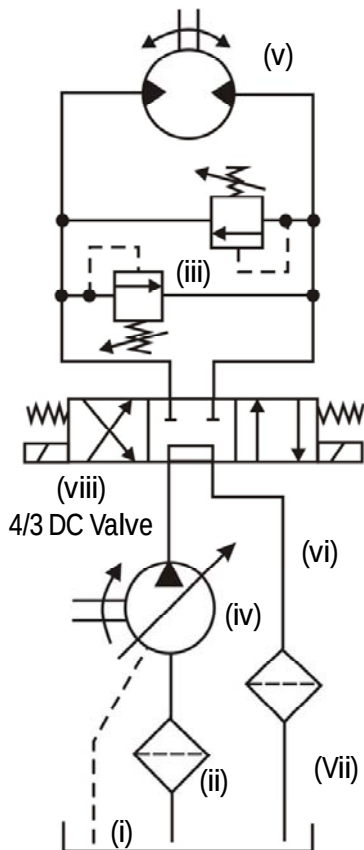


Fig. 6.23-2 : Open Circuit HST

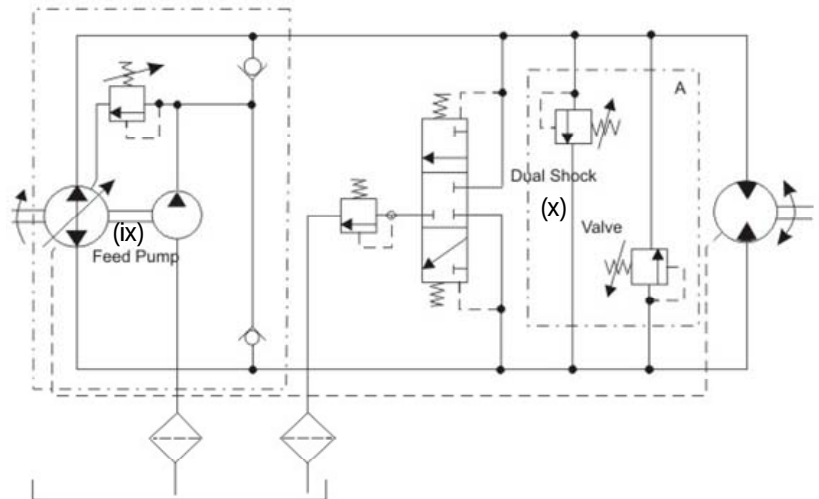


Fig. 6.23-3 : Closed Circuit HST

A closed circuit includes, essentially with these, a few other elements. Those are- (viii) Feed or Charge pump unit to replace the leakage oil, (ix) Dual shock valve to protect the system from the damage in case of pressure over ride and over running condition. To improve the performance and to fulfil other desired tasks many other appropriate components, such as accumulator, cooling system, special purpose valves etc. are included in the circuit.

2.5 Different types of LOAD and Employed HST system.

Performance of a HST is not only dependent on the inherent characteristics of the transmission system (including the prime mover characteristics) but also on the nature of loads. Usually, the performance of an HST means the overall performance of a closed circuit system.

2.5.1 Type of Load.

There are four main classes of loads which, in combination, can describe most actuation problems. These would be called (i) friction, (ii) elastic, (iii) gravity and (iv) inertia loads. Any load will have some friction and some inertia, but usually, one effect is dominant. Friction denotes any dissipative loads, which includes rubbing friction along with resistive loads such as electric generators, propeller drives, fluid transfer systems, etc. Elastic loads have force as a function of position only. Gravity loads are constant or quasi-constant loads independent of direction of motion such as winches. Inertia loads are dominated by acceleration effects. All except friction loads store energy which can be recovered during the return stroke of the cycle.

2.5.2 Type of closed circuit HST.

There are four types of HSTs, as illustrated in the Table 6.23-1

Table. 6.23-1 : Type of HSTs

Displacement		Transmission		Output Speed	Commonly Known as
PUMP	MOTOR	POWER	TORQUE		
Fixed	Fixed	Constant	Constant	Constant	--
Variable	Fixed	Variable	Constant	Variable	Constant Torque System
Fixed	Variable	Constant	Variable	Variable	Constant Power System
Variable	Variable	Variable	Variable	Variable	--

2.6 Control system

i) Manual control of output ii) Pilot operated control of output. iii) Constant Horse Power Control and iv) Constant Pressure Control.

To determine the actual size of the components all losses must be properly included. The losses are:

- (i) Leakage losses through active zone. (Mainly internal leakage) such as barrel valve plate inter face, active load transmitting contact zone.
- (ii) Leakage losses through slip region i.e., slip flow (external leakage) through piston, cylinder wall, hydrostatic pad on swash plate etc.

Apart from these leakage loss, which is proportional to the pressure drop and affects the volumetric efficiency, there are few other losses. It can be mentioned here that the design of HST systems is a more complex undertaking than when dealing with individual pumps and motors. However, the distinguished losses which affect the performance of pumps and motors independently are as follows:

- i) 'Coulomb friction' resulting in slick-slip or cogging motion (that which occurs between dry surfaces and at slow accelerated speed i.e. at starting region).
- ii) 'Viscous drag' (also called windage losses), which is related to velocity.

- iii) ‘Inertia’ which is not an actual loss, but acts like one during breakaway and acceleration, because inertia torque adds to the load and friction torque. In open circuit these three losses are included while calculating the power of motor.

Another important feature, to be accounted, is the ‘stall torque characteristics’ of Motor. The key factor is the torque vs. speed characteristics at very low speed range (usually below 50 r.p.m.). The torque efficiency (which is minimum at 0 speed) at this low speed range is called ‘stall torque efficiency’ (up to 25% below operating efficiency). This is an very important factor in the selection of motor in fluid power transmission and it would force a designer to specify a hydraulic motor up to twice the size. This peculiarity of conventional High Speed, Low Torque (HSLT) motors has led to the development of low speed, High Torque (LSHT) motors, the basic features of which are discussed in the later part of this article.

2.7 Corner horse power (CHP).

CHP is a numerical value which describes the capability range of a transmission, and is based on the product of maximum torque and maximum speed. It is to be remembered, while designing such system, that these two values do not occur simultaneously. Using infinite number of torque multiplier steps one can bring down the corner horse power curve to match with actual engine output horse power curve. A completely variable control HST is an appropriate device.

2.8 Special Hydrostatic units.

The hydrostatic units possess irregularities at low speed range as discussed earlier. The remedies, which have led to develop special pumps and LSHT motors, are described in Table. I-2.

Table. I-2 : Different measures to be taken to improve irregularities.

Measures to be taken		Improvement
1.	Decrease the weight, size and number of the movable components	Low inertia. Better startability
2.	Increase the displacement per chamber per revolution, with minimum possible stroke length.	Less leakage. Reduced torque and flow fluctuation. High torque output.
3.	Increase the number of power strokes and hence the displacement per revolution	Least torque and flow fluctuation High torque output.

Irregularities are reduced or eliminated, in case of pumps, usually by improving the valve port feature and introducing efficient control system. But in case of motor the hardware is changed to multiply the torque internally. The LSHT motors may be classified, according to their internal feature, as follows :

Class-A: Number of power strokes are increased either by increasing the number of the pistons or by increasing the number of power strokes for output revolution.

Example : Double row multi-cylinder piston motor, multi-lobe ball piston motor, ORBIT motor etc.

Class-B : Piston area is increased.

Example : Radial piston motor.

Class-C : Combination of A and B.

Example : Multi-lobe radial piston motor. Multi-lobe Radial ball piston motor etc.