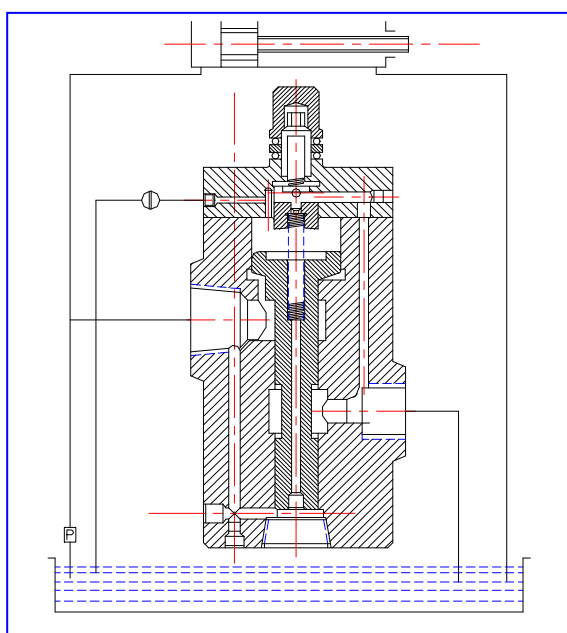


# INDUSTRIAL HYDRAULIC SYSTEMS & CIRCUITS



By

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## PREFACE



The logical and sequential arrangement of various elements to obtain the desired function through fluid is called hydraulic system. Industrial hydraulics was introduced as a useful medium for power transmission during the beginning of the 20<sup>th</sup> century. Since then the technology has undergone continuous evolution by responding to the challenging demands poised by a wide variety of applications. Over these years, it has competed with other competitive power transmission technologies to find its present place. The strengths of hydraulic drives that make them the preferred choice are their high force and acceleration capability, ability to operate at full torque even at zero speed, continuous speed variability and stiffness.

These superior features combined with the development of components that can interface with complex electronic controls have created an undisputed domain for hydraulics in power transmission. Hydraulic systems are being used on wide variety of machines today and they form subsystems of many machines deployed in agriculture, construction, mining, earthmoving, material handling, defence and aeroplane. Hydraulics has long provided the muscle for the mobile equipment to load and unload heavy and voluminous materials. The system is more widely used in machine tools as principal and feed movement drives providing rotary as well as translatory motion with stepless regulation of feed and speed rate , speed changing devices, automatic control of machine cycle, etc.

Now-a-days, the principles of oil hydraulics have very successfully replaced even mechanical and electrical drives in some machine-tools and equipment. This extensive use of hydraulic system is due to their capability of providing infinitely variable speed over a wide range, smooth reversal of moving machine members, automatic overload protection, easy lubrication, etc. All this development raised demand for team of engineers and technicians well trained in industrial hydraulic system and circuits.

Since Oil hydraulic systems can be built using readily available standard elements together with electrical/ pneumatic interface to perform any complicated sequence of operation, technological developments in this field were carried out mostly by their manufacturers who have been reluctant to share their knowledge with others. So for the application of hydraulic systems and circuits, different types of books, manufacturer's catalogues and manuals need to be referred. Attempts, therefore, have been made to collect all such study material and compile in the form of a book.

## **Preface: contd...**



This book covers the literature regarding various types of standard hydraulic system elements like different types of pumps, pressure controlling elements, flow control valves, check valves and direction control valves. Details of different types of tailor made auxiliaries like hydraulic tank and their accessories, filters, piping, fittings and accumulator etc. have also been described. In addition to the above, special devices right from the conventional copying attachment system to latest electro-hydraulic system like proportional valves and servo valve with electronic controls are given in this book.

Since, the hydraulic circuit of equipment is devised purely by intuition, there may be hundreds types of circuit. Many circuit variations are possible through the use of basic components of standard elements of hydraulic system. A few typical hydraulic circuits are being described here. To illustrate further, practical applications of the system and circuits in the fields of hydraulic drives, hydraulic controls, hydrostatic transmission and hydrostatic bearings have been given in detail. Installation, maintenance and testing of the various hydraulic systems and elements have been added as concluding chapter to make this book more useful on the shop floor.

The subject matter has been well illustrated with over 100 figures in more than 160 pages covering more than 30 typical hydraulic circuits. The book will be very useful for the practicing engineers, designers and students of mechanical, and production engineering and technical personals handling different types of machineries.

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# CHAPTER 1

## INTRODUCTION TO HYDRAULIC SYSTEM

### 1.1. PRINCIPLES OF HYDRAULICS

The name 'Hydraulics' has been taken from the Greek word 'HYDOR' meaning water and 'AULOS' meaning pipe. For the first time 'Hydraulics' was put to use by the person who converted the energy of flowing water into useful mechanical energy, by means of the water wheel. Later on the idea of Industrial Hydraulics or Oil Hydraulics emerged. It is the science of transmitting energy through the medium of pressurized fluid. Advancement of this science started when Pascal discovered a fundamental law called Pascal's law which states: "Pressure generated at one point in a confined liquid, acts actually in all directions and acts perpendicular to the surface of the container". The law helped in developing this new field of hydraulics, dealing with power transmission, control of mechanical motion and characteristics of fluids under pressure. The developments resulted into the use of network of high-pressure of fluid pipes from the pressure generating station i.e. pump to the application points through the controlling system. In this process various auxiliaries like valves, accumulators and seals etc. were invented. Now-a-days, the principle of oil hydraulics are applied for power transmission and control and very successfully replaced even mechanical and electrical drives in some machine-tools and equipment.

The logical and sequential arrangement of various elements to obtain the desired function through fluid is called hydraulic system. Oil hydraulic systems can be built using readily available standard elements together with electrical/ pneumatic interface to perform any complicated sequence of operation. The system is more widely used in machine tools as principal and feed movement drives providing rotary as well as translatory motion with stepless regulation of feed and speed rate, speed changing devices, automatic control of machine cycle, etc. The innovation of electro hydraulic servo valve and proportional valves, which could conveniently interface with electrical and electronic measuring and signaling devices, led to the popular use of electro-hydraulic servo drives in CNC machines. The latest is the application of electro-hydraulic stepping motors with hydraulic torque amplifiers for feed drives in an open loop configuration. This extensive use of hydraulic system is due to their capability of providing infinitely variable speed over a wide range, smooth reversal of moving machine members, automatic overload protection, easy lubrication, etc. Among their shortcomings is leakage of hydraulic fluid through seals and gaps, ingress of air into fluid, effect of temperature and time on fluid properties, etc.

### 1.2. HYDRAULIC FLUIDS

Fluids for hydraulic systems are subject to a wide range of pressure, velocities and temperatures.

During the operation of the system the temperature of the hydraulic fluid changes owing to its heating and cooling. In the suction line the supply of liquid is affected by the vacuum formed in the suction end of the pump. In the pressure piping the fluid is subjected to high pressure.



index is an empirical number that indicates the effect of change of temperature on viscosity of oil. A higher viscosity index signifies smaller change in viscosity with change in temperature than a lower viscosity index. For oil based on petroleum products viscosity index of 90-100 is supposed to be very good if it is not doped with viscosity index improver. So hydraulic oil should have been made from predominantly paraffinic refined base oil which have sufficiently high viscosity index, required for such applications.

Viscosity temperature relations can be stated approximately as  $\mu_t = \mu_{20} \left( \frac{20}{t} \right)^K$

$\mu_t$  or  $\mu_{20}$  = Viscosity at 20° c or t° c

K = 1.63 for Ex light oil

= 1.88 for light oil

= 2.08 for heavy medium oil

= 2.55 for heavy oil

Higher the viscosity-index the smaller the change in viscosity with variation in temperature. To improve VI further, say upto 200, viscosity-index improver is added. Those in common use are Poly isobutylene, polymethacrylate esters and polyfumarite ester-derivatives between 1% and 5% being added to the oil. Paratone is a polymer of butylenes having the formula  $(C_4H_8)_n$ , where n may vary from 180 to 270, The large size of the molecule being typical of viscosity index improvers.

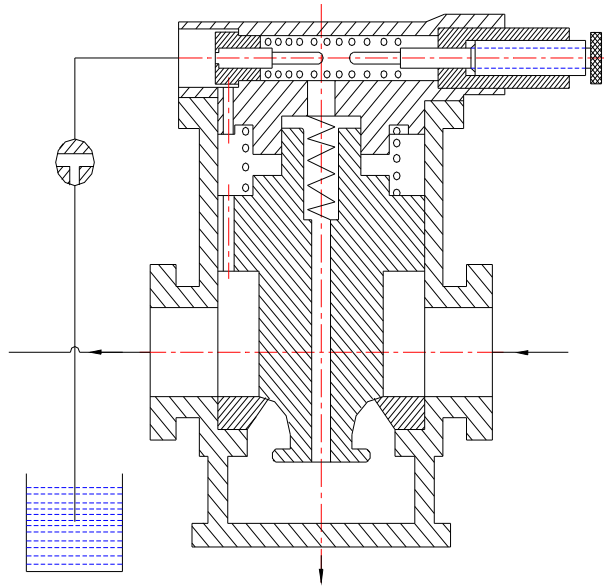
The 'Acryloid or plexol' range of additive consists of concentrates of methacrylate polymers. They are viscosity index improvers pour points depressants or low temperature sludge depressants suitable for use in crank case oil, automatic transmission fluids or hydraulic oils. Indicating additives it must be kept in mind that low additives molecules weight decreases shear loss, while high molecular weight gives reduced cost of doping. The development of viscosity index improvers has facilitated the production of multi-grade motor oils.

### 3. Anti-wear properties

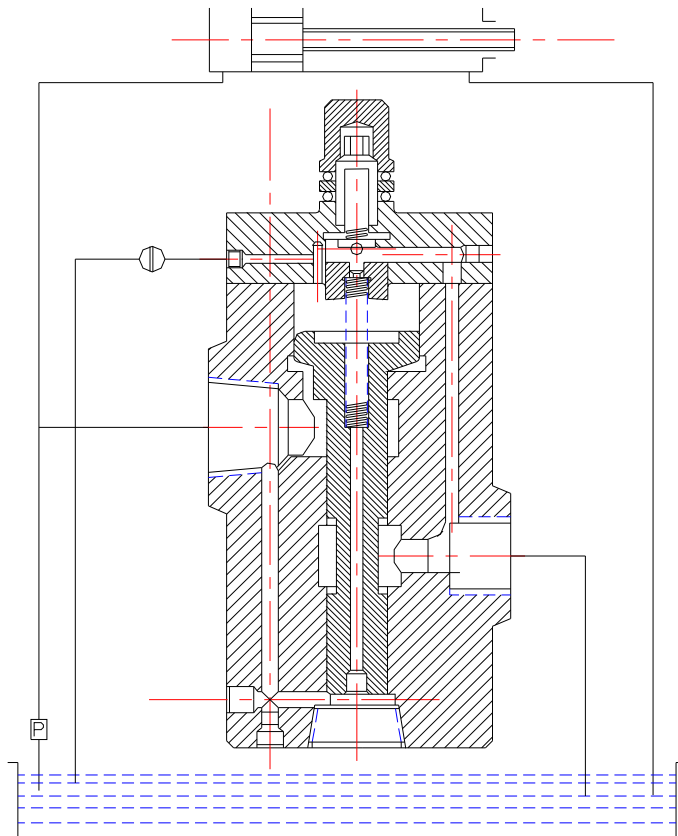
Anti-wear properties are more specifically required for oil used in hydraulic and hydrostatic transmission systems because of the involvement of more close fitting and rubbing elements. Anti-wear property is required to produce a chemical polishing at lower temperature. Popular anti-wear additives are tricresylphosphate and zinc dialkyldithiophosphate. The later one is good anti-oxidant also.

### 4. Anti-oxidation properties

There are a number of elements like heat, water, pressure, and metal surface that accelerates Oxidation. Oxidation reduces service life of hydraulic components. Tests have shown that below 55°C, oil oxidizes very slowly. But the rate of oxidation doubles for every increase in temperature. The general deterioration is due to the formation of oxidation products. The oil may become more viscous and undesirably acidic in nature because of the presence of oxidized oil. Though sulphur and phosphorus are effective oxidation inhibitors but they have corrosion action on certain nonferrous metals. For oil required to be working in normal temperature, phenolics and di-thiophosphates are generally used as oxygen-inhibitor.



*Fig.4.2 Pilot operated compound relief valve (poppet type)*



*Fig.4.3 Pilot operated compound balance piston valve (spool type)*

## CHAPTER 10

# ELECTRO HYDRAULIC SYSTEM

### 10.1 INTRODUCTION TO ELCTROHYDRAULICS

Electronics is being successfully integrated with the hydraulics to make best use of muscle power of hydraulics retaining precision controllability of electronics. This hybridization of hydraulics with electronics is termed as electro-hydraulics. Electro-hydraulic system combines the flexibility of electrical system, with the power handling ability of hydraulic system. Hydraulic system can be designed to be consistent, smooth, and quiet and trouble free by adapting electro-hydraulic controls. The electronics takes care of compressibility of fluid, low system stiffness and dynamic behaviour of load. It also ensures that that forces and speeds always available in correct ratio leading to energy conservation. In power hydraulics, there are only three functions to control pressure, flow and direction. The introduction of electro-hydraulic devices added new dimensions like remote and multifunction control. Any physical quantity, position, velocity, acceleration, force, pressure, that can be measured electrically, can be controlled electrohydraulically. Thus major benefits of electro-hydraulic system over conventional hydraulic system can be listed as follows:

- ◆ Precision controllability to achieve motion control
- ◆ Higher operating efficiency
- ◆ Capability to perform multiple functions
- ◆ Introduction fail-safe features
- ◆ Flexibility of expansions and modification
- ◆ Positioning of remote control and finger tip controls.

The advantages of electrohydraulic drives over other types of drives are, stiffness, high response, a good low speed characteristics. Electrohydraulic proportional valves and servo valves are the principal units under this category having wide application in several engineering field, like aerospace industry, winch control, antenna drives, earth moving, mobile equipment, and N.C. machine tools. In machine tools these are used primarily to control the position of machine slide. To match the electrical circuits and sensors with the hydraulic system, packages of electro-hydraulic proportional valves and cylinders with position feedback signals along with the matching electronics are easily available in the market.

### 10.2 PROPORTIONAL VALVES

A proportional valve is electrically controlled, enabling the volumetric flow rate at the valve output to be controlled proportionately to an electrical input signal. Now a day proportional valves are being introduced in place of conventional valves, in order to achieve fast control of pressure, velocity and acceleration of hydraulic cylinders and motors. Basically the proportional control valves are the solenoid operated valves with electrical position feed back control. The solenoids mounted with such valves are of proportional type and can be modulated electrically. Spool movement is measured by an inductive position sensor and the out put is fed back to the proportional amplifier, which helps in compensating the input signal. Thus the valve could be regulated in proportional

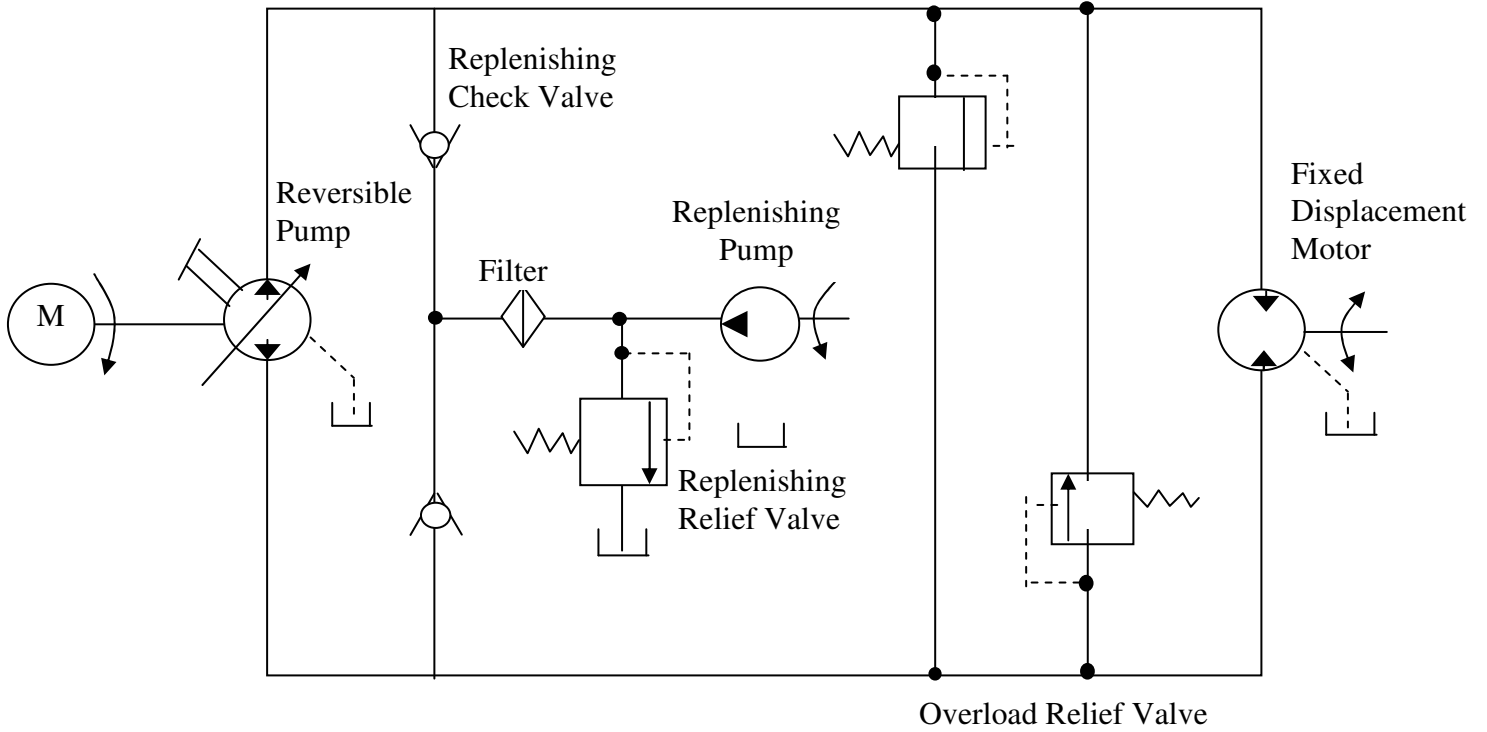


Fig.11.18 Closed-loop drive circuit-Reversible

### 11.10 PREFILL CIRCUITS

Pre-fill circuit provides an efficient method for filling the main ram on large presses, eliminating the need for a high volume pump.

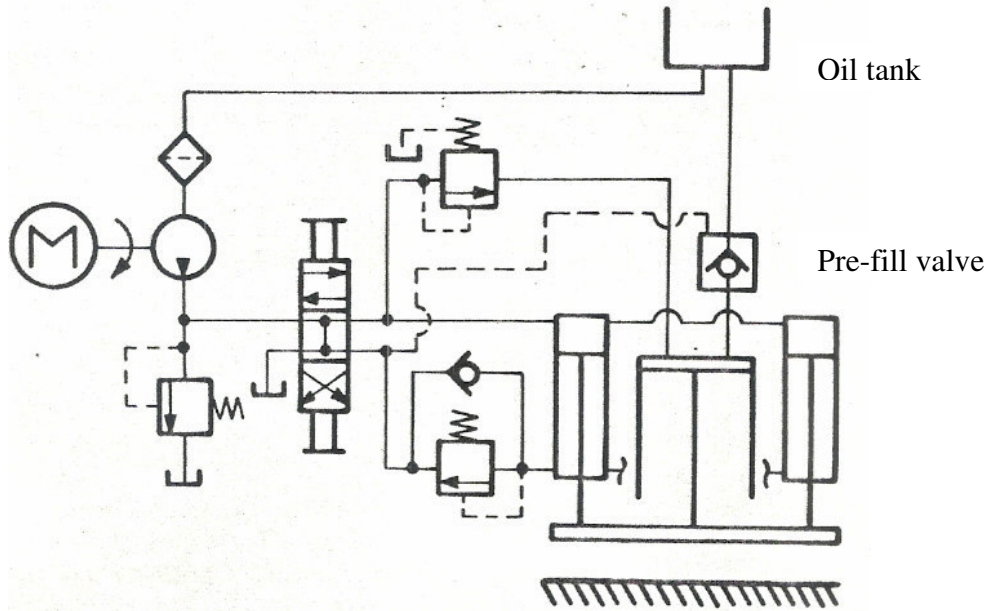


Fig. 11.19 Pre-fill circuit of typical hydraulic press

## HYDRAULIC DRIVES FOR STEP LESS SPEED REGULATION

The usual hydraulic system for spindle drive is based on a constant speed electric motor driving a hydraulic pump, which then supplies hydraulic oil under pressure to drive a hydraulic motor. The pumps and motors may be of either the fixed or the variable displacement type. The closed circuit is most suitable for frequently reversible speed and feed drive where jerking or stick slip motion is not permissible. For varying the speed of the hydraulic motor following two methods are commonly used.:

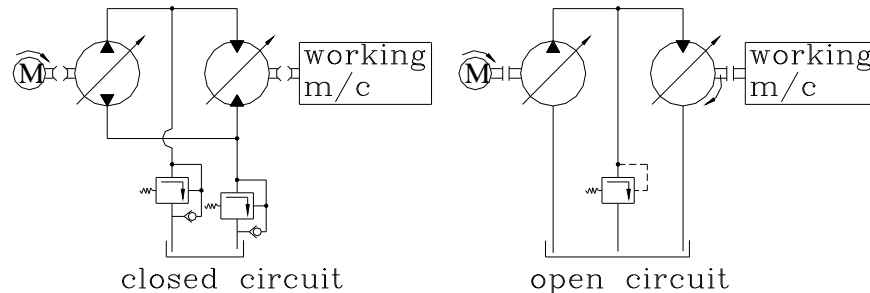
- (i) Varying the discharge of the pump.
- (ii) Varying incoming quantity of oil to the hydraulic motor.

This is analogous to the Leonard method of electrical circuit. That is why it is termed as "hydraulic Leonard rule".

The advantage of hydraulic systems incorporating both variable delivery pumps and variable displacement pumps are:

- a) Wide range of steplessly variable speeds.
- b) High rotating rigidly
- c) Possibility of repeated and sudden reversal
- d) No backlash
- e) Transmission of high power and torque's

As excessive heating of oil takes place in this process. So an effective heat exchanger should be provided for cooling of the oil.



*Fig 12.1 Hydraulic circuits for stepless speed regulation*

## HYVARI DRIVE

It is a compact hydraulic drive comprised of an axial piston pump and hydraulic motor housed in a single body. Input shaft (1) drives the pump (2), which delivers the pressurized oil to the axial piston motor (3) through a control disc located in the middle between pump and motor. Finally rotary motion of the motor is transmitted to the driven shaft (4) through rotary housing (6) fitted in the stationary body (5).

Function of the system can be described as follows:

If in a hydraulic pump with stationary pump housing, pump delivery at the outlet is blocked, oil pressure would theoretically increase till a few parts get damaged. But here pump housing is mounted on bearings and so it is free to rotate with the same speed as that of its rotor. In this process a part of the oil delivered by the pump is passed in to the