Using Load Sensing Control Systems to Increase Energy Efficiency of Hydrostatic Transmissions

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Abstract: *This paper makes a pleading reasoning the promotion of devices type "Load sensing" to control the flow and pressure in hydrostatic drive systems, in order to increase their energy efficiency.*
There are shown the operating principle, typical basic diagrams and some industrial applications. There is also shown a hydraulic diagram developed in INOE 2000-IHP, which is to be tested in the Laboratory of Hydraulics of the Institute.

Keywords: *load sensing, hydrostatic transmissions, regulator, energy efficiency*

1. Introduction

There are well known the great advantages of using hydrostatic transmissions, which in addition to high power density per kilogram of equipment, in combination with electronics provide a great flexibility and very broad possibilities for automation of drive processes.
There are situations where electronics cannot be used to its full capabilities, especially in mobile equipment/ machinery which also have heavy-duty regimes, such as shovels etc.
A most current issue is energy saving, especially saving of fossil fuels, which are on the verge of depletion globally.
Therefore, increasing energy efficiency of devices, machinery and equipment, particularly the mobile ones, including the hydrostatic drive ones, is required acutely.
The overwhelming majority of hydrostatic drives must provide variable speed at hydraulically driven working mechanisms and, consequently, variable flow at hydraulic motor of the driven mechanism, and also control of working pressures.
The most efficient way in terms of **energy** for ensuring variable flow is for the pump supplying such flow to have **adjustable / variable capacity / displacement.**
To this end, there have been developed a couple of devices for adjustment of capacity / displacement of positive displacement pumps and therefore adjustment of flow and pressure, but also power adjustment.
There are a variety of regulators which, according to the way they reduce energy losses in the system, are classified into: pressure regulators and power regulators.
Regulators are automatic devices for adjustment of displacement; during operation they do not require human operator intervention. They are mounted directly onto the pump or motor body, and adjustment of displacement is achieved under the effect of steering fluid pressure, fluid which can be collected from inside or outside the body [1].
Pressure regulators maintain a constant (or almost constant) pressure inside the circuit as long as the total flow rate demanded by consumers is lower than "breaking" flow rate. They are particularly useful when consumers of the system require variable flow rates.
The existence of a **pressure regulator** causes the pump to provide a flow rate in line with requirements of the consumers in the system; it prevents the **conversion into heat** of certain part of the energy supplied by the pump **as a result of excess fluid spilling toward the tank** via system safety valve, as it happens in systems equipped with fixed displacement pump [2].
One particularly interesting version of pressure regulator is the one in which the regulators track actual variations in the load of working parts, that is they are regulators/compensators sensitive to

load variations, also known as devices / compensators type **"Load sensing"**, which will be discussed below.

2. Operating principle of load sensing type devices

Load sensing type devices have emerged from the desire to **improve the energy balance** of hydrostatic drive systems. Equipping a variable capacity/displacement pump with such a device makes the flow and pressure along its discharge / working circuit be in line with requirements of the motor in the system; thus, **there are always provided speed and torque, or force,** needed at the output element of the motor.

Many companies active in the field of fluid power have developed such devices, with very good practical outcomes [3], [4], [5].

Control based on load sensing is a type of control of a variable displacement pump used in hydraulic drive **open circuits** [6].

Basically, this controller is made up of the same components as a piloted pressure regulator. The difference is that in this case for the level of "pressure balance" there is made a comparison between the pressure force $p_x S$ and the force developed by the pressure $p_y S$, plus force of balance adjustment spring, where S is surface of "pressure balance" spool valve. Pressure p_y must be collected as close to the motor as possible; to this end, there can be used a circuit selector consisting of two one-way valves, Figure 1. Presence of the pressure force $p_y S$ in the equilibrium equation of forces acting on the spool valve determines changes in control pressure, so that the latter could be permanently in line with the pressure required by the motor.

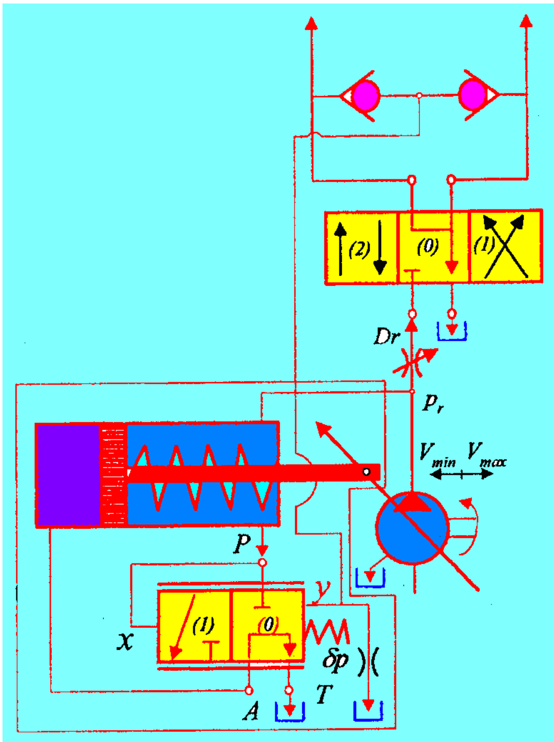

Fig. 1. Basic diagram with Load Sensing

This is the reason why these regulators have been named **pressure regulators / compensators that track load variations**. The adjustment spring (rather a spring for **returning** the spool valve to the neutral position) in the absence of pressures p_x si p_y is dimensioned such that pressure difference $\Delta p = p_x - p_y$ be enough for the balance spool valve to pass from neutral position (0) to position (1): normal $\Delta p \approx 1..2$ MPa.

When the main directional control valve in the system (the directional control valve serving the motor, in this case a 4-port and 3-position directional control valve) is in the neutral position (position 0) pilot pressure p_y is zero. In order for the flow discharged by the pump to be null (in this case the consumer does not require flow) it is necessary that cylinder rod be fully emerged; hence the balance spool valve must be maintained in position (1), and consequently $p_r = \Delta p$. As the value of Δp is very small, flow losses and friction moments are almost **eliminated in their entirety, which reduces heat generation and power consumption even more.**

When the main directional control valve executes one of the side positions (1) or (2), flow inside the circuit is adjusted using the throttle Dr; pressure loss on this equipment is:

$$\Delta p_{Dr} = p_r - p_m, \tag{1}$$

where p_m is pressure inside the motor active chamber. When writing the above relation load loss in directional control valve was neglected. Since $p_x = p_r$ and $p_y = p_m$, it follows that load loss in throttle is Δp itself.
It is known that the flow rate is calculated according to the following relation:

$$Q = S * C * 60 * \sqrt{\frac{2}{\rho}} * \sqrt{\Delta P} \tag{2}$$

where: Q is flow rate in l/min, S is drain hole section in cm^2, ρ is fluid density in kg/cm^3, C is orifice flow coefficient (rank 0.72), and Δp is pressure difference at section holes, in bar.
Since load loss in throttle Δp is very small, power loss imputable to the throttle is negligible and energy efficiency of the system is significantly improved. Moreover, **this load loss remains constant even if the load of the motor in the system varies. The flow rate, respectively the speed at the working element is thus kept constant, regardless of load variation.**

3. Basic diagrams and applications of load sensing devices

In scientific literature there are many examples of using control devices type load sensing, there being many companies that have created their own schematic diagrams and systems.

3.1. Hydraulic diagrams with Load sensing

Figure 2 presents a Load Sensing hydraulic control system, for linear motion (linear hydraulic motor), where both pressure and pump flow adapt to the conditions required by the consumer, based on pressure drop through proportional solenoids (1). In order to maintain the required pressure in the hydraulic cylinder (4), the variable displacement pump with Load Sensing type device (2) changes its geometric displacement volume, so that the flow of oil coming from the tank (3) to maintain constant pressure drop, that is constant speed at the cylinder rod, whatever the variation of resistant forces. Load Sensing helps to increase energy efficiency, because power losses are reduced [7].

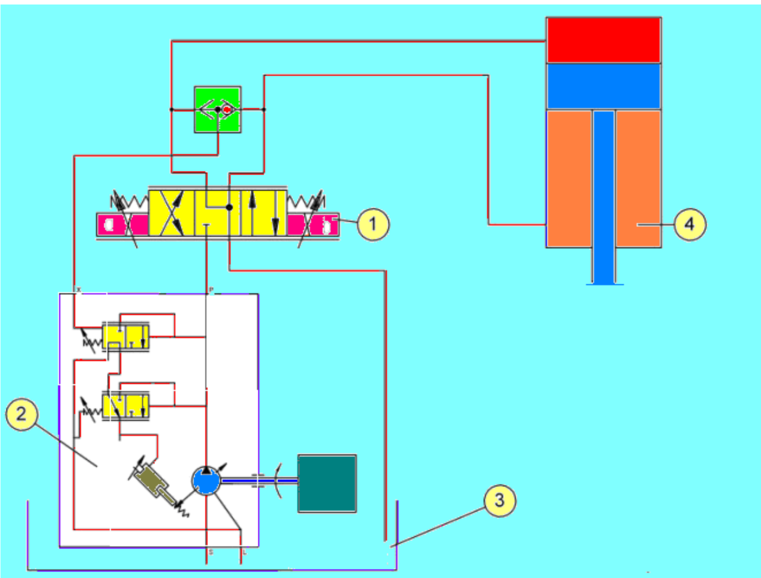

Fig. 2. Linear motion control with Load Sensing device

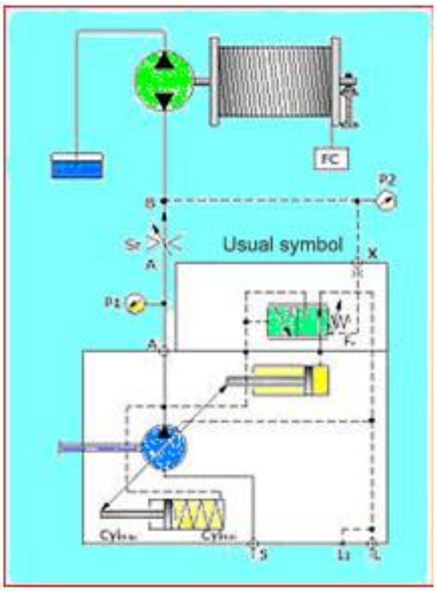

Fig. 3. Rotary motion control with Load Sensing device

Figure 3 presents another Load Sensing hydraulic control system, for rotary motion (rotary hydraulic motor) of a hydraulically driven winch [8]. The Load sensing device detects variation in work load by measuring the pressure, and adjusts pump flow to the requirements of the installation, achieving thus optimization of hydraulic drive efficiency. The system compares the pressure P2, downstream of the throttle **Sr,** necessary to the hydraulic motor, with pump discharge pressure P1, and through this "**pressure balance**" it maintains constant pressure drop ΔP = P2 – P1, that is, according to the calculus relationship of flow shown above, maintains constant flow respectively working speed, regardless of the variation of work load.
A Load Sensing control system belonging to MOOG is shown in Figures 4 and 5; on principle, it is a flow and pressure regulator / compensator. The system is based on a variable flow pump [3, 4], a variable throttle (hydraulic resistance) (1) and a pressure balance with a slide valve (7), comparing the pressures upstream and downstream of the throttle valve, the pressure drop being typically 10...12 bar, and according to some authors, up to no more than 20 bar.
Figure 4 presents the pump equipped with Load Sensing type device, and Figure 5 shows the schematic diagram of the system [9].

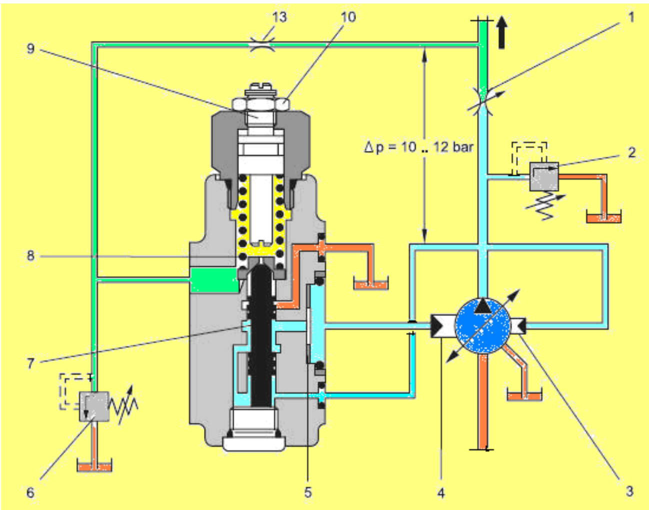

Fig. 4. Pump with Load Sensing device

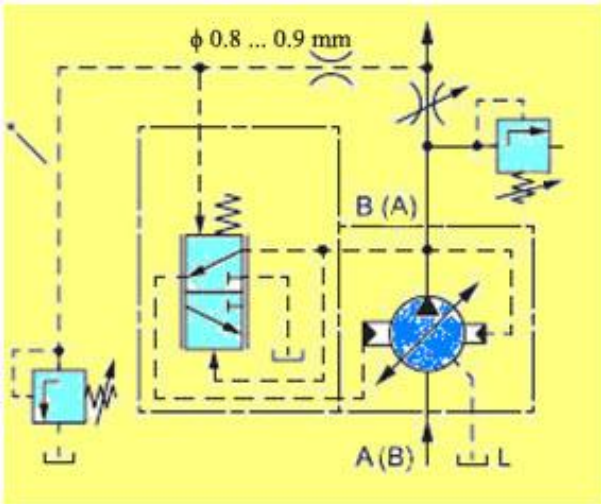

Fig. 5. Schematic diagram of Load Sensing pump

As one can seen in the diagram in Figure 4, the Load sensing device is simultaneously a flow and pressure regulator / compensator. Flow is adjusted by use of throttle 1, and pressure by use of valve 6. The function of pressure control is performed identically to the pressure regulators. Pump displacement is proportional to the throttle 1 opening. The pressure upstream of the throttle 1 is taken over and it acts on the lower area of the slide valve 7, and the one downstream - on the upper area. The pressure drop in the throttle 1 and the spring 8 together generate balance of the slide valve 7. Changing the throttle 1 setting entails change in the pressure difference between upstream and downstream of the throttle, putting the slide valve 7 out of balance, change in position of the piston 8, and hence in the pump capacity.
Changing the pump capacity/displacement entails change in the pump flow, to the amount that produces the pressure drop preset by the throttle 1.
Figure 6 presents a hydraulic diagram with Load Sensing type device designed in INOE 2000-IHP, which has been designed in order to control the speed of descent of the masses / weights, to a laboratory experimental model of a load lowering-lifting installation (crane). The experimental model has an actuation based on a fixed-displacement hydraulic rotary motor. The fixed-displacement pump, originally planned, is to be replaced with a variable-displacement pump, equipped with a Load Sensing type device [10].
Testing the below presented hydrostatic drive diagram in the Laboratory of General Hydraulics within INOE 2000-IHP will give the opportunity to improve it, if necessary, and in the end will lead to validation of the proposed solution, which has two ways to improve energy efficiency of hydrostatic drive systems: first- using Load Sensing type devices, and second- the concept of energy recovery.

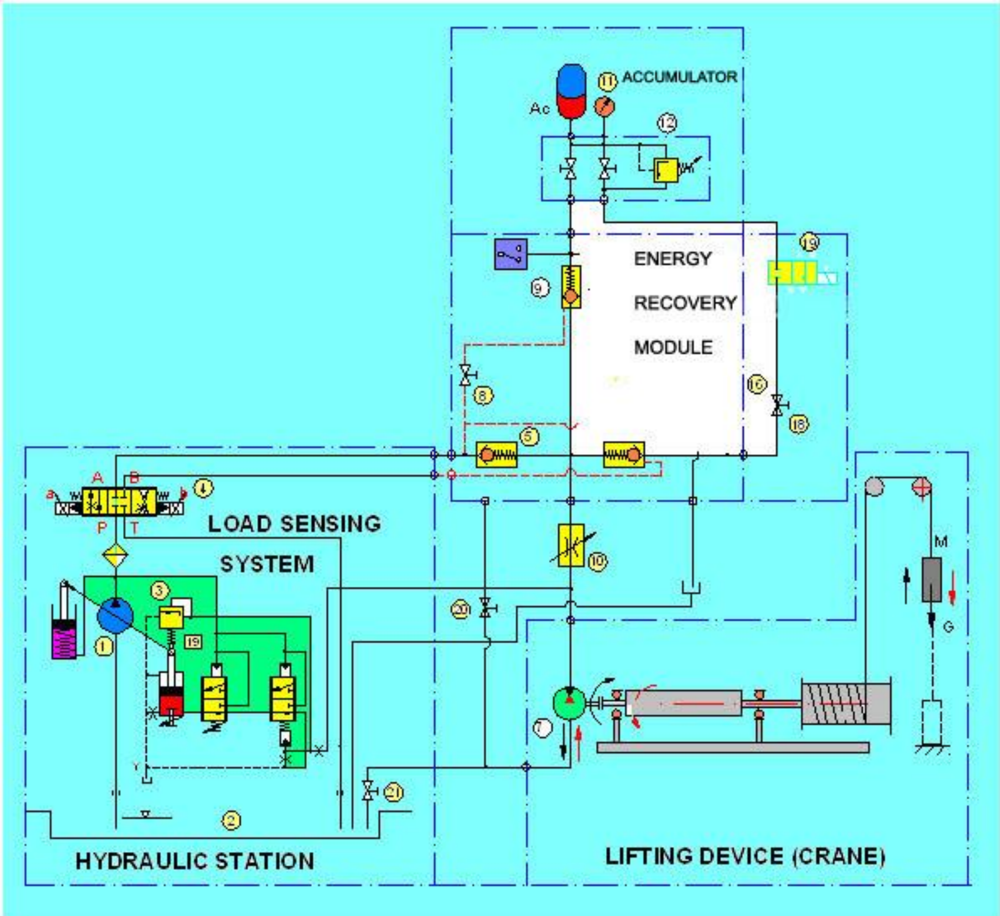

Fig. 6. Hydraulic diagram with Load Sensing type device designed in INOE 2000-IHP

3.2. Industrial applications

Worldwide, there are a lot of industrial applications using Load sensing type devices/compensators.
Thus, the company Bosch-Rexroth Group has created a special range of open circuit pumps, provided in product design stage with compensation systems / devices type load sensing, which are called axial piston Load sensing pumps, Figure 7, [11]. The pumps have displacement volume of 55, 80 and 107 cm^3, and they are working at a pressure of 400 bar.
This is a Load sensing pump with axial conical piston driving gear in bent axis design with special features and dimensions meant for use in commercial vehicles. The load sensing pump only carries as much pressure fluid as needed by the end user. In case the operational pressure exceeds the setpoint adjusted at the integrated pressure control valve, the pump is turned back and the deviation from the norm is reduced.

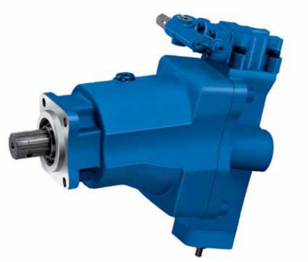

Fig. 7. Axial piston Load sensing pump

Fig. 8. The A1VO variable axial piston pump

Also, REXROTH has developed the A1VO variable axial piston pump, Figure 8, specifically for the smaller power classes of mobile machinery. In this manner, there is facilitated the economical

switch to a load sensing system. In tractors of 100 hp or less or forklifts up to around four tons the A1VO reduces fuel consumption by several thousand liters over the entire service life – and all without sacrificing performance [12].
The pump has displacement volume of 36 cm^3, and it operates at a rated pressure of 250 bar, but it can also reach 280 bar for a short period of time. Maximum working speed can be 3000 rpm.
Calculations based on a 90 hp diesel motor commonly used in tractors and a corresponding load range indicate fuel savings between 10 and 15 % per operating hour in mixed use. Assuming a life time of 6,000 hours for the tractor, this translates into fuel savings of up to 10,000 liters. The efficiency rate of the new A1VO is almost 90 percent.
The calculation of specific savings potential is based, especially, on Rexroth's expertise about the hydraulic system in question (load-sensing technology with A1VO variable axial piston pump).
In Figure 9 there is shown the hydraulic block diagram for driving the mechanisms of a 90 hp tractor, which, by using a manifold block (control block), enables simultaneous control of its working mechanisms [12].

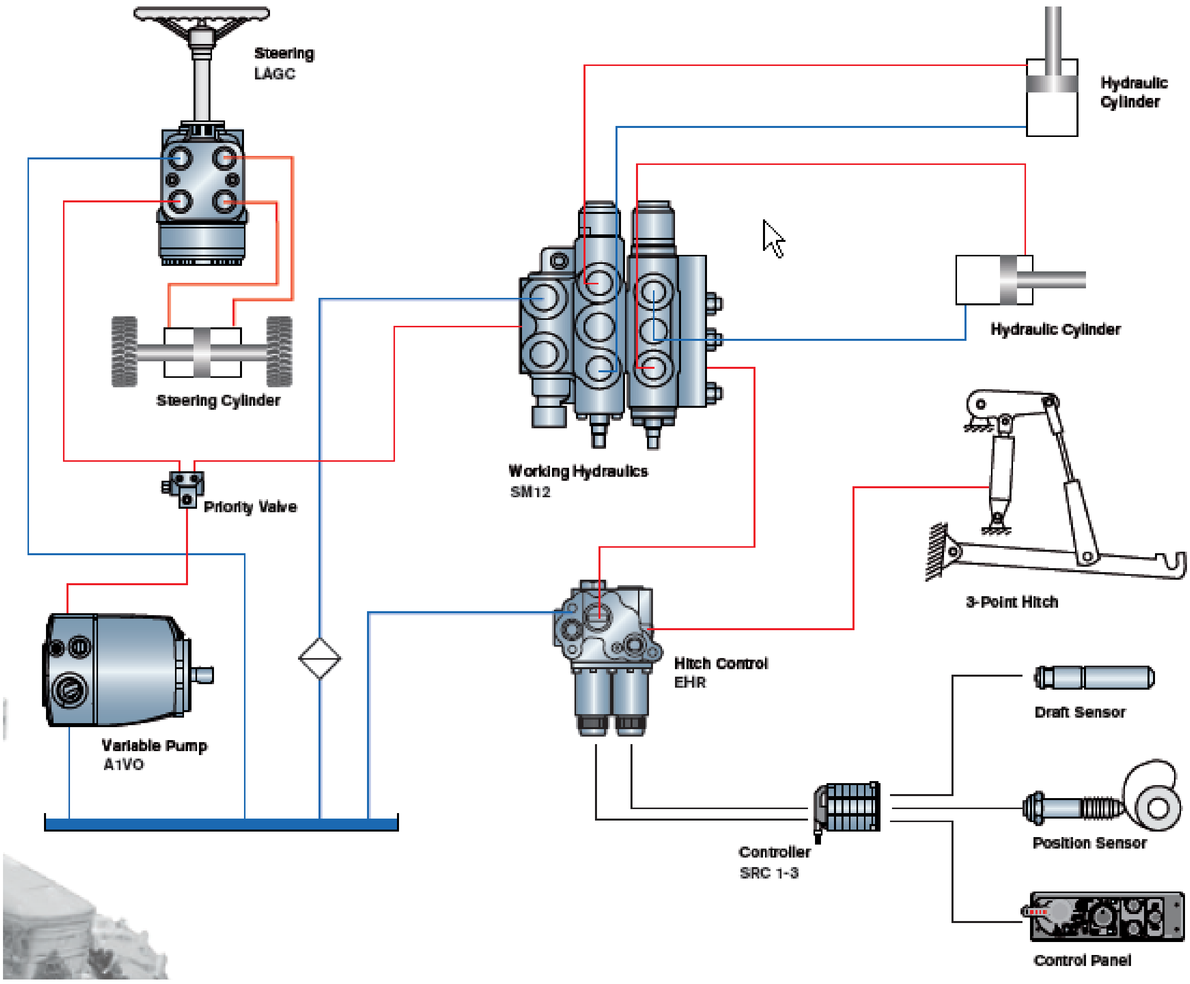

Fig. 9. Schematic diagram and installation location of A1VO in a 90 hp tractor

This diagram includes all work which does not demand full hydraulic power, such as vibration damping of the attachment, the chassis and the cabin while traveling on field and road, steering movements or various other activities [12]. Accounting for more than two thirds from working time, such operations considerably outweigh the times under full load, when the saving is not possible.
The hydraulic system contains a A1VO axial piston pump, with variable capacity and Load Sensing device, which has an up significant savings potential in the partial load range.
In paper work [12], there is presented another application, namely: Schematic diagram and installation location of A1VO pump, for a forklift up to four tons.

In the references consulted, and especially on the Internet, there are presented plenty of applications of Load Sensing type devices, but in this paper we stop here.

4. Conclusions

Load Sensing type devices have emerged from the desire to improve the energy balance of hydrostatic drive systems on industrial machinery and equipment.
The Load Sensing system is a hydraulic servo control attached to a variable displacement pump**,** used in open drive circuits, by which load variation is sensed, which results in varying the pump flow to maintain a constant pressure in the circuit.
The Load Sensing hydraulic system ensures maximum efficiency, distributing the oil flow where and when needed, thus achieving substantial energy savings.
Variable displacement pumps provide the exact oil flow required with no loss, and they guarantee a minimum power consumption, and also major productivity of the machine, which will automatically adapt to operator requirements. Also, Load Sensing system allows simultaneous movement of multiple motors / actuators powered by the same pump [3].
As the variable displacement pump equipped with Load Sensing control produces only the flow effectively required by the actuator, the system consumes little energy, and heat losses are also small. In this way it is avoided increased oxidation of hydraulic oil leading thus to extended oil lifetime, greatly improving operation of the actuator [6].
Load sensing devices are very energy efficient devices and they create the possibility for faster and more precise operations, and also increase comfort in operation due to the minor vibrations.

Acknowledgements

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