Energy Saving Strategies of an Efficient Electro-Hydraulic Circuit (A review)

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Abstract—In the past few years, considerable effort has been made to improve the power efficiency of electrohydraulic systems; many energy saving strategies have been successfully developed and used. However, most of them can only be useful in specific applications. For instance, displacement control and secondary control only focus on those systems in which the efficiency concerns are more important. Although these systems have very high efficiency, they are not designed for applications in which the flow rate is varied during the duty cycle. Compared with pump controlled systems and other energy efficient systems, the valve controlled system demonstrates good dynamic performance and controllability especially for inertia dominated loads but at the expense of power efficiency. For electrohydraulic circuits which employ load-sensing systems for example, the design objective has been made to combine the advantages of high dynamic performance with better energy utilization. However, this high efficiency can only be obtained under particular operating conditions, such as single-load or multi-loads with similar load pressure requirements. No one approach is available for general system design where both good dynamic performance and high-power efficiency are important.

The objective of the present paper is to highlight the different technological processes used for improving the performance of efficient electro-hydraulic circuit in energy saving.

Keywords— Electro-Hydraulic circuit; Energy Saving; Artificial Intelligence Technique; Intelligent Control.

I. INTRODUCTION

Hydraulic systems are used to transfer energy by converting mechanical energy to fluid energy, and then back to mechanical energy. The principle reason for converting to fluid energy is the convenience of transferring energy to a new location. Hydraulic drives have many advantages over other technologies. The ratio of weight, volume and inertia to available power is significantly lower than in electromechanical drives, especially for linear motion. The dynamic performance is superior when compared to electrical or electrical-mechanical drive systems in large power drive systems [1-3]. For those systems that require an output power larger than 10 kW and a fast response speed, hydraulic drive systems are often the appropriate choice. Hydraulic systems are especially suitable for those operations characterized by abrupt loading, frequent stops and starts, reversing and speed variations that cause sharp peak, cyclic and fluctuating power demands. These advantages make them very popular in applications such as aircraft, mobile equipment, lifting machines and forest machines.

Mobile working machines play an important role in modern industry. These machines are widely used for instance in the mining, process and goods manufacturing industry, forest harvesting, harbour terminal work, telehandler machine and tractor bacheo.

The heart of any electrohydraulic system is its pump. From the energy consumption point of view, pumping systems account for nearly 20% of the world’s energy used by electric motors and 25% to50% of the total electrical usage in certain industrial facilities, [1]. Clearly, pumping systems consume a significant amount of the total electrical energy. The combined total of United States and Canadian energy efficiency program budgets for ratepayer funded electric and gas programs reached nearly $6.2 billion in 2009, [2].

Figure 1 illustrates the energy use in a typical pumping system. From the energy use, the opportunity to save energy is illustrated by the size of the percentage. The figure says that only 8% of the energy produces valuable work. The remaining 92% is wasted energy and available for more efficient operation. The motor accounts for only 8% of the energy loss, and yet that is the main target for energy reduction in systems today through a history of both utility incentives as well as legislation.
For instance, displacement control and secondary control only focus on those systems in which the efficiency concerns are more important. Although these systems have very high efficiency, they are not designed for applications in which the flow rate is varied during the duty cycle. Compared with pump controlled systems and other energy efficient systems, the valve controlled system demonstrates good dynamic performance and controllability especially for inertia dominated loads but at the expense of power efficiency. For electrohydraulic circuits which employ load-sensing systems for example, the design objective has been made to combine the advantages of high dynamic performance with better energy utilization. However, this high efficiency can only be obtained under particular operating conditions, such as single-load or multi-loads with similar load pressure requirements. No one approach is available for general system design where both good dynamic performance and high-power efficiency are important.

Industrial applications increasingly require electrohydraulic systems that offer a combination of high force output, large workspace and high accuracy. Typical applications include robotic manipulators, motion simulators, injection molding, and material testing machines, [1-10]. Electrohydraulic circuits with fast dynamic response are often characterized by low power efficiency; on the other hand, energy-efficient circuits under certain circumstances, can demonstrate slow transient responses. Continuously rising energy costs combined with the demand on high performance has necessitated that hydraulic circuits become more efficient yet still demonstrate superior dynamic response. However, the continuing success of electrohydraulic systems over competing drive technologies is contingent upon surpassing traditional performance levels, both in terms of physical measures such as motion precision and in terms of economic measures such as product cost.

Variable displacement piston pumps have found widespread application in the field of fluid power industry. The most common way to vary the flow rate of a pump is to vary its “displacement” or “piston stroke” when it is operated under a constant rotational speed. A variable displacement pump is designed such that the displacement can be varied from zero to some maximum value while the pump is operating. Changing the angle of the swashplate can change the piston stroke. Since the displacement of the pump is proportional to the piston stroke, the displacement can be changed by varying the angle of the swashplate, [6].

Several investigators [7, 8] have applied research about the dynamic properties of a variable displacement piston pump. Most of these investigations are based on a linearized model of the pump dynamics. In industrial application, the dynamic characteristics of the variable delivery pump are always complex and highly nonlinear, [6]. Moreover, there are too many uncertainties in it; as the viscosity of the oil, the bulk modulus, leakage coefficient, equivalent torque coefficient, volumetric displacement and others. So, the design of such pumps control flow at different pump pressure levels needs various controllers that cause the pump output to match different load characteristics more efficiently and effectively. The design of these controllers, however, is often based on compromise and thus their performances are very operating condition dependent.

Soft computation methods have become very popular recently involving mapping of input-output vectors for cases where no theoretical model works satisfactorily. An artificial NN [11-17] is an information-processing paradigm inspired by the manner in which the heavily interconnected, parallel structure of the human brain processes information. They are collections of mathematical processing units that emulate some of the observed properties of biological nervous systems and draw on the analogies of adaptive biological learning. NNs are trainable systems whose learning abilities, tolerance to uncertainty and noise, and generalization capabilities are derived from their distributed network structure and knowledge representation. Learning of a NN typically implies adjustments of connection weights and biases so that the square error (between NN output and desired output) is minimized.

Neural networks are used to tune membership functions of fuzzy systems that are employed as decision-making systems for controlling the hydraulic system. Although fuzzy logic can encode expert knowledge directly using rules with linguistic labels, it usually takes a lot of time to design and tune the membership functions which quantitatively define these linguistic labels. In proposed study a Neural Network learning techniques can automate this process and substantially reduce development time and cost while improving performance of the pump flow rate and compensate its back pressure effect.

II. SYSTEM MODEL

With these values, an approximation of the hydraulic energy requirements can be made using the fact that the energy absorbed into the fluid will be,

\[ E = \frac{1}{2} Q P dt \quad (1) \]

where is the volumetric flow rate of the pump and is the pressure at the pump outlet. The worst case scenario
would be if the pump had to operate at its maximum pressure at all times. Any pressure below this value will require less energy input. It will be assumed that the pressure is at the system maximum for now to book end the problem. By making this assumption, the energy integral becomes,

\[ E = P_{\text{max}} \int Q dt = P_{\text{max}} V_{\text{displacement}} \quad (2) \]

where is the volume of fluid displaced over the loading cycle. The analysis was done based on a single stop and assumes that the work circuit hybrid will only operate the loading functions of the vehicle. The compacting and ejection of the waste is assumed to be done using the standard method because these operations require a lot more fluid. Rear loaders often pack and sweep the garbage is a single operation; therefore, both a pack and sweep cycle and just the sweep cycle were evaluated.

As illustrated from Fig. 7, the volume displaced by the pump during this deceleration can be calculated using.

\[ V_{\text{disp}} = \int Q dt = \int_{0}^{t_{\text{stop}}} \eta_{p} \omega_{p} d\theta/dt \quad (3) \]

The word energy is abused for both energy and power though out the paper. It is obvious that there may be two ways to reduce the energy usage:
1. reduce the supply pressure
2. reduce the pump flow rate

III. STRATEGIES FOR IMPROVING THE PERFORMANCE OF EFFICIENT ELECTRO-HYDRAULIC CIRCUIT

The hydraulic power which is function of flow and pressure varies as the actuator speed rises and falls at acceleration and deceleration period in response to cycle time of machines by controlling the rotating speed of the hydraulic pump and prevent unnecessary loss of motive energy by stopping the pump during idle time. A conventional hydraulic system which controlled by hydraulic or electric system, most of the electro-hydraulic system has low efficiency with high energy loss [18-20]. Therefore, this research is interested in a development of a power unit electrohydraulic energy saving system using a typical induction motor with an inverter controller. The inverter is characterized by load sensing by using impedance controller and employing a fixed displacement pump. To better understand the shortcomings regarding energy efficiency in any hydraulic system, it is important to look not only at the system itself, but also under what loading conditions it operates.

In most valve controlled systems used in mobile machinery one pump is shared among several drives of cost reasons. The problem in doing so arises when the load pressures differ among the drives in the hydraulic system, shown in Fig. 3. Any simultaneous motion of drives with unequal pressure levels results in an undesired pressure difference over all valves but the one controlling the drive operating at the highest pressure level. This pressure difference multiplied by the required actuator flow is referred to as a metering loss and is an issue where parallel operation takes place. This is a well-known fact that can be compensated for by dimensioning the cylinder drives to minimize the power loss for a given duty cycle. This will always lead to a compromise in efficiency and component size.

Another approach in valve controlled systems is based on distributed throttle control. In contrast to the valve arrangement using spool valves the meter-in and meter-out orifices are no longer mechanically coupled. These concepts provide a higher degree of freedom in control as all four orifices are separated and can be controlled individually. Much work has been done on such concepts, both in academia and industry [21-22]. Some systems based on this technology have reached the market over the years, even if the focus has not always been on saving energy.

In more recent studies, for example [23], a greater emphasis is laid on the efficiency aspects of separate metering valve controlled systems. When the appropriate hardware is combined with sophisticated control strategies, these systems can potentially save a considerable amount of energy in mobile machines. The state-of-the-art systems in this field of research not only minimize the meter-out losses but also enable energy recuperation.

Energy recuperation in this case refers to letting back pressurized flow to the supply line to be shared by other hydraulic drives in the hydraulic system. As mentioned earlier, a general problem with valve controlled systems is that controlling multiple drives with unequal drive pressure levels can lead to
substantial power losses. In a concept presented in 2007 the loads are controlled with the objective of minimizing these losses by using the asymmetrical cylinder as a discrete transformer [24], shown in Fig.4. Furthermore, the controller presented together with this concept is capable of recuperating energy by letting the overrunning cylinder provide any simultaneously operated drive with flow and pressure.

Moreover, in the field of distributed digital hydraulics a substantial energy saving potential has been shown, for instance by [25-28].

Another obvious approach to eliminate these metering losses is to introduce a separate pump for each hydraulic drive. Figure 5 shows an example of this using load sensing hydraulics. This solution of course comes with a higher cost for components, but for some applications this can be justified by higher system efficiency.

**Advanced Control Concepts**

To further improve the energy efficiency of flow controlled systems, the electronic control unit allows for several advanced control strategies. Without the LS-inherent pressure dependence of the oil flow delivered by the displacement pump, the system may be operated in a state of controlled undersupply. For this undersupply, different operating strategies are conceivable, all affecting control precision but further enhancing efficiency. Djurovic stresses the importance of compensating leakages in valves and consumers into the pump flow rate calculation [7]. Generating a rather high oil flow the machine operator is to balance out inaccuracies by adjusting his flow demand. As Finzeldeploys post compensators with flow sharing properties, these compensators distribute the entire pump flow relative to the individual valve openings. This gives the control system one extra degree of freedom, that may be used to minimize the pressure drop across the metering orifices. Finzel suggests to open the orifice of the load-leading consumer completely and to adjust the opening of the remaining orifices according to the demanded flow shares. The potential additional energy savings of those four advanced control concepts are investigated in a dynamic simulation model of the forestry crane, [8].

A novel control concept is being introduced to prevent flow oversupply in case of consumers reaching cylinder end stops. In this case the consumer velocity inputs and the actual consumer oil flows do not match any more. If the aggregate flow of the pump is solely calculated through addition of these consumer velocity inputs, the pump delivers too much oil into the systems, accelerating the residual consumers in an undesirable manner. To overcome the issue, the control valves are equipped with additional pressure transducers and electronic pressure limiting functions. Reaching an end stop, causes the consumer pressure to rise to its preset maximum. In turn the related control valve switches from flow control mode to pressure control mode, ignoring the joystick input and controlling the pressure by reducing the control edge opening. The respective closed-loop control is displayed in Fig. 6.

**IV. Conclusion**

In the past few years, considerable effort has been made to improve the power efficiency of electrohydraulic systems; many energy saving strategies have been successfully developed and used. However, most of them can only be useful in specific applications. A brief idea is to highlight the different technological processes used for improving the performance of efficient electro-hydraulic circuit in energy saving was presented.

**REFERENCES**


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