ENERGY LOSSES IN HYDRAULIC SYSTEMS

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1. Introduction

Energy losses in the current hydraulic systems, ranging between 30% and 50%, can no longer be accepted and therefore relevant scientific research carried out in the last 20 years has analyzed the main causes, vulnerable places in the installations and ways to reduce them. In fact, energy losses are determined, among others, by the friction of the fluid layers between them and with the pipes through which they pass and by the pressure drops on the equipments, at bends and diameter changes. Finally all these cumulated hydraulic pressure losses turn into heat, and thus to the energy loss is also added the destructive action of the high temperature and the obligation to introduce additional cooling equipment in the system. Another way of losing energy in hydraulic systems is given by the hydraulic leaks, which are small in the beginning and increasingly larger over time. Over time there was another way of losing energy, namely by sending to the tank through the safety valve of the excess flow given by the pump. There is excess flow in the system in some phases, because the system works with constant flow at all time. It should be noted that this type of losses was greatly limited, modern proportional hydraulic systems solving the problem of flow adaptation to the requirements of the serviced equipment.

2. Structure of hydraulic systems

Any type of system in question, whether using traditional hydraulics (on/off) type A, proportional hydraulics type B, digital hydraulics with parallel connected components type C or switching-type digital hydraulics type D, is composed of pumping group, distribution equipments, hydraulic motors, pipes and auxiliar components.

2.1. Pumping equipments

The pumping group is composed of an electric or mechanic driving motor, an oil tank with all its constructive elements and a pump. The pump type is different for the four types of systems analyzed. For systems of types A (fig. 1) and B (fig. 2) the pumps are common, well developed as project and realization and today with a total efficiency of approximately 90%. The most used are the gear pumps (fixed) and the axial piston pumps. Axial piston pumps can be fixed or adjustable and for the case of adjustable pumps they can be equiped with many types of controllers, each managing to close the flow discharged to the load requirements of the system, on coresponding work phases.

For systems of types C and D there is an option using classic pumps, in which the flow is selected by switching valve (fig. 3a) or by pump size (fig. 3b) and another option that uses pumps with independently controlled pistons, as shown in Figure 4a.

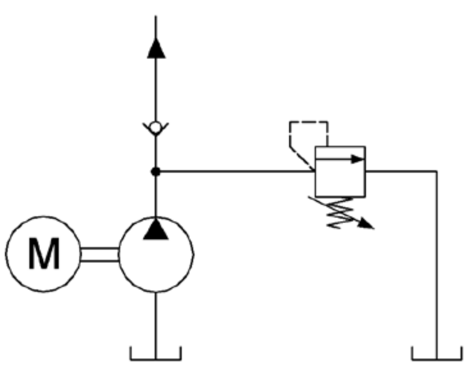


Fig.1 Type A (traditional – all/nothing) hydraulic system

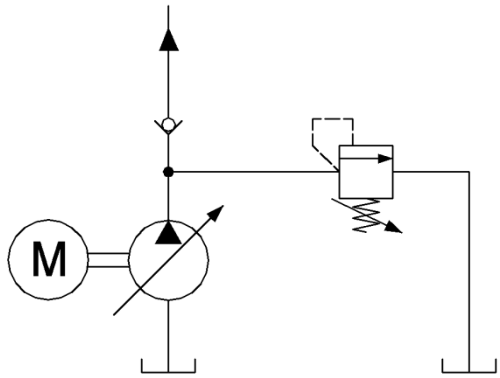
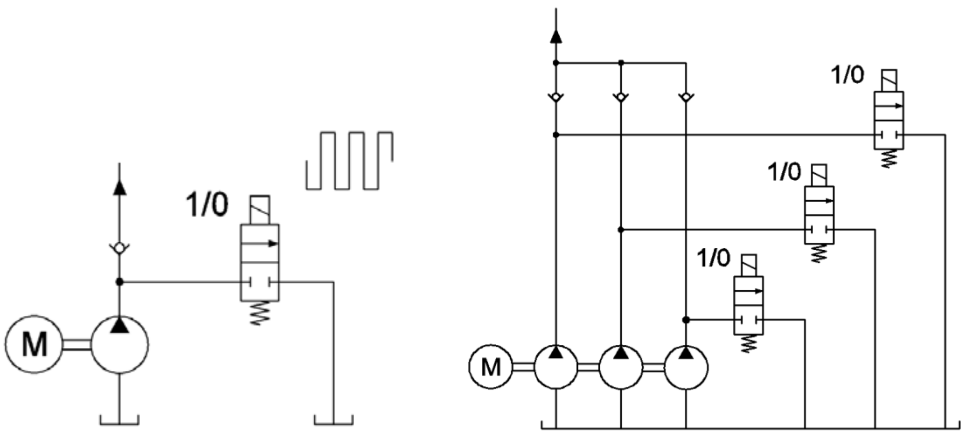


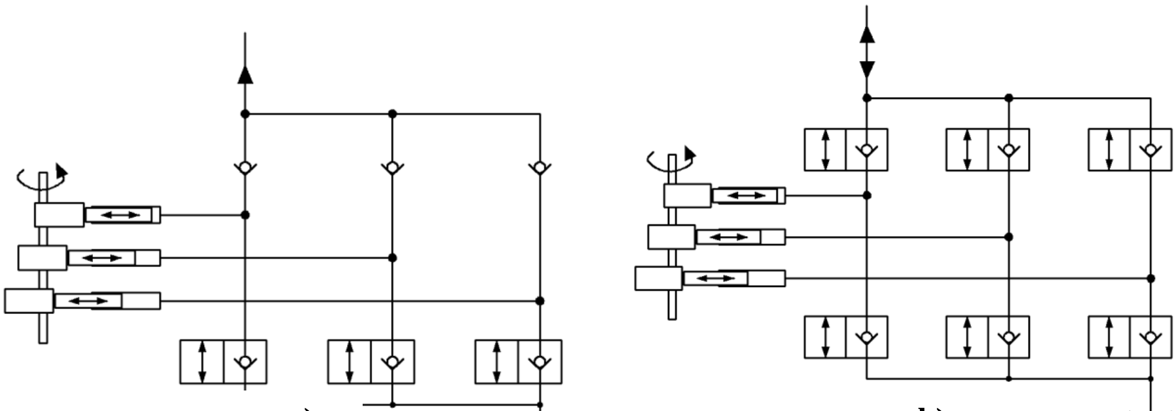
Fig.2 Type B (proportional) hydraulic system

In Figure 3a, the pump is fixed and the flow in the system is adjusted by switching the switching valve at a level required every time. Theoretically no safety valve is necessary, but in practice things are different. In Figure 3b are shown three fixed pumps driven by the same motor. The flow adjustment is ensured through individual connection to the system or tank, according to the flow requirements of each work phase. Besides the differences in the type of pumps, it is noted that there are no differences in the general structure of the pump group, meaning that the tank and its annexes don't disappear.



a) **b)**

Fig. 3 Switching pump (a) and parallel connected pumps (b)



a) **b)**

Fig. 4. Piston type digital pump (a) and pump-motor (b) [1]

2.2. Distribution equipments

This group of equipments includes elements for distribution and for the flow control. Because of the major differences between the four types of systems in what concerns the distribution, our research will focus here, for the begining. It is important that the results of this research will lead to elements simple from the technological point of view, as fast and as accurately as possible both in achievement and in repeating the performances.

In systems of type A (fig. 5) besides the common directional valve are also introduced flow control elements such as throttles and flow valves with two or three ways. In the case of throttles and two way flow valves, the excess flow will be sent to the tank through the safety valve, hence at the maximum system pressure. Solutions to introduce variable pumps and 3-way flow valves were huge steps in reducing energy wastage, but not enough.

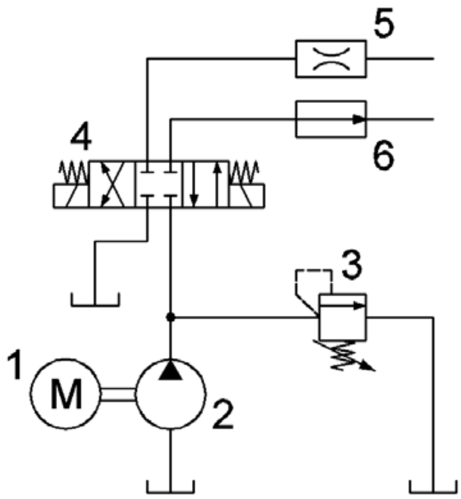


Fig. 5. Type A hydraulic system: 1-drive motor; 2-hydraulic pump; 3-safety valve; 4-hydraulic directional valve; 5-throttle; 6-flow valve

In systems of type B (Fig. 6), by including servovalves and/or proportional directional valves, the system was simplified, the price increased slightly, while the energy losses were greatly reduced by their combination with modern control schemes for pumps, including load-sensing in recent versions, and increased by pressure drop on servovalve.

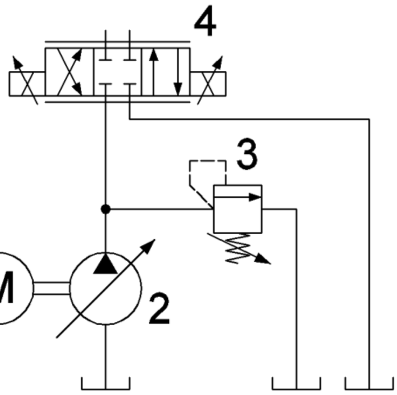


Fig. 6. Type B hydraulic system: 1-drive motor; 2-adjustable hydraulic pump; 3-safety valve; 4-servovalve

C-type systems (Fig. 7), well represented by the team of Prof. Linjama and Prof. Vilenius of the Tampere University, have gained a great development, representing the most analized digital hydraulics solution, with good theoretical results, but with still many technical and financial problems.

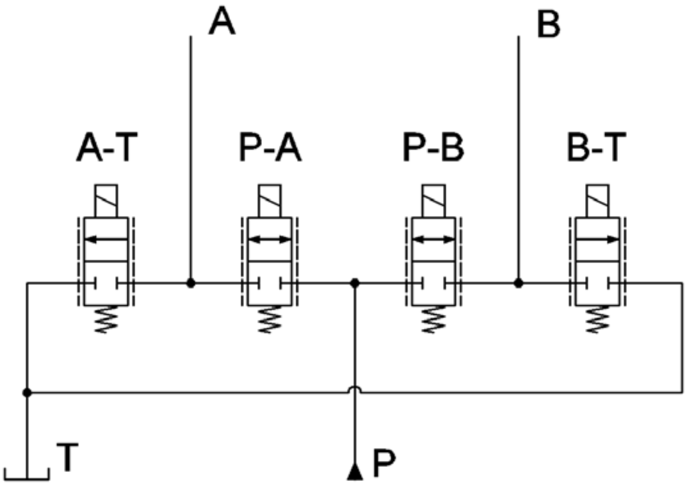


Fig. 7. Type C hydraulic system: implementation of distributed four-way valve by digital fluid control units [1]

D-type systems (Fig. 8), developed mainly by the team of Prof. Scheidl in Linz, promises a great organological simplification and a substantial reduction in energy losses, without currently imposing on the hydraulic market.

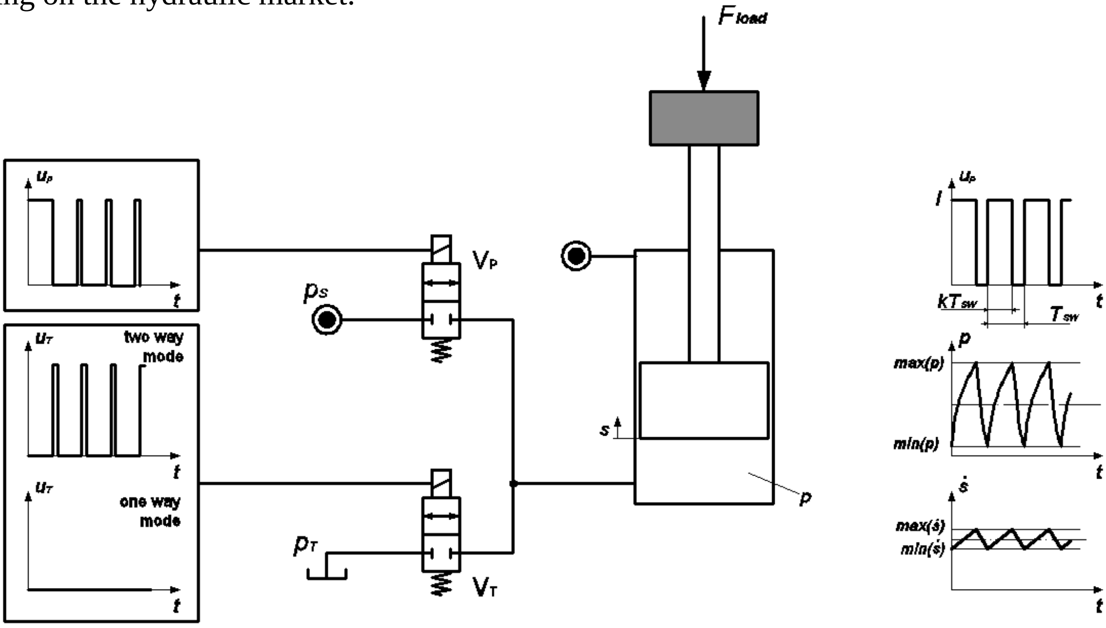


Fig. 8. Elementary switching control scheme (left) and typical signals in one way mode operation (right) [11]

2.3. Pipes and auxiliar components

In the group of auxiliar components are included firstly the elements for conditioning the working fluid such as filters, coolers, check valves, pressure valves, as well as hydro-pneumatic accumulators. They are definitely necessary for type A and type B systems, quite possible necessary for several C-type systems, and even for those of type D for which it theoretically states as unnecessary. Long pipelines, who through their length, bends and section variations are an important source of energy losses, are included in all types of systems at about the same level even if it seems that for type D-systems the simplified structure greatly reduces their influence.

2.4. Hydraulic motors

In all the systems are rotary or linear hydraulic motors (cylinders) and used to convert pressure into torque or driving force. To reduce energy losses the solution that is looming for hydraulic cylinders is to create variants in which it can be changed the active surface, as shown in Figure 9. This are solutions that are considered today as very important for systems of type C. For installations of type A, type B and even D, hydraulic cylinders are those traditional, for which energy losses are difficult to reduce. Rotary hydraulic motors are usually similar to rotary pumps, so it is interesting to find industrial solutions for systems of type C and type D, given the fact that for the systems of type A and type B solutions for modernization are difficult to find.

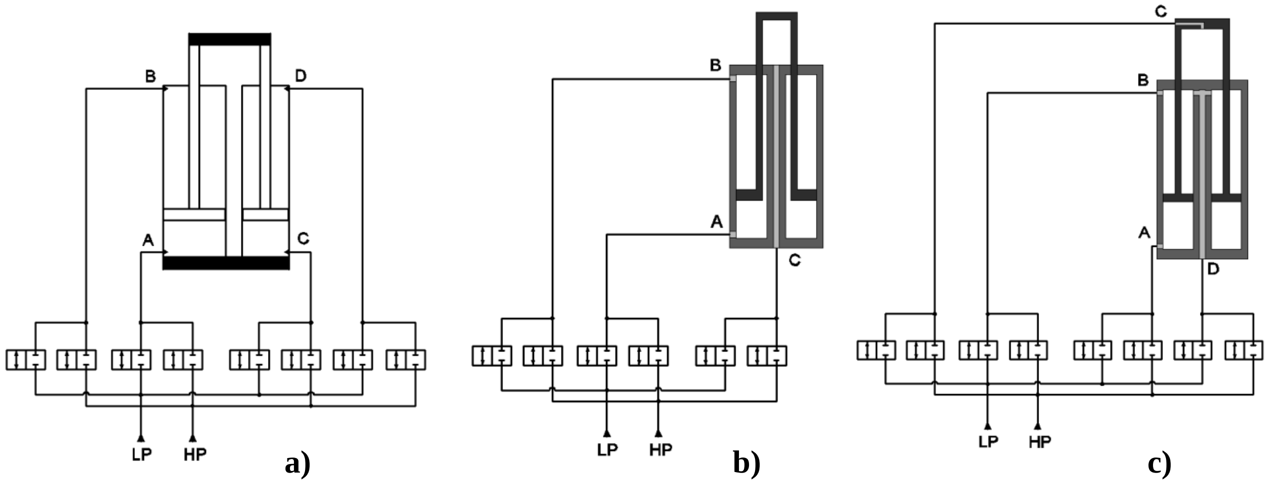


Fig. 9. Different implementationsof multi-chamber cylinders. LP=low pressure line, HP=high pressure line [1]

3. Energy losses in components and systems

3.1. Energy losses in hydraulic systems of type A

In this section will be taken into considerarion losses in pumps, distribution and control systems, pipes and hydraulic motors.

a) Losses in pumps are determined by internal losses and mechanical friction, and the total efficiency, which represents the energy efficiency, will be determined as the product of volumetric efficiency and mechanical efficiency. An increase in the technological level of pumps manufacture, together with improved materials and increased tribological performances, made that the volumetric efficiency determined primarily by side clearances, as well as the mechanical efficiency determined by friction, both have values over 90%, so that in the end the total efficiency will also be over 90%.

b) Losses in the distribution and control section are local losses determined by either construction of the equipment or the working methodology of the system. If losses on every component can be treated as local losses and reduced by improving the forms of flow, within fairly narrow limits, technological losses recorded on flow control valves and regulators can be minimized through a proper design of the whole system and especially through the use of adjustable pumps with high level of automation. Upgrades in this area of a hydraulic system could lead to the greatest reductions in energy losses with current equipments and technologies. In fact, the most important thing is to devise a system by which the discharges to the tank through the safety valve to be minimized.

c) Losses on pipelines and auxiliar components are generally quite high and are comprised of linear losses and losses on auxiliary equipments such as filters, accumulators and coolers. Generally, losses on auxiliar components can be treated as local losses with relatively small values, with rather small possibilities of reduction, as some of these components don't permanently intervene into operation (accumulators), and others can be bypassed.

The big problem are the linear losses in the pipelines, which generally have high values and on which is working much and generally efficient. Designers choose the shortest routes, reduce them to the minimum, avoiding the forming of local areas of turbulence. Very important when designing a hydraulic system is that the choosing of the pipes – material, shape, inner part processing and diameter – to ensure as little friction as possible and the velocity profile to approach the form in Fig. 10.

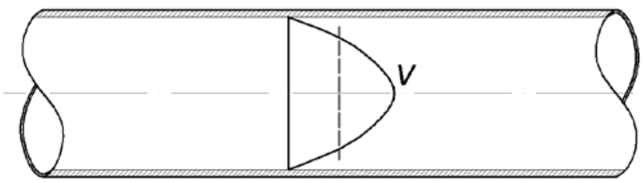


Fig. 10. Speed profile of the fluid in a straight tube

d) Energy losses in hydraulic motors are quite important, even though not essential. Losses in rotary motors are similar to energy losses in pumps because also in this case the one that counts is the tribological element and less the technological element, through which are produced at normal prices side clearances that can reduce internal flow losses. Hydraulic cylinders, with their component materials and the structure may reduce losses, but can not remove them.

In any case, in the cylinders used today in hydraulic systems, we find the friction between the rod and rod cap seal, between the piston and cylinder body and in the couplings by which the cylinder is attached to the mechanical equipment. Much important and more dangerous are the problems caused by a poor grip on the machine, because high radial forces are introduced which induce high friction and therefore high power losses. Unfortunately, mostly these bad assemblies do not depend on hydraulics, but cause faults devastating for the hydraulics. For the hydraulic cylinders are taken into account the sum of Stribeck friction, Coulomb friction and viscous friction. To reduce the influence of Coulomb friction and viscous friction were made new materials for seals and bearings in the cylinder, as well as fluids with reduced friction.

3.2. Energy losses in hydraulic systems of type B

Losses in pumps, pipes, auxiliar components and motors are quite similar to those described above for Type A hydraulic systems. The news for the systems of Type B are related to the command type of adjustable pumps, which basically started to be used in all classical installations, and to the distribution and control parts. It is known that the flow control is done by varying the fluid passage section, by the servovalve or proportional hydraulic control valve, according to the comand current size and the pressure drop on the device. If in the catalog this pressure drops have normalized values of 70 bar for servovalves and 10 bar for proportional control valves, in order to give the static and dynamic parameters of the devices, in reality we can discuss of another level of pressure drop established in the system, as a relationship between the load level and the safety valve setting. The idea is that through the automated system to obtain a closeness of the flow delivered by the pump to the flow delivered by the servovalve for each phase, so that losses to be as small as possible, but unfortunately not zero. The curves shown in Fig. 11 and in Fig. 12 show that the flow variation is closely related to the pressure drop and the slide valve's position in the body, namely the size of the crossing area.

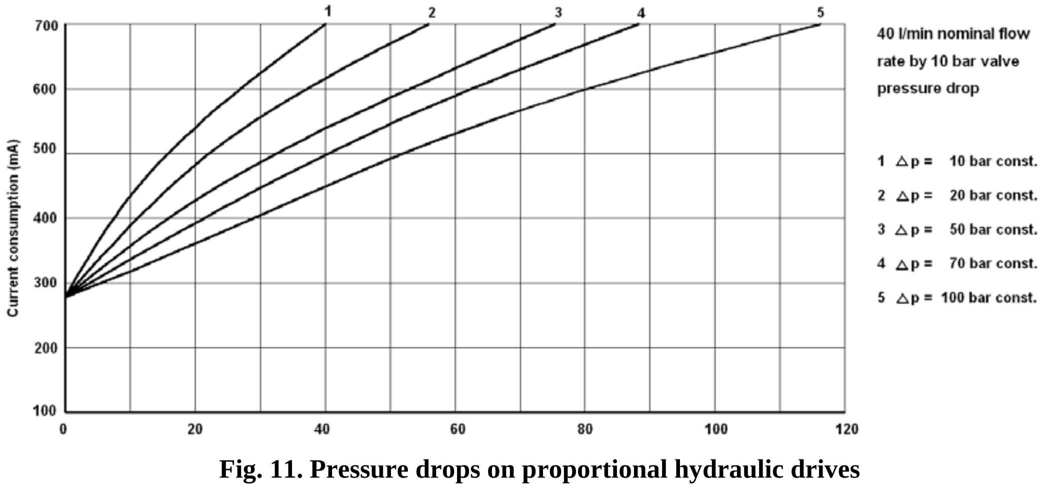


Fig. 11. Pressure drops on proportional hydraulic drives

3.3. Energy losses in hydraulic systems of type C

a) Losses in pumps are basically about the same as those in pumps of type A and B, as it comes about creating pressure by mechanical drive of some axial pistons. Losses on pipelines and auxiliar components are similat to those of type A and type B, since the pipeline routes are about the same and the quality of processing, materials and diameters are similar.

b) Energy losses on distribution equipments are greatly diminished by a configuration specific to digital control valves and by removing other elements of flow control. Whatever the constructive version chosen, hydraulic pressure losses on the device are reduced, but not completely removed. It is very important that in the selection process of control valves to have the posibility of choosing them depending on the required flow in the system in each working phase.

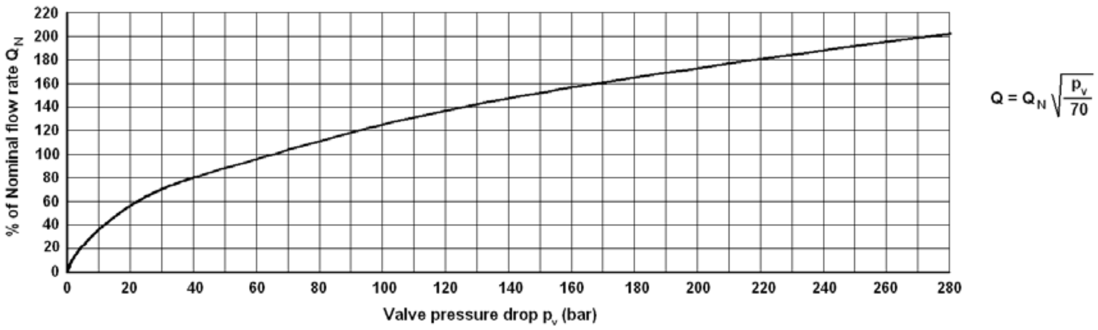


Fig. 12. Pressure drops on servovalves

c) By the many new solutions of digital actuators can be reached a full use of the hydraulic energy delivered by the system, mostly just by the pump. New solutions don't entirely reduce the internal friction, but they substantially improve its overall functioning.

3.4. Energy losses in hydraulic systems of type D

Switching-type digital hydraulics represents a solution of great interest which provides close proximity between the available flow rate and the required flow rate in each phase of work and also greatly reduces the number of hydraulic equipments for distribution and control. Another great advantage is the reduced number of pipelines and hence linear losses. Otherwise the problem of the pumps and motors is similar to Type C systems.

4. Methods to reduce losses in hydraulic systems

Energy losses in hydraulic systems can be reduced by both interventions on component equipments, as well as through interventions on the system.

a) Interventions on equipment

- Choosing of modern materials, more resistant to high forces and pressures, but especially to friction, in order to reduce wear, for use in the construction of pumps and motors.
- Use of modern technologies which reduce side clearances and all areas where flow losses can occur for pumps, motors and control valves.
- Choosing of pipes made of materials that can be better processed on the inside and compatible with the working fluid.
- Setting of circuits as short as possible, with little direction changes and as lew as possible diameter changes.
- Choosing of a suitable working fluid, with viscosity adapted to the type of movement, to the type of materials used for pipes and equipments, and especially to the temperature and temperature variation in the system.
- The choice of materials for hydraulic cylinders and bushings of and for the sealing elements on the basis of reduction of friction forces and wear.

b) Interventions on the system

Over time, in the last century, the role of hydraulic drives in industrial development has increased continuously and only recently appeared signs that there are areas where electric drives have become an economical alternative. Interesting is that instead of exclusive criteria of technical level or production price, the criterion of energy losses appeared, where hydraulic drives apparently do not stay well in all situations. To remedy this obstacle, researchers in the field approached a few ways including major modernization including the following, important from the author’s point of view:

- Using variable pumps.
- Creating regulators for pumps to fit easily in an automation system which to approach the flow value delivered by the required flow value in each phase of work.
- Reducing equipment in functional schemes by transferring part of tasks to the electronics and informatics, mechatronizing the system.
- Transition to the new principles such as the digital hydraulics, which means new equipments and schemes with new general concept.
- The use of digital hydraulic power management systems (DHPMS) for the purpose to reduce energy losses purposed.
- Hydraulic coupling of the pump with the motor almost totally reduce other distribution and control elements for digital hydraulic switching drives.
- Starting from all the elements presented above, the authors wrote in Table 1 the elements of a qualitative comparison between the four types of hydraulic systems.

Table 1. Comparison of energy losses for hydraulic systems

Type of energy loss	**A (On/off hydraulics)**	**B (Proportional hydraulics)**	**C (Parallel type digital hydraulics)**	**D (Switching type digital hydraulics)**
Hydraulic friction	L_2	L_2	L_2	$L_2 \longrightarrow L_1$
Mechanical friction	L_1	L_1	L_1	L_1
Pressure drops on equipments – pumps, valves, actuators etc.	L_2	L_2	$L_2 \longrightarrow L_1$	$L_2 \longrightarrow L_1$
Local pressure drops – connec-tions, diameter changes etc.	L_1	L_1	L_1	L_1
Leakages	L_2	L_1	L_0	L_0

Flow discharged under pressure to tank	L_3	$L_1 \longrightarrow L_0$	L_0	L_0
System complexity and linear losses	L_2	L_2	L_1	$L_1 \longrightarrow L_0$

L_0 – very small losses, close to 0;
L_1 – small losses;
L_2 – medium losses;
L_3 – high losses.

5. Conclusions

The research results in the last years have started to show in practical action.

Proportional hydraulics and classic reduced greatly the energy losses through massive coupling with electronics and informatics, making the step to mechatronization.

The emergence of digital hydraulics has opened a new way, which is still not accepted and applied widely in industry, primarily due to price and secondary due to the novelty of the idea.

The rapid development of digital hydraulics and increase in its usability will soon lead to sharing applications between all 4 types of hydraulic equipments.

Hydraulics is generally still quite used, is in a permanent increase in technical level and a production price equalization.