ISSN 1454 - 8003
Proceedings of 2016 International Conference on Hydraulics and Pneumatics - HERVEX
November 9-11, Baile Govora, Romania

DIGITAL HYDRAULIC MOTORS

Petrin DRUMEA[1], Ioan PAVEL[1], Gabriela MATACHE[1]

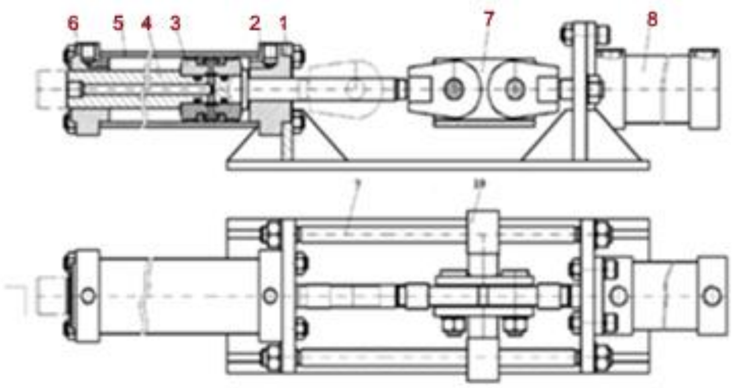
[1] INOE 2000-IHP Bucharest, ihp@fluidas.ro

Abstract: *General trends for reducing the energy consumption have led through innovation, in the case of hydraulics as well, to new solutions for equipment which could meet this challenge. Since the 1990s the concerns in implementation of the existing theories on digital hydraulics have increased.*
Conversion of hydraulic energy into mechanical work is done by using rotary or linear hydraulic motors. Digital hydraulics solutions for rotary hydraulic motors consist of pressure and flow control directly in pressure chambers of the rotary hydraulic motor. For linear hydraulic motors the solution investigated is based on constructive solutions, either direct or intermediate, for variation of the linear motor piston surface.

Keywords: *digital hydraulics, hydraulic motor, actuator*

1. Introduction

As it is known, in hydraulic systems conversion of electrical or thermal energy into hydraulic energy (pressure, flow), and further into mechanical work is done with quite significant energy loss consisting in pressure loss (Δp) through heat. For instance in the servomechanisms the pressure drop required to be projected when sizing hydraulic installations is of 70 bar, and total energy loss could reach even 65% of energy required for a proper functioning. Nevertheless, hydraulic installations have no alternative; they benefit from great power and torque potential, with low power density/kg (it is about three times lower than in electric motors).
Linear hydraulic motors (also called actuators or hydraulic cylinders) can be found on the market in several constructive types depending on operating and use conditions within hydraulic systems. Thus, there are soft series actuators -for maximum 160 bar, medium series actuators -for maximum 250 bar, heavy series actuators -for maximum 315 bar, or special actuators for more than 315 bar or with speeds higher than 0.5 m/sec.
Depending on the constructive series of linear actuators, inner seals and rod and piston guides introduce resistance forces during the relative motion, materialized in tightening and friction, which can reach values equivalent to a pressure of 5-15 bar. The starting pressure is defined as the pressure at which the actuator rod starts moving, while minimum steady operating pressure is defined as the lowest pressure at which rod moves with constant speed all along the stroke.
An example of mounting diagram for testing the parameters above is the following one:



Caption
1-frame,
2,6-caps,
3-piston,
4-rod,
5-liner,
7-hitch,
8-standardized hydraulic cylinder

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It takes innovation in hydraulic systems to meet the new requirements for energy efficiency and decrease in CO2 emissions in the chain of production and in use on fixed or mobile equipment.
Areas in which digital hydraulics interferes are: digital control of hydraulic motors, with parallel or switching distribution, efficient energy management and reduction of energy losses [1].
In a classic hydraulic system with linear actuator in the case of a variable load the chosen solution will be the classic one, with fixed active surface of the actuator and variation of working pressure. Theoretically it has been found that efficiency of a hydraulic system is better when area of the actuator varies, compared to the case when working pressure varies, precisely because of Δp and because of power oversize for peak load in the case of variable loads [2].
The solution to vary the area of the actuator results in reduced overall sizes, reduced weight and energy consumption. Along with reduction of Δp and residual heat energy savings also intervene; this energy would have been used to cool oil in hydraulic installations for optimal functioning. Applying digital hydraulic drives, which have smaller overall sizes and weight, on mobile machinery contributes to fuel savings estimated to be 5-10 % [3].
Another advantage of digital hydraulics is digital control location very close to controlled element, thus obtaining shorter response time and better system dynamics without price increases and with enhanced effectiveness.
Components of digital equipment are fewer and less complicated from the technological point of view compared to the equivalent conventional equipment; they have simple design and can have modular construction [4].

2. Simplified diagrams of digital hydraulic motors

The hydraulic motors can be controlled digitally by independently controlling pistons in their structure or through mounting diagrams with switching directional valve or parallel mounting.

a) Simplified diagrams of digital rotary hydraulic motors

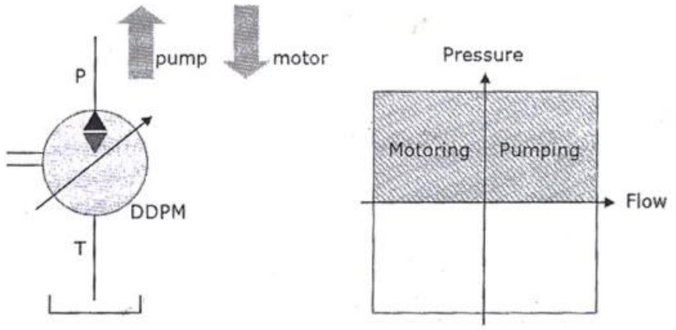

Fig 1. Digital Pump/Motor (DDPM) [5]

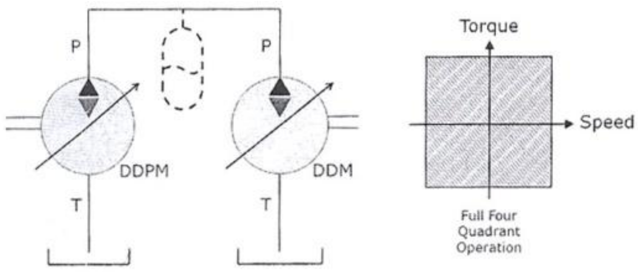

Fig. 2. Full digital hydraulic transmission [5]

One way to implement the digital pump or motor is to control each piston of them by using digital on/off directional valves. An example of diagram is shown in Figure 3, where each piston can work in pump or motor mode depending on the position commanded in the digital directional valve.

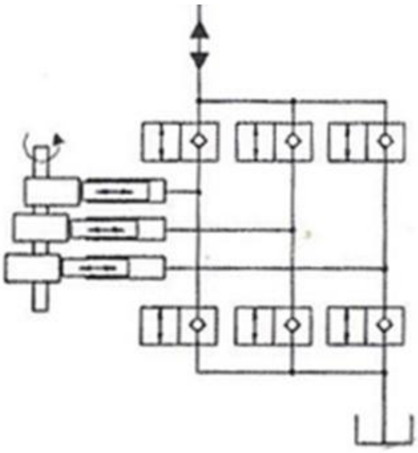

Fig. 3. Piston type digital pump (a) and pump-motor (b) [6]

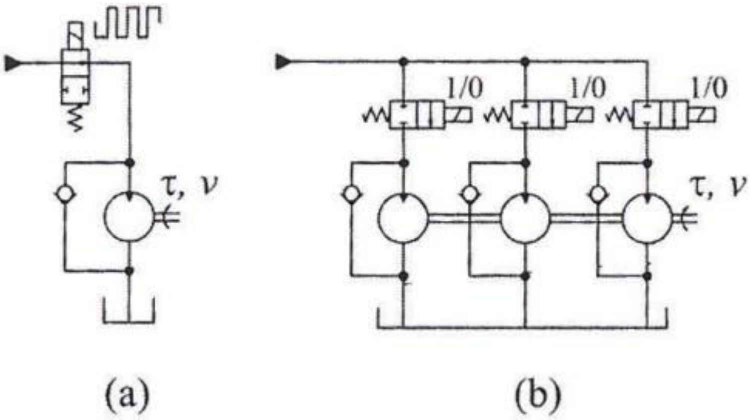

Fig. 4. Switching motor (a) and parallel connected motors (b) [6]

b) Simplified diagrams of digital linear hydraulic motors

Consider the multi-chamber cylinder of Fig 5. If the control valves are large on/off valves -as in the figure- the system can generate 16 different forces. Sufficient inertia is needed for proper controllability and the system can be seen as secondary controlled cylinder without any losses. In practice, small compressibility and flow losses occur, but according to the authors' knowledge, this approach is the most energy efficient way to control hydraulic cylinder from the constant pressure lines. The weak point is that continuous switching between control modes is required in order to obtain quasi-steady velocity. The situation is not so demanding as in the switching systems because there are much more force values available.
If the on/off valves are replaced by directional valves, such as two-way proportional valves or DFCUs, the result is the extended version of the normal cylinder plus distributed valve system with pressurized tank. Losses are much smaller than in traditional systems because the pressure losses can be optimized by selecting the correct control mode on the fly. This approach combines good performance of the valve control and small losses, but the control code -especially the mode switching logic- becomes very complicated [6].

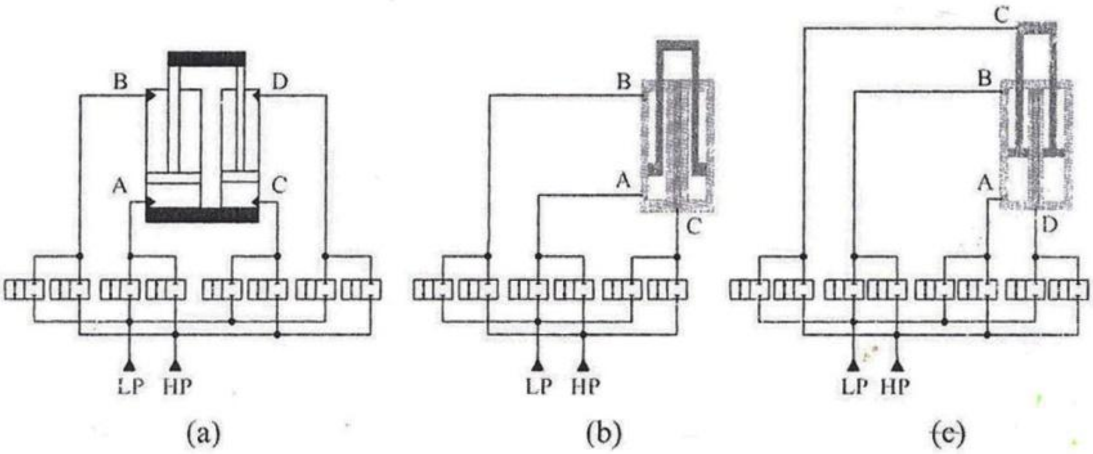

Fig. 5. Different implementations of multi-chamber cylinders [6]
LP= low pressure line, HP= high pressure line.

In 1998, Elton Bishop raised the issue of efficient energy hydraulic systems comparable to the human body muscles, where each one can respond to certain effort but all together they can handle a much greater effort, or even more effective when for a certain task there are used the muscles that have to be used, for as long as they have to, and when they have to. In digital hydraulic muscles are assimilated to active pressure chambers of rotary hydraulic motors or to divided active piston surface of the linear actuator. The primary objective of the new solutions for digital hydraulic equipment is to reduce the energy loss, mainly by varying flow and pressure directly on the hydraulic motors by using new performances of modern hydraulic equipment, especially parallel distribution and digital control switching frequency in distribution equipment.
In the case of linear actuators varying of their surface may be made by dividing the active area of the piston into several concentric annular surfaces, with binary weighted areas (figure 6) which are fed separately, but also cumulatively, following some rules, in order to get to combinations of fed areas by which one gets linear movement with variable speed or load (figure 7), thus meeting the requirements of hydraulic system.

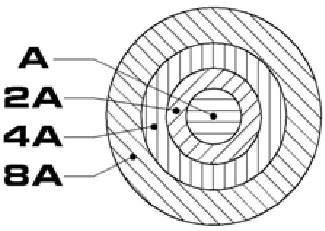

Fig. 6. Concentric arrangement of binary weighted annular areas [6]

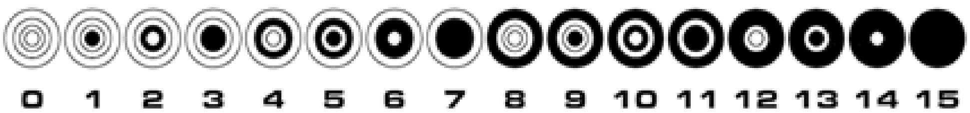

Fig. 7. Range of cumulative output force
White =Low Pressure; Black= High Pressure [6]

Other simplified solutions for mounting of actuators in line or in parallel are shown in figures 8 (a) and (b), while figures 8 (c) and (d) show constructive solutions for dividing the active area of a linear actuator into several concentric annular surfaces, with binary weighted areas.

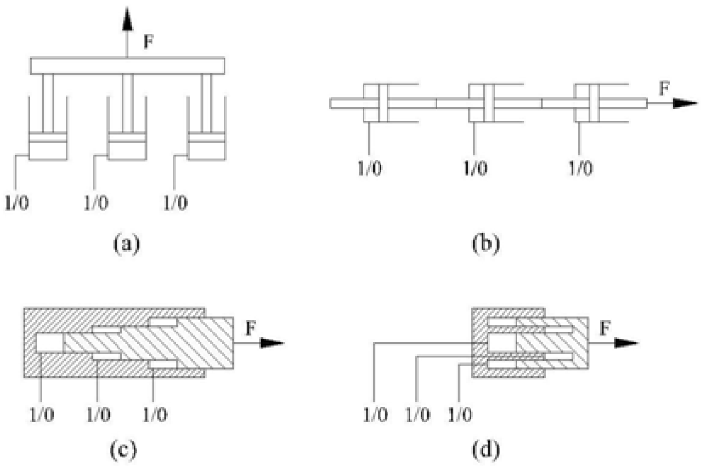

Fig. 8. Possible bit arrangements of VDLA [6]

3. Solutions

There are intense concerns to introduce the concept of digital hydraulics and intensify research on this topic. The team of specialists within INOE 2000 - IHP in Bucharest has submitted a patent application [7] for a solution of hydraulic actuator with multiple areas which meet the demands of a digital linear motor.
The digital hydraulic actuator, see fig. 9, with divided, multiple active areas, compact design, has the piston active surface made up of three concentric areas, with binary weighted areas, which can be fed separately, but also cumulatively, following some rules, in order to get to combinations of fed areas by which one can get fairly linear movement with variable speed or load, thus meeting the power and speed requirements of a hydraulic system.
The hydraulic actuator with multiple areas consists of a piston with four concentric diameters, a cylinder liner with three concentric diameters, a centering and supply cap, a guidance cap and guidance and sealing systems. The small number of parts and their simplicity make the patent application be a feasible solution from a technical and technological point of view.
The piston has three concentric areas, binary weighted. Thus, A2=2A1 and A3=2A2. This solution enables, by selecting combinations of fed areas, to obtain a fairly linear adjustable speed or force.
Control of supply to the 4 ports, i1, i2, i3, i4, by using digital directional valves, makes the multiple areas actuator be a linear hydraulic motor, digital, feasible, which may be the subject of study for the implementation of digital hydraulics.

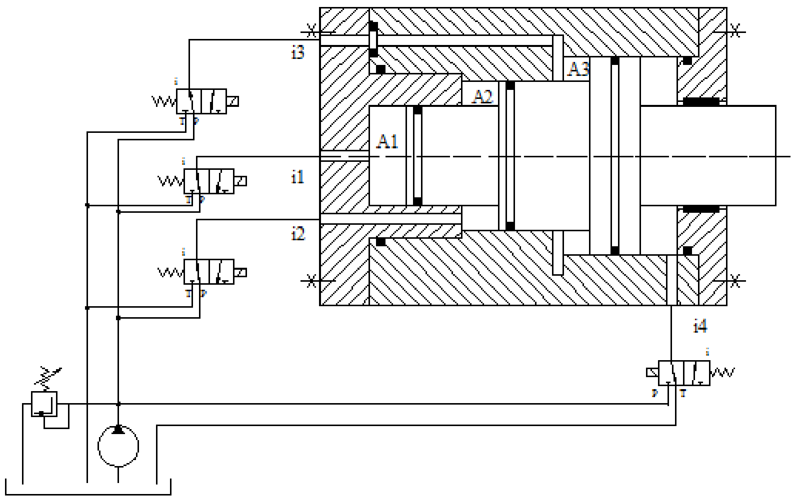

Fig. 9. Novel solution for a digital linear hydraulic motor

4 Conclusions

In the next period, reducing costs and increasing energy efficiency will be prevailing as success factors for any industry. Currently, the hydraulics industry is not fit to meet these requirements: conventional hydraulic systems and components are pretty expensive and have low energy efficiency.

Technological development of digital hydraulic motors could revolutionize the industries that use hydraulic systems and it could transform them into the fastest and most efficient form of power transmission. Energy savings resulting from implementation of digital hydraulic motors can improve technical and economic performance of technological lines which they are used in, this being ultimately shown in the execution price of the products on the market. At the same time, through energy savings and efficient use of resources, it contributes to laying the foundations of sustainable development.

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