Maintaining Position of Servo Cylinders by Means of Digital Hydraulics

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Abstract: *Replacing hydraulic proportional equipment and servovalves by simple-design systems in the area of digital hydraulics within positioning applications that use hydraulic cylinders is a solution that can lower the production price and can bring important energy savings in operation.*

Keywords: *Servo cylinder, digital hydraulics, on / off electrovalves, digital valves, positioning applications*

1. Introduction

The structure of classic hydraulic positioning servo systems comprises: devices for generating, conditioning, adjusting and distributing the working fluid, and also linear hydraulic servomotors, as hydraulic actuators, which, in fact, perform transformation / conversion of hydrostatic energy of the system into mechanical energy, in order to carry out the mechanical work required by the system / work equipment [1]. The linear hydraulic servomotors, which are hydraulic actuators within positioning equipment, perform a linear motion controlled with a certain force on the working mechanism, and they are characterized by controlled rectilinear motion. They are commonly known and currently referred to as 'servo cylinders' (Fig. 1) or 'hydraulic actuators' [2].

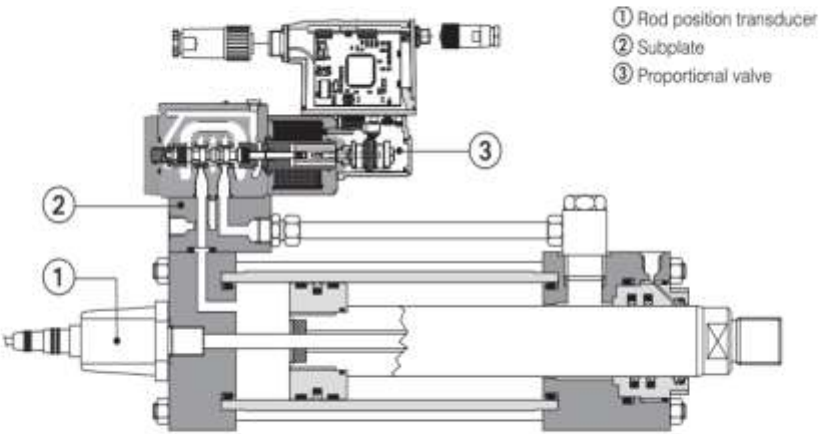


Fig. 1. Positioning servo cylinder [1]

Hydraulic proportional directional valves and servovalves (Fig. 2, left) are part of the linear hydraulic servomotors. They are expensive and demanding in operation, require very good oil filtration, cooling systems and pumps with increased flow. A good functioning of the system requires continuous operation of pumps to ensure the working flow and current flow and pressure losses which are not to be neglected. Each type of hydraulic proportional directional valve and servovalve is designed for specific conditions, so there are a very large number of types of such equipment. In the event of a failure in the operation of the proportional device, the functioning of the equipment is totally compromised.

In digital hydraulic systems (Fig. 2, right), with a combination of simple, robust and cheap on / off electrovalves or with directional switching valve, one can replace a proportional valve. The control module has the role of controlling the on / off position of the electrovalves to accurately ensure the flow and pressure required in the system, at lower production and operating costs compared to the classic solution.

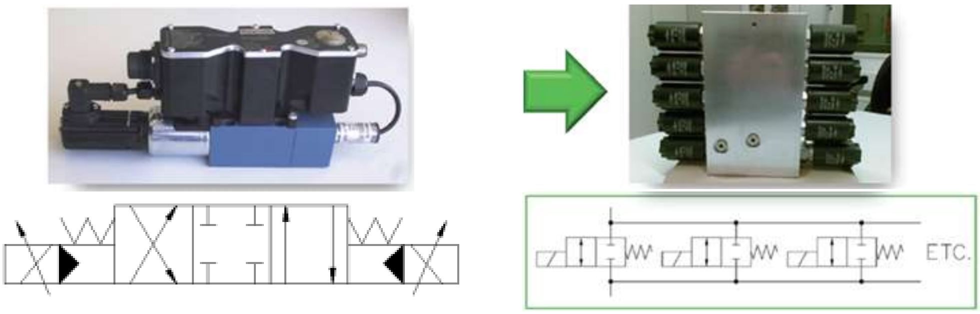


Fig. 2. Hydraulic proportional directional valve and servovalve (left); group of digital electrovalves (right) [3]

2. Solutions involving digital hydraulic devices

In the following we will present two solutions that can be applied. The first one is a solution which involves a digital hydraulic cylinder and classic on / off directional control valves, and it has been successfully applied in the specialized laboratory of INOE 2000-IHP. The second is the solution presented by Professor Matti Linjama in Finland, and it uses digital hydraulic directional valves.

2.1 The solution with digital hydraulic cylinder

A group of specialists within INOE 2000-IHP has developed a patent application [4] for a multiple area hydraulic actuator meeting the requirements of a digital linear motor.
The hydraulic actuator [4] (Fig. 3) with multiple active areas, divided, in compact structure, has the active surface of the piston made up of three concentric surfaces, with binary multiplied areas, which can be fed separately but also cumulatively, according to well-established binary rules, to achieve combinations of powered areas with which one can obtain relatively linear controlled movement, with variable speeds or loads, thus meeting the force and speed requirements of a hydraulic system.

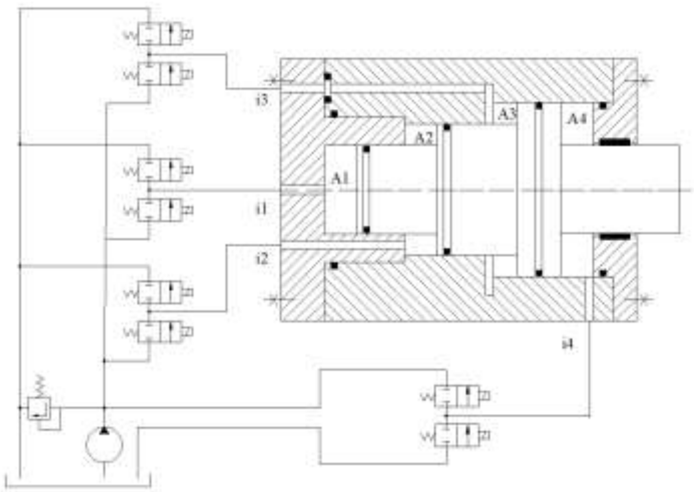


Fig. 3. Drive solution for a linear digital hydraulic motor [5]

The multiple area hydraulic actuator consists of a piston with four concentric diameters, a cylinder liner with three concentric diameters, a centering and feeding cap, a guiding cap and guiding and sealing systems. The small number of parts and their simplicity make the above mentioned patent application a technically and technologically feasible solution.
The piston has three binary multiplied concentric areas. Thus, A2=2A1 and A3=2A2. The solution enables, by selecting combinations of areas fed with constant flow and pressure, a relatively linear adjustable speed or force to be achieved:
F= f(Ai), when P = ct
V=f(Ai), when Q = ct

Where:
F= force
Ai= active area
P= pressure
V= speed
Q= flow

Supply control at the 4 ports i1, i2, i3, i4 by means of on/off directional control valves turns the multiple area actuator into a linear, digital hydraulic motor, feasible, which may be the subject of study for the implementation of digital hydraulics.

There are intense concerns about introducing the concept of digital hydraulics and intensifying research on the topic. In INOE 2000-IHP a specialized laboratory in Digital Hydraulics has been set up, for the two branches of this field, namely switching technology and parallel distribution technology. In the near future, two digital servo cylinders will be developed and tested. Testing the solution will be conducted on a specialized test bench (Fig. 4), with controlled hydraulic load, equipped with a force transducer, for active control of the adjusted force and for data acquisition, and with displacement transducer, also for active control of the adjusted force and for data acquisition. The results of this research will be the subject of several papers that will appear in specialized publications.

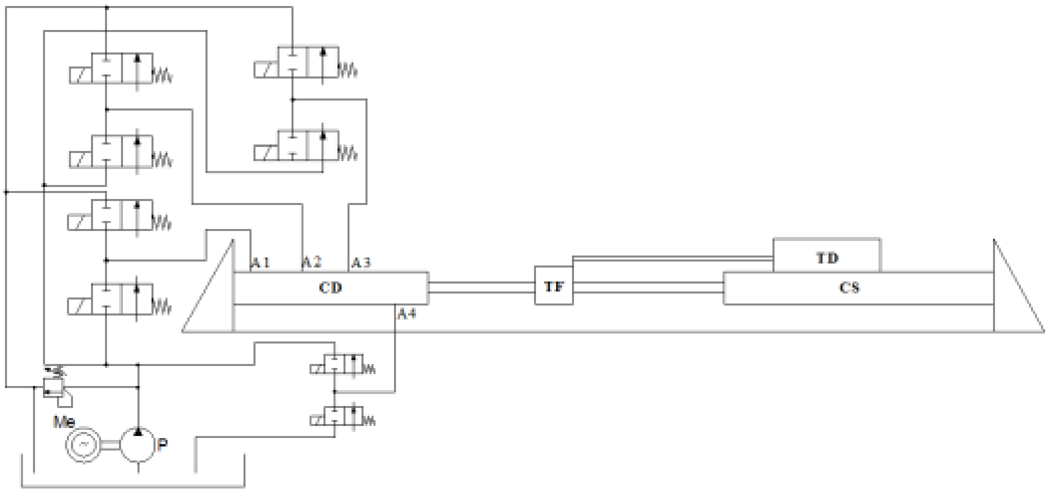


Fig. 4. Test bench for a linear digital hydraulic motor

Servomotors with digital hydraulic cylinders are controlled by a group of simple, cheap and very resistant electrovalves, individually actuated by a control unit which ensures their operation according to an optimal algorithm [6,7], enabling the functioning of systems with the same performance as in the case of actuation with proportional drive equipment, but at lower construction and operation costs. They are two-way normally closed directional valves which can maintain position of servomechanism when the electromagnet is disengaged, and when powering it enable flow transiting to adjust its position. Electrovalves do not lose oil in normal operation, and for this reason, when maintaining the position of a servomechanism there is no need for the pump to work continuously, and the working flow can be provided by a battery located near it, thus shortening the connection lines and eliminating the ΔP parameter, which is the loss along the connection lines. This solution can significantly reduce energy consumption because the pump may be smaller and will only work for charging the battery.

Digital electrovalves (Fig. 2 right) are smaller, cheaper, more reliable, and they are produced in large series, compared to proportional devices (Fig. 2 left) which have more complicated, expensive, and less reliable controls (torque motors or proportional electromagnets), and require higher initial, maintenance and operation costs.

In the event that a digital valve fails, (Fig. 5) the control unit automatically reconfigures the other valves in order to maintain the position of the servomechanism and mitigate negative effects on system performance. Compare this with the situation when the proportional device would fail; in

this event the equipment can no longer work or even worse, parts of it may degrade by fatal loss of position control.
Even the locking of an electrovalve on the open position can be compensated by the rest of the group's electrovalves by way of reconfiguring the digital controls. In this situation, flow consumption will unnecessarily increase, but the system will operate until the next scheduled stop. If a load peak accidentally occurs in the system, the digital system will react more quickly compared to the classic system, due to the multiple opening of the electrovalves.

Fig. 5. Digital control reconfiguration in case of failure of a digital electrovalve [3]

Digital electrovalves are very quick (Fig. 6), with the performance of switching open / closed mode within a few milliseconds, and by programming a PLC in a binary system one can get very good performance for a positioning system [8, 9].

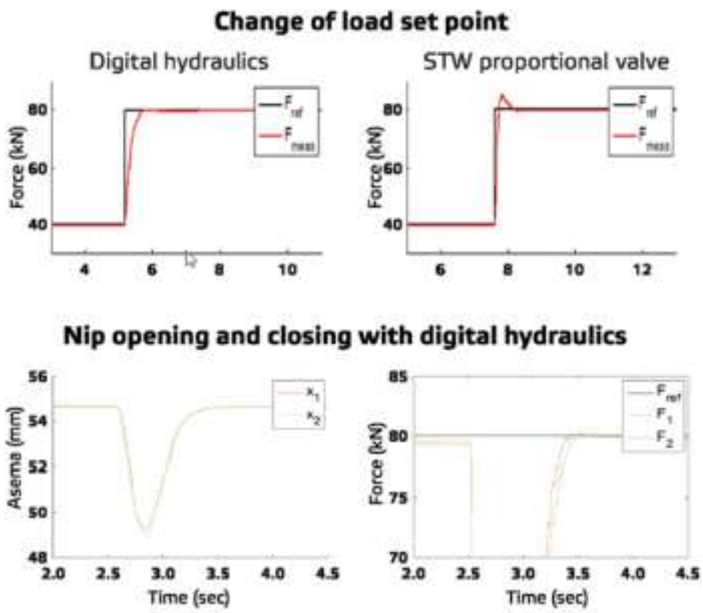
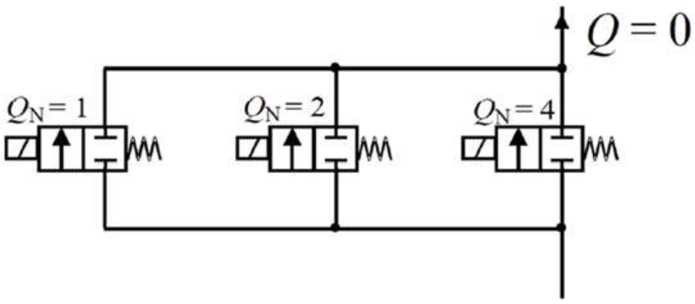


Fig. 6. Response time of digital electrovalves compared to classic servovalves [3]

2.2 The solution with digital hydraulic directional valves

An example of the use of digital electrovalves to obtain a variable flow rate [8] is shown in Figure 7.



V1	V2	V3	Q
0	0	0	0
1	0	0	1
0	1	0	2
1	1	0	3
0	0	1	4
1	0	1	5
0	1	1	6
1	1	1	7

Fig. 7. Flow control unit diagram (left); table of binary combinations for 7 flow stages (right) [3]

Electrovalves individually allow transit of a flow rate of dimensional size of 1, 2 and 4 measurement units (m.u.), and by combinations of controlled electrovalves variable flow rates are obtained within the range 0 - 7 m.u. (table in Fig. 7). If there is necessary a more accurate flow adjustment another electrovalve of dimensional size of 8 m.u. can be added, thus obtaining flow rates stages from 0 to 15 m.u., which can be equated with the performance of a proportional valve. The performance of a servovalve can be met by a group of 6 electrovalves (of 1, 2, 4, 8, 16, 32 m.u), obtaining a continuous flow adjustment in the range 0 - 63 m.u. Adding an electrovalve to the group of electrovalves doubles flow rate value and increases resolution.
In figure 8 one can notice the shape of the flow control chart in the three variants: with proportional device (left), with 4 digital electrovalves (middle), and with 6 digital electrovalves (right).

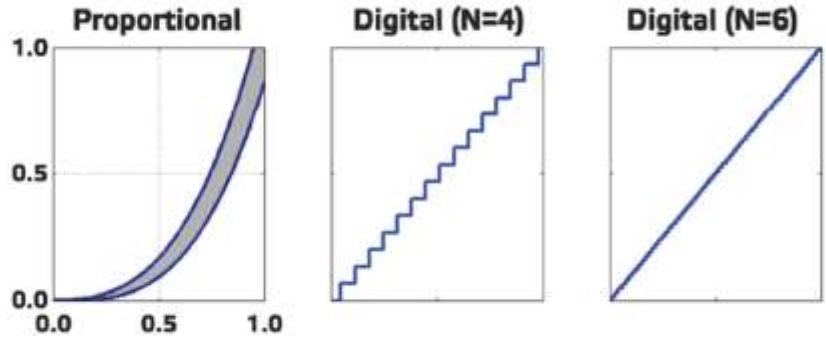


Fig. 8. Flow control by using proportional device (left), a group of 4 digital electrovalves (middle) and a group of 6 digital electrovalves (right) [3]

Using digital hydraulic drive equipment for hydraulic positioning systems shows a number of advantages. The first and most important is reliability. Classic proportional devices have small tolerances and sensitive electronic components located right on the device, in a not really friendly environment, as they are exposed to vibrations and temperature variations, which shortens significantly their normal operating time. In the event that the proportional hydraulic device fails, in the best case scenario the process stops and the valve must be replaced, which means costs for a new proportional device and losses in the working process during the repairing. In the worst case scenario, failure of the proportional device can lead to failure of the parts along the production line, or even worse, failure of the positioning system, which means high repair costs and significant looses in the working process.
Proportional devices (directional valves and servo valves) control the flow by moving the spool in both directions and, though the tolerances are very small, on high pressure flow leaks occur to the drainage port of approx. 0.40-0.65 l/min. Also small tolerances require very good filtration of the working oil.
In case of digital electrovalves no flow leaks to the drainage occur, because by construction they have a sealing face. They allow a contamination of the working oil up to 30 times higher comparative with proportional valves and can work correctly up to a oil temperature of 75° C, in many cases not requiring the cooling of the oil. Due to their simple and robust construction digital

electrovalves are very reliable and can work very well even in the range of 300 millions – 1 billion working cycles, thus avoiding unscheduled stops. The lack of oil losses at the drainage allows the utilization of the hydraulic accumulator for maintaining the position, and in steady situations the servo system stays on the position, under pressure, for long periods of time, solution which can bring energy savings of up to 90%. In any situation, the control unit chooses the optimal combination of opened electrovalves, with minim energy consumption, according to an algorithm with high speed switching, to meet the system requirements. Digital electrovalves are on/off, and combining them enables the development of any proportional device diagram; they have a small response time because do not require tray position control and have linear behavior, without hysteresis or uncontrolled command peaks (Fig. 4).
Each flow direction (P-A, P-B, A-T, B-T) is independently and firmly controlled with an electrovalve, and their parallel opening results in small response time, high accuracy and working speeds, and finally productivity is increased and energy consumption is lowered.

3. Conclusions

The main benefits of digital hydraulic system, comparative with conventional proportional hydraulic devices are reduction of energy consumption and reliability. Digital hydraulic systems offer additional benefits relative to higher productivity, smaller procurement price, cheaper spare parts, space savings, fewer connecting pipes, resistance to higher temperature, higher accuracy and control.
Technologic development of digital hydraulic motors could reform the industries which use hydraulic systems and could transform them into the fastest and most efficient form of power transmission. Energy savings resulting from the implementation of digital hydraulic motors can improve the technical and economic performance of the technological lines where they are used, and they are reflected in the end in the manufacturing price of the products placed on the market. At the same time, by energy savings and efficient use of resources, they contribute to the foundations of sustainable development.

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