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EXPERIMENTAL ACHIEVEMENTS IN THE FIELD OF DIGITAL HYDRAULICS

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Abstract: *Digital hydraulic actuation systems have had a resounding success in the scientific world since the beginning and have had good results, regarding the degree of intelligence, integration, energy losses, etc.*
In recent years, the phenomenon has gained momentum and attracted more and more researchers to this field, and with them, the interest of companies to introduce such systems to the market has also developed.
In this work, the authors intend to review the achievements in Romania in this field and bring a national update of the level of knowledge of the field.

Keywords: *Digital hydraulics, energy efficiency*

1. Introduction

Hydraulic systems developed rapidly starting with the 20th century, along with the evolution of microprocessor technology, so that hydraulic systems could integrate microprocessors, electro power amplifiers and sensors, in order to improve dynamic control, intelligence and reliability. With the entry into the 21st century, the huge cost of labor and energy forced the industry to develop in the direction of energy conservation and increasing the degree of intelligence of the systems. However, the cost of hydraulic equipment and low energy efficiency are key factors that limit the development of this field and future applications. In addition, with the introduction of the concept of Industry 4.0 by Germany in 2013, there was even more pressure for industrial hydraulic systems to be even smarter and to be integrated into the concept of the Intelligent Factory [1].
Considering all these general trends, if hydraulic systems want to survive in this competition on the industrial market, they must inevitably develop in the direction of high energy efficiency and low acquisition cost, and digital hydraulics offers the possibility to achieve this.

2. Definition of digital hydraulics

The definition of digital hydraulics is still not a stable one, and the current definitions can only partially reflect the characteristics of digital hydraulics, so the definition of digital hydraulics can be ambiguous.
That being said, the definition of digital hydraulics is based on the views of researchers around the world. We define digital hydraulics as a system that realizes an active and intelligent control of the system output. Hydraulic components with such technical characteristics can be defined as digital hydraulic components. In addition, the essential feature of digital hydraulics is intelligent control; technology that can only achieve on/off control cannot be classified as digital hydraulics.
Digital hydraulics is defined by the active control of the system outputs of a hydraulic component (directional valve, pump, actuator). Digital hydraulics is not limited to digital control of analog components, but relies on intelligent control using PWM (Pulse Width Modulation) signals and achieving flow and speed adjustments using the on/off directional valve, coded either PNM (Pulse Number Modulated), or PCM (Pulse Code Modulated).

3. Types of digital hydraulics

Digital hydraulics is divided into two categories, the parallel digital hydraulics and the switching one, as well as that with a stepper motor, which comes as a subdivision of digital switching hydraulics.

3.1. Digital hydraulics in parallel and switching

At the European level, two types of digital hydraulics are known, the parallel one, developed by the University of Tampere in Finland, under the leadership of Matti Lindjama [2] and digital switching hydraulics, developed at the University of Linz in Austria under the leadership of Rudolf Scheidl [3].
Digital hydraulic systems in parallel are realized by connecting the components in parallel, and the value of the flow passing through each component must be in the progression made by one of the PNM (Pulse number Modulated) and PCM (Pulse Coded Modulated) series.
Digital hydraulic systems in parallel have a fixed number of discrete outputs that depend on the nature of the components and do not require continuous switching of the components between the closed and the open position.
On the other hand, the digital switching hydraulics uses components that can quickly switch between the closed and the open position, in order to obtain a discrete adjustment of the flow at the exit from the system. The high-frequency switching of digital switching systems is performed with a PWM (Pulse Width Modulated) signal.

3.1.1. Stepping digital hydraulics

These digital hydraulic systems use a precise stepper motor controlled by discretely modulated digital signals. The rotation of the stepping motor is transmitted to the directional valve spool through a mechanical structure, so that a discrete adjustment of the flow rate is obtained in order to realize the intelligent control of the output from the system.
Because the stepper motor has no accumulated error and almost no hysteresis, the digital stepping directional valve has higher spool movement accuracy. Four typical forms of stepping digital hydraulic directional valve are shown in Fig. 1.
However, the stepping motor produces rotary motion, which must be converted into linear motion to drive the spool. Therefore, conversion mechanisms such as cam and ball screws are indispensable. However, all conversion mechanisms have high friction and inertia, which act on the frequency response characteristics of a stepping digital hydraulic directional valve. In addition, the stepping motor is prone to overstepping at high frequency. These problems limit the application of these methods and it is a much more difficult method to implement than the digital switching hydraulics proposed by Rudolf Scheidl.

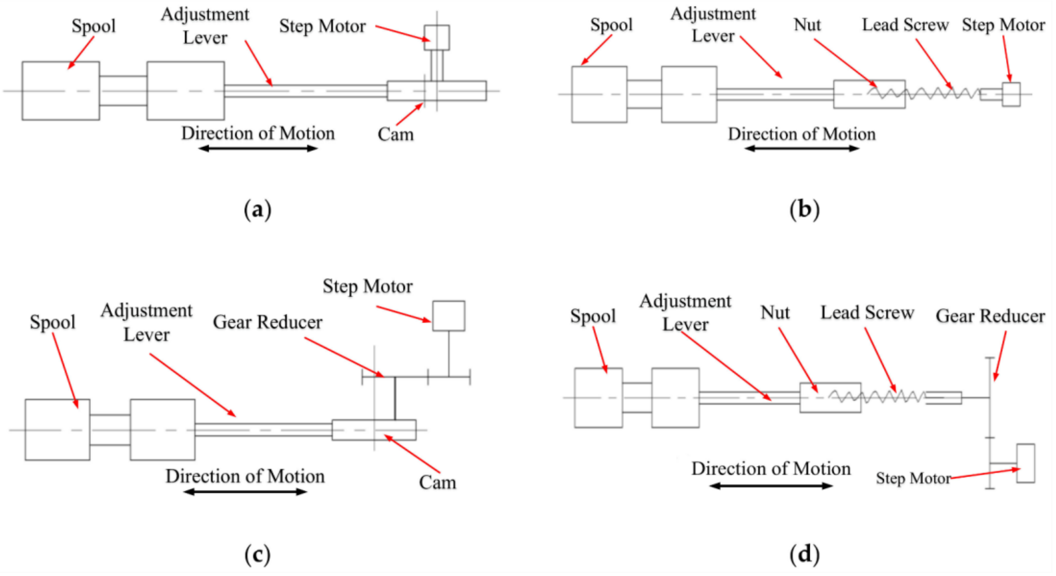


Fig. 1. Four typical forms of stepping digital hydraulic valves

4. Digital hydraulic equipment developed in National Institute of Research & Development for Optoelectronics / INOE 2000 – Subsidiary Hydraulics and Pneumatics Research Institute (IHP)

Within the Research and Development Institute INOE 2000 - IHP, the authors have until now developed various digital hydraulic systems, some up to the concept level, others up to the demonstrator level, and in the following these systems will be presented.

4.1. DFCU with five binary coded directional valves

DFCU shown in Fig. 2 consists of the following components: internal combustion engine marked M; fixed flow pump (HP); hydraulic accumulator (HA); 2/2 directional valve (DV6); 5 directional valves (on/off) DV1- DV5 type 2/2, which are transited by different flow rates in binary progression; the directional valve DV7 type 4/2 that changes the direction of rotation of the hydraulic motor; HM hydraulic motor; FM flow transducer; PT pressure transducer; F filter, and PLC that controls the operation of the entire system.

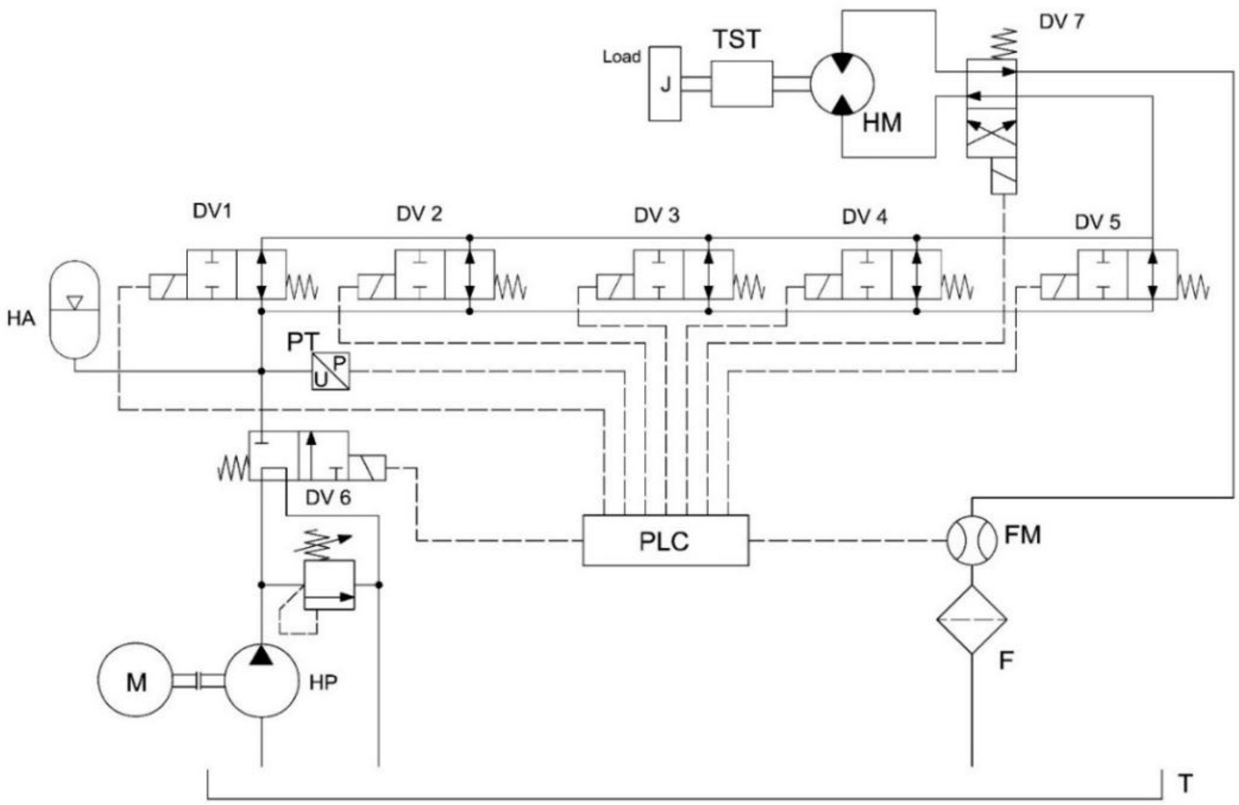


Fig. 2. DFCU with 5 binary coded directional valves [4]

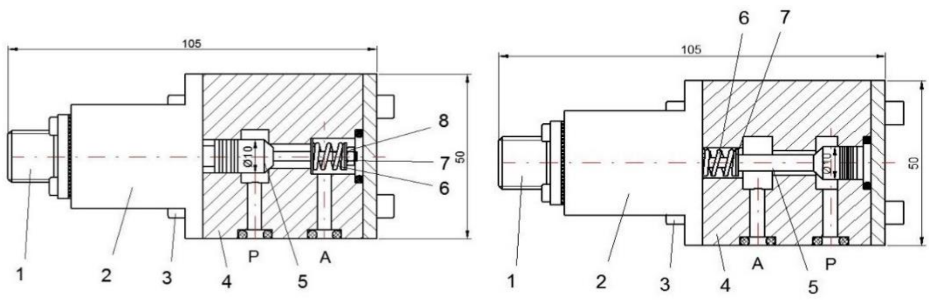
The status of each directional valve and the achieved flow rate for each of the 31 adjustment steps can be seen in Table 1.

Table 1: The status of each directional valve and how to obtain the 31 adjustment steps

Q State	q=2 [l/min]	q=4 [l/min]	q=8 [l/min]	q=16 [l/min]	q=32 [l/min]	Qt [l/min]
0	-	-	-	-	-	0
1	+	-	-	-	-	2
2	-	+	-	-	-	4
3	+	+	-	-	-	6
4	-	-	+	-	-	8
5	+	-	+	-	-	10
6	-	+	+	-	-	12
7	+	+	+	-	-	14
8	-	-	-	+	-	16
9	+	-	-	+	-	18
10	-	+	-	+	-	20
11	+	+	-	+	-	22
12	-	-	+	+	-	24
13	+	-	+	+	-	26
14	-	+	+	+	-	28
15	+	+	+	+	-	30
16	-	-	-	-	+	32
17	+	-	-	-	+	34
18	-	+	-	-	+	36
19	+	+	-	-	+	38
20	-	-	+	-	+	40
21	+	-	+	-	+	42
22	-	+	+	-	+	44
23	+	+	+	-	+	46
24	-	-	-	+	+	48
25	+	-	-	+	+	50
26	-	+	-	+	+	52
27	+	+	-	+	+	54
28	-	-	+	+	+	56
29	+	-	+	+	+	58
30	-	+	+	+	+	60
31	+	+	+	+	+	62

4.2. Digital switching directional valve

The directional valve developed for digital switching hydraulics is composed of the electromagnet (2) supplied with an electrical signal through the connector (1), which is attached to the steering valve body (4) by four screws (3). The coil is marked with the position (5) and the position of the return spring (6) is located depending on the construction version (NC - normally closed, Fig. 3.a, or NO - normally open, Fig. 3.b) towards the electromagnet or at the opposite end of the electromagnet. In the picture one can also see the spring plate (7) and nut (8) for the NC version.



a. b.

Fig. 3. Variants of digital switching hydraulic directional valve - a. normally closed, and b. normally open [5]

4.3. DHPS – Digital Hydraulic Pumping System

The hydraulic system (Fig. 4) uses 4 fixed flow coaxial pumps connected to an electric motor (3). Pump selection is done with a normally open on/off directional valve (6). When one of the on/off directional valves is switched to the closed position, the flow is directed from the tank to the consumer through the directional valve (7). The safety valve (8) provides system overload protection. Each directional valve is transited by a different flow (Q1, Q2, Q3, Q4) from which we can select for the system one, two or even all of them to achieve flow regulation with the help of a programmable logic controller (9) (P.L.C.).
Q1 = First pump with the flow displacement of 4 cm^3/rev
Q2 = Second pump with the flow displacement of 8 cm^3/rev
Q3 = Third pump with the flow displacement of 16 cm^3/rev
Q4 = Forth pump with the flow displacement of 32 cm^3/rev.

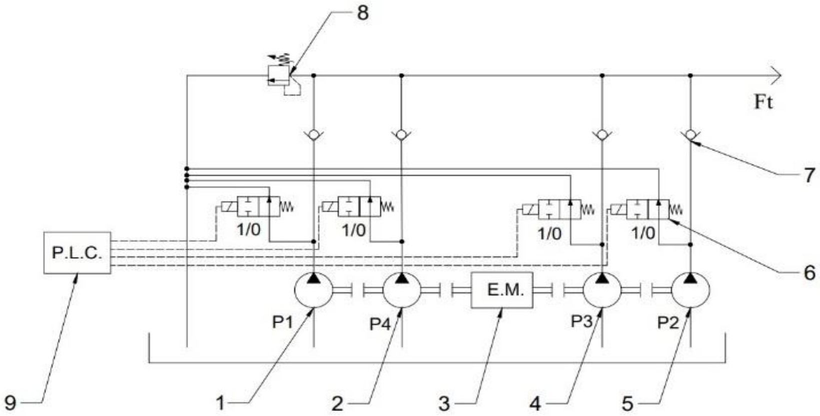


Fig. 4. Hydraulic system with four fixed displacement pumps consists in: (1, 2, 4, 5) fixed displacement pumps, (3) biaxial electric motor, (6) 2/2 directional valve, (7) one-way valve, (8) pressure relief valve

4.4. VDLA – Variable Displacement Linear Actuator Hybrid with binary coded surfaces

The hybrid VDLA (Fig. 5) was so named because its construction uses two types of coding, namely PNM coding and PCM coding, and consists of a large diameter piston (13), driven by 9 smaller diameter pistons (4) positioned symmetrically around the axis of the main piston (13), and their operation is carried out according to the table below.

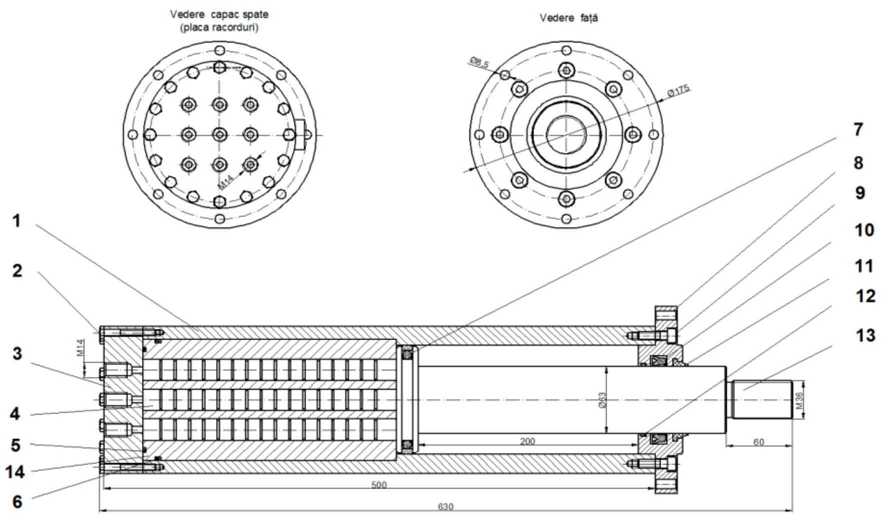


Fig. 5. VDLA Hybrid with binary coded surfaces [6]

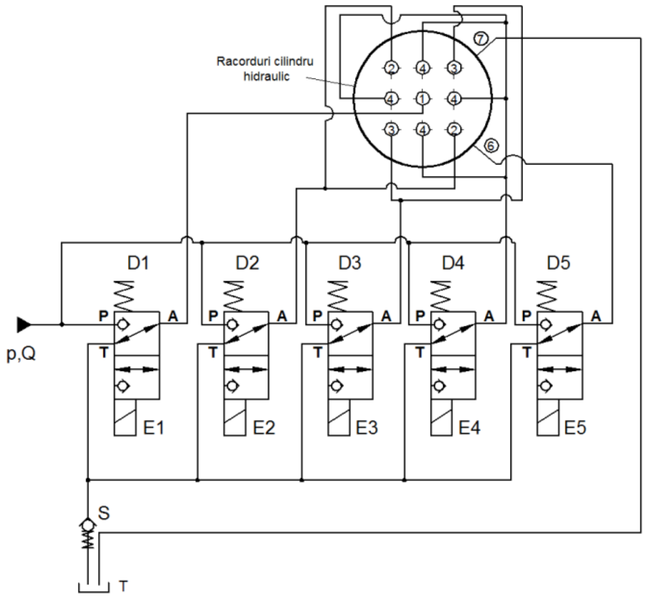


Fig. 6. Hybrid VLDA actuation diagram consists in: 5 2/2 directional valves (D1, D2, D3, D4, D5), 1 one way valve (S), and the VDLA

Table 2: The state of each directional valve depending on the desired setting

Elmg. / Motion	E1	E2	E3	E4	E5
Advance 1	+	-	-	-	-
Advance 2	-	+	-	-	-
Advance 3	+	+	-	-	-
Advance 4	-	-	-	+	-
Advance 5	+	-	-	+	-
Advance 6	-	+	-	+	-
Advance 7	+	+	-	+	-
Advance 8	-	+	+	+	-
Advance 9	+	+	+	+	-
Withdrawal	-	-	-	-	+

4.5. VDLA with three binary coded surfaces

VDLA with three concentric zones, binary coded, thus, A2 = 2A1, A3 = 2A2, thus obtaining 23-1 = 7 different variations of force and speed. This type of VDLA allows by separately supply the 3 concentric zones, using on/off type directional valves, to obtain a relatively linear force and speed variation curve.

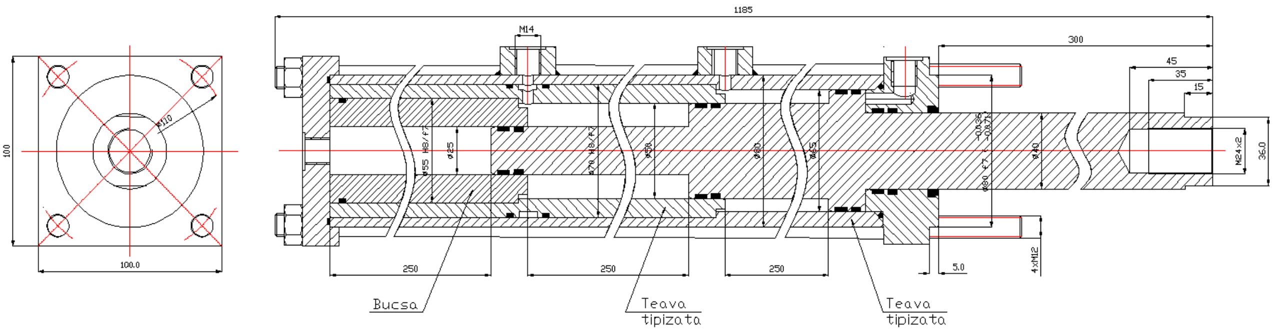


Fig. 7. VDLA with 3 binary coded surfaces

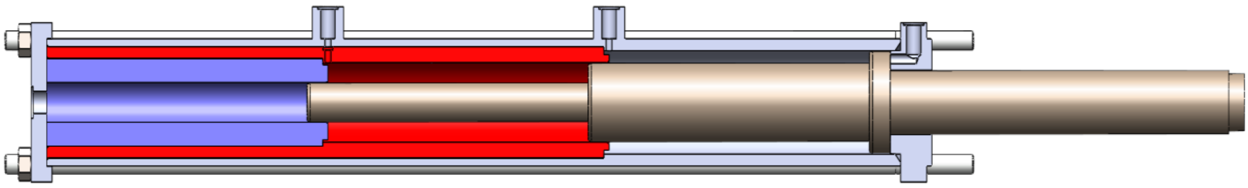


Fig. 8. Section through VDLA, where one can see the three chambers colored with blue, red and gray

Table 3: The variation of the three surfaces of the VDLA

The cylinder with three surfaces binary multiplied		The cylinder with three surfaces with typical diameters	
Area [cm²]	Diameter [mm]	Area [cm²]	Diameter [mm]
4.906	25	4.906	25
9.812	43.3	14.712	50
19.624	61.24	19.503	65

5. Conclusions

The development of digital hydraulic systems is on an upward slope at the moment and they are becoming more and more appreciated in the field.
From year to year, more and more articles and solutions appear in this field both in the country and worldwide. Digital hydraulics is a modern, reliable solution with a low purchase cost compared to classic hydraulic solutions.
Digital hydraulics reduces energy losses as it can deliver the necessary flow to the work point without the need for additional adjustments and sending energy-carrying flows to the tank.
At this moment, some of these systems are already implemented in the industry and we expect that in the coming years their number will increase considerably and they can be directly purchased from traditional manufacturers of hydraulic equipment.

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