

DEVELOPMENT AND LABORATORY TESTING OF A DIGITAL FLOW CONTROL UNIT

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Abstract: *Industrial and mobile equipment uses proportional hydraulics to perform precise movements such as positioning of machined parts or movement of the tools. In recent years, digital hydraulics has developed a lot in terms of control schemes and equipment such as digital valves (parallel hydraulic valves, high speed switching hydraulic valves and stepping hydraulic valves) or digital hydraulic pumps (switching and parallel digital hydraulic pumps etc.). By using digital hydraulics, proportional hydraulic valves, which are expensive and demanding in terms of hydraulic oil filtration conditions can be replaced. This paper presents the development and laboratory testing of a digital flow control unit that can be used to step-change the speed of a hydraulic motor.*

Keywords: *Digital hydraulics, DFCU, PCM, control software*

1. Introduction

Digital Flow Control Units (DFCU) can be used in industries (construction, manufacturing, agriculture) due to their efficiency, reliability, and precision. In industrial machinery, particularly in sectors like pulp and paper, they are applied to achieve precise flow and pressure control. By replacing traditional proportional valves with durable on/off valves, DFCU enhance system reliability, can reduce downtime, and lower operational costs [1,2].

In hydraulic drives and actuators, DFCU systems facilitate intelligent and independent metering control. This capability allows for improved tracking of velocity and pressure, even at low flow rates, making them ideal for applications requiring high precision.

Energy efficiency is another significant advantage of systems containing DFCU. These units help reduce energy consumption by eliminating the need for pumps to run continuously during steady states [3].

In heavy machinery and construction equipment, DFCU systems can play a role in managing the precise movement of large and heavy components [4,5]. DFCU systems can be used in research and experimental rigs where hydraulic control is crucial. Their versatility and precise control make them ideal for laboratory environments and custom industrial applications.

In the case of the parallel digital hydraulic system in present paper is used the Pulse Code Modulation (PCM) method with the 2^n series, i.e. 1, 2, 4, 8, 16, ..., depending on the value of n , where n is the number of solenoid valves and is the most common coding method in the implementation of such systems. Calculation of the number of flow rate adjustment points using the PCM method with binary series is done using the formula $2^n - 1$, where n is the number of valves.

In the case of the present work, the developed DFCU unit uses 5 binary coded throttle valves and 5 normally closed 2/2 solenoid valves, obtaining $2^5 - 1 = 31$ flow rate adjustment points [6,7].

2. Physical realisation of the DFCU

The hydraulic diagram of the system It is found in figure 1. For its construction, in-line hydraulic devices connected with hydraulic pipes were used. Normally such a parallel flow control system would have been made up of binary-coded solenoid valves of different sizes.

The solution of using adjusting throttle valves was chosen to enable future research using different methods of encoding the throttle opening, so that several types of research on parallel digital hydraulic systems can be carried out on this unit.

The DFCU system is composed of a group of ON/OFF 2/2 cartridge type solenoid valves, a group of throttle valves, the elements for measuring the system parameters and the electrical command and control system with programmable logic controller (PLC).

The hydraulic diagram of the DFCU is made up of the following components:

- the group of ON/OFF 2/2 cartridge type solenoid valves marked with DH1,...,DH5;
- the group of throttles DR1,...,DR5 adjusted so that the flow rate passing through each throttle is coded using the binary series, i.e. 2, 4, 8, 16, 32 l/min;
- pressure transducers TP;
- throttle valve for pressure load DS;
- temperature transducer TT;
- flowmeter DM.

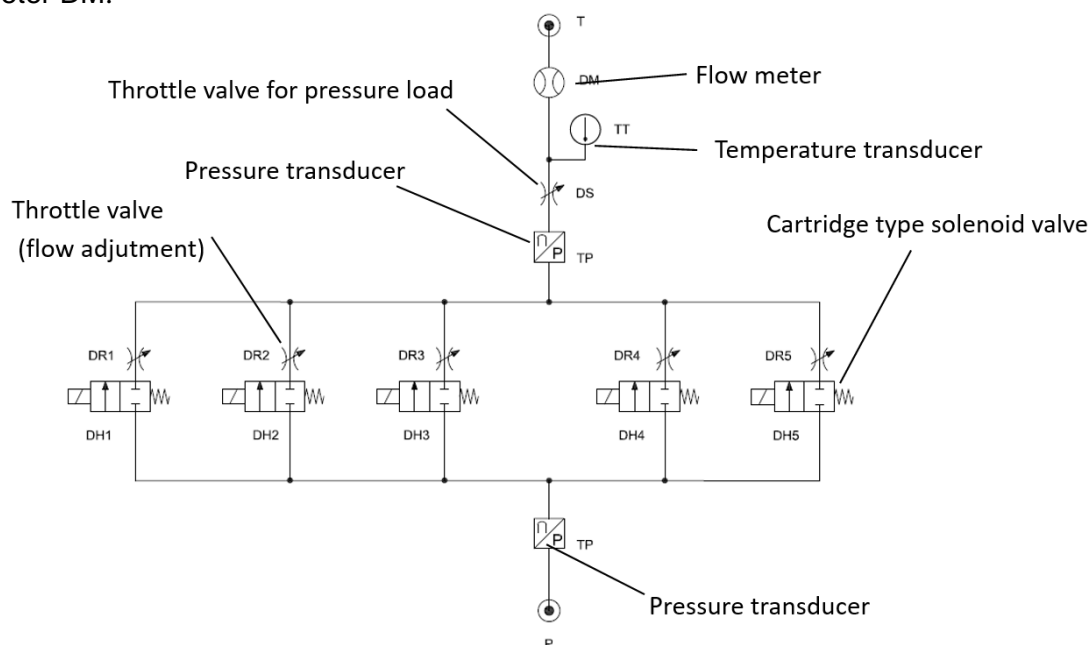


Fig. 1. Hydraulic diagram of the DFCU



Fig. 2. The assembled DFCU

Figure 2 shows an image of the assembled DFCU system, which contains the following elements:

- the group of 2/2 ON/OFF cartridge type solenoid valves, which are electrically operated by means of solenoids located on them;
- the group of throttles valves consists of 5 throttles valves, of which 2 with an inlet size of $\frac{1}{2}$ inches and 3 with an inlet size of $\frac{3}{4}$ inches;
- two pressure transducers (0...250 bar), one located at the entrance to the system and the other at the exit from the system;
- a flow transducer with the measuring range: 1...75 l/min;
- a temperature transducer with the measuring range: 0...100 °C.

3. Electric system and control software

For the laboratory testing of the digital hydraulic unit, an electrical cabinet (figure 3) was created that contains a 10A, 24V power supply for powering the solenoids, an automatic circuit breaker, 5 relays for controlling the solenoids of the hydraulic valves and a programmable logic controller equipped with an analog input module for the transducers included in the digital hydraulic unit. The PLC has implemented software for controlling the solenoids through digital outputs (discrete output coils) and monitoring the signals from the transducers through analog inputs (analog registers). The PLC communicates discrete or analog data through the Modbus TCP/IP protocol. Thus, a computer with the corresponding software connected to the same local network as the PLC can access the data.

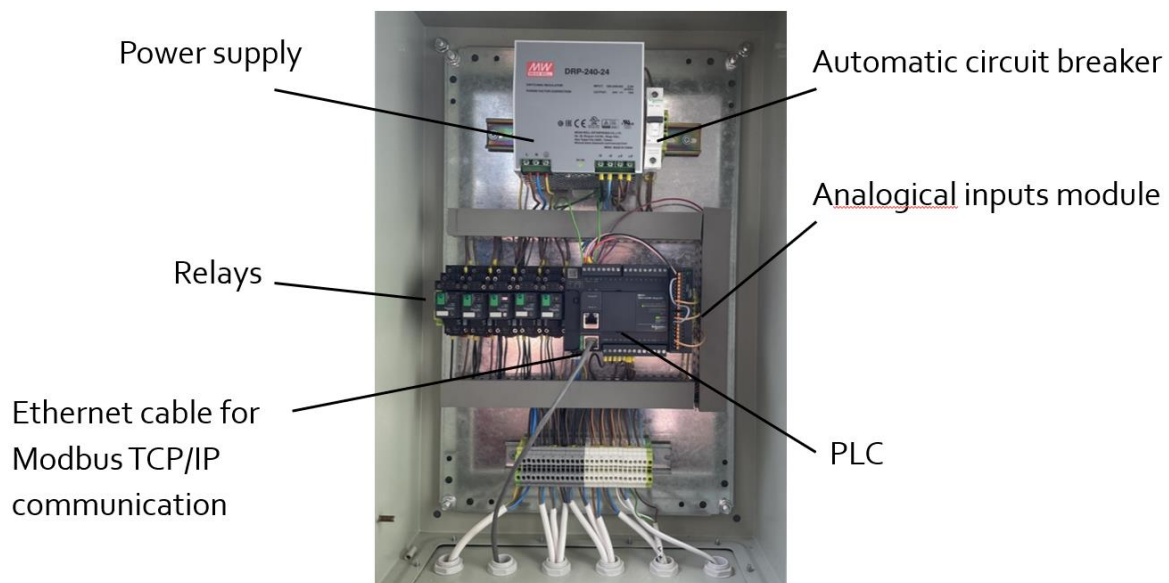


Fig. 3. The electrical cabinet for command and control of the digital hydraulic unit

In order to be able to perform tests for DFCU a control interface is made in the form of an application installed on a computer (figure 4). The application is designed in such a way that it is possible to perform tests in which the operator can manually select the command of each solenoid valve, but also automatic tests that perform system testing using a previously defined action table in an excel file (Table 1). In the application's control window, there is also a section for numerical visualization of the system parameters (flow, pressure at the entrance to the system, pressure at the exit from the system, temperature at the exit from the system), but also a section for graphical visualization of the parameters, with the possibility of viewing both the graphic curve of each parameter and the curves of all parameters on the same graph [8].

Table 1: Command steps to obtain increasing flow rate

Step	Step time [s]	Valve 1	Valve 2	Valve 3	Valve 4	Valve 5	Flow [l/min]
0	0	0	0	0	0	0	0
1	5	1	0	0	0	0	2
2	10	0	1	0	0	0	4
3	15	1	1	0	0	0	6
4	20	0	0	1	0	0	8
5	25	1	0	1	0	0	10
6	30	0	1	1	0	0	12
7	35	1	1	1	0	0	14
8	40	0	0	0	1	0	16
9	45	1	0	0	1	0	18
10	50	0	1	0	1	0	20
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25	125	1	0	0	1	1	50
26	130	0	1	0	1	1	52
27	135	1	1	0	1	1	54
28	140	0	0	1	1	1	56
29	145	1	0	1	1	1	58
30	150	0	1	1	1	1	60
31	155	1	1	1	1	1	62

In order to process the data obtained from the experiment, the application generates an Excel file at the end of the test with all the system parameters acquired at a sampling interval that can be set between 50...200 milliseconds.

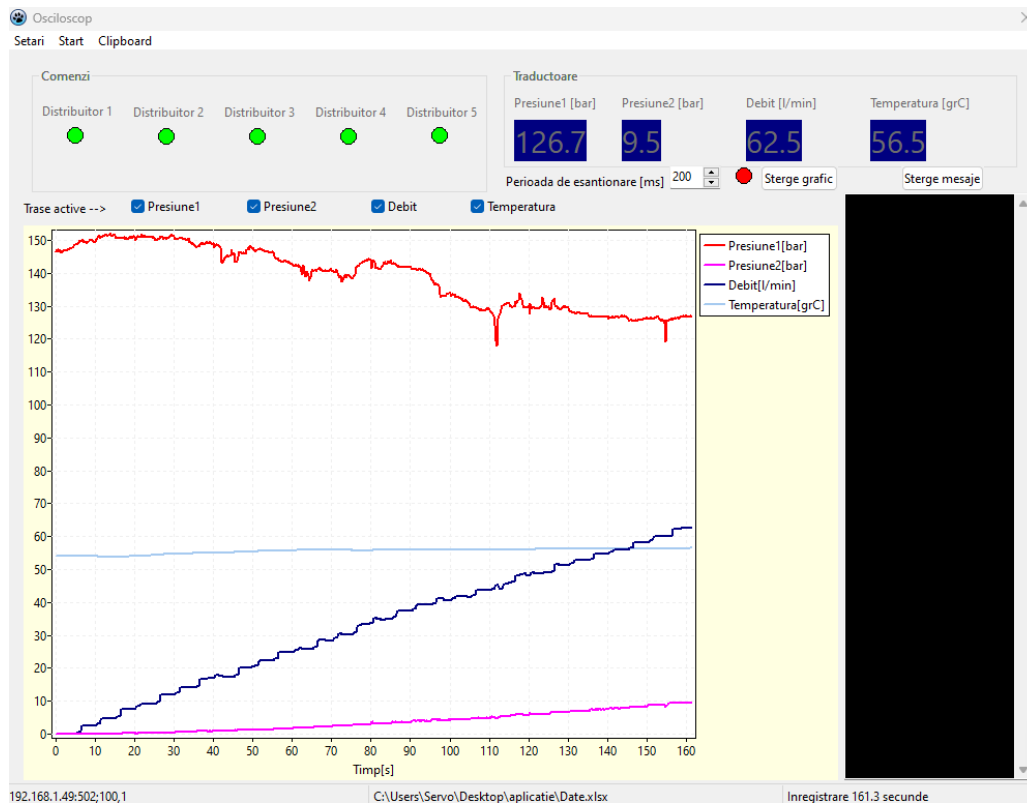


Fig. 4 The software interface with the recording of the increasing flow of the DFCU

In Figure 5 can be seen the decreasing variation of the DFCU flow rate.

A similar control system for a DFCU can be implemented in the PLC of mobile or industrial machines for custom applications.

A disadvantage of this digital flow control unit may be the pressure peak phenomenon that occurs when switching hydraulic circuits with valves, and some authors are studying their minimization [9,10].

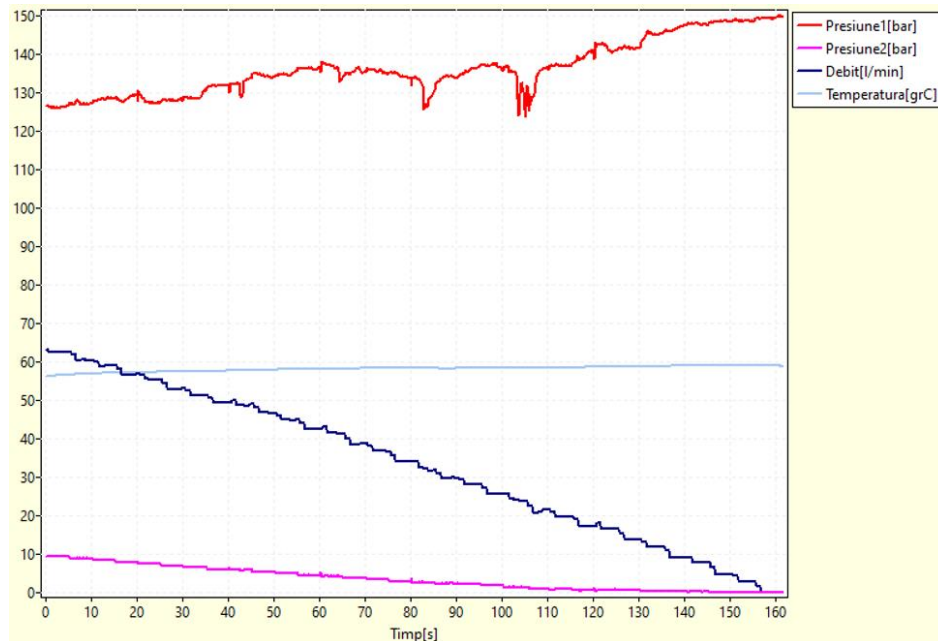


Fig. 5 Decreasing variation of the DFCU flow rate

4. Conclusions

The flow control unit developed for experimental purposes works well, achieving 31 flow values, and by increasing the number of valves, very good resolution can be obtained.

The developed software allows testing of the DFCU with recording of supply pressure, load pressure, flow rate and temperature at the hydraulic fluid discharge.

DFCU allow precise control of flow rates through a combination of multiple on/off valves operating in parallel.

By assigning discrete flow rates to each valve, DFCU effectively acts as a hydraulic digital-to-analog converter.

Overall, DFCU technology represents an advancement in hydraulic systems, enabling more efficient, precise, and reliable operations while presenting opportunities for optimization in control methods and manufacturing.

In the future, our team aims to develop a compact DFCU version in the form of a hydraulic block containing solenoid valves and sensors for measuring operating parameters.

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