UNIVERSITY „POLITEHNICA" OF BUCHAREST

Nr. Decizie 672 din 23.04.2021

PHD THESIS SUMMARY

HYDRAULIC POWER UNITS ENVISIONED AS MECHATRONIC SYSTEMS

Author: Eng. Valerian-Emanuel SÂRBU
Leading Professor: Prof. PhD. Eng. Mihai AVRAM

BUCHAREST
2021

Contents

I. INTRODUCTION

Keywords: Internet of Things, Hydraulic power units, Energy Efficiency, Intelligent Machines.

This paper aims to study the feasibility and efficiency of intelligent control systems dedicated to existing hydraulic systems. Several constructive variants and configurations were studied and carried out with the aim of transforming classical pumping groups or even whole hydraulic systems that did not have advanced control systems into intelligent mechatronic systems.

The thesis begins with building a theoretical foundation of the concepts used and a brief history of mechatronics, hydraulics, and industrial revolutions. In the next chapter a description of the current state of the hydraulic power units as a whole but also a description of its constructive elements are presented, the hydraulic power units that were made available to be modified are characterized and a brief presentation of the existing solutions on the market is shown. Numerical simulation of the hydraulic systems and experimental results are developed and described and then compared so that in the final chapters conclusions can be issued.

The thesis was carried out under the guidance of prof. dr. Eng. Mihai Avram, to whom I sincerely thank for the professionalism with which he guided me in supporting and developing the doctoral work and the confidence offered thus facilitating the significant modification of the existing structures in the laboratory for the practical and documentation stage. I would also like to thank conf. dr. Eng. Alina Spânu for the invitation to participate in these doctoral studies, support, patience and help during the preparatory period.

An intelligent system uses sensors to monitor working conditions as well as other external variables to modify its working regime automatically to adapt to these changes without the need for an operator's intervention.

A technical system that can carry out its specific task in the presence of uncertainty and variability of its environment thus is considered intelligent. The system's ability to monitor the environment allows it to adapt its actions based on measurements, which is a prerequisite for intelligence. The term intelligent system is an anthropomorphism in the sense that intelligence is defined by the criterion that actions would seem intelligent if taken by a person. There is no precise, unambiguous definition for an intelligent system. [1]

Hydraulic systems are increasingly being used justified by the perspective offered for increasing the productivity of the systems served, their static and dynamic performance, the reliability and total efficiency of the system. The increase in the production of hydraulic automation equipment registered in advanced industrial countries, such as China, the U.S., Germany, Japan supports the above. There are sustained efforts concerning the following topics:

- increasing working pressures.
- increase in rotation frequency and travel speeds.
- ensuring multiple functions for typed equipment,
- increase in yields,
- reliability and sustainability.

Particular attention is given today to energy issues, with sustained concerns about improving energy indicators. It should be know that proportional hydraulic equipment performs its function based on the resistive method of adjustment (which involves sending a quantity of liquid to the tank resulting in significant energy loss).

In conclusion, hydraulic actuators must be used with discernment, aware of their advantages and disadvantages in terms of economic, constructive and exploitation.

In recent times, several main directions envisioned by specialists in the field can be identified, namely:

- research in the field of high-pressure hydraulics and ultra-high pressures,
- development of proportional hydraulics to identify new constructive solutions of cheaper, better proportional equipment with smaller size, etc.,
- design, optimization, and simulation of hydraulic circuits using specialized software,
- increasing the performance and reliability of hydraulic automation equipment,
- increasing the modularization and flexibility of hydraulic actuators,
- research on the behavior of tribological and gasket effectiveness,
- research and experiments to improve the methodology for the calculation and design of hydraulic components.

II. CURRENT STATE OF DEVELOPMENT OF HYDRAULIC POWER GENERATION GROUPS

The basic requirements to survive as a manufacturer are the following: good quality production, low costs, short production time, opportune time and of course all of this done without harming the environment. [2]

The profit margin for manufacturers being quite small any failure and unplanned shutdown has a significant cost that can be the difference between profit and loss. To have a competitive advantage, expenditure must be reduced in an organic way without, however, affecting the quality of the finished product. Intelligent interconnected systems offer all the advantages necessary to guarantee success on all frontiers. Therefore, the current trend is to associate a smart control system based on microcomputers or microcontrollers with technical systems.

Hydraulic power unit manufacturers have adapted and included in the offer both equipment for applications where the initial costs matters more than the cost during use and others that are connected, efficient, self-diagnosis and have intelligent control loops. [3] [4]

To increase the efficiency of the hydraulic power generation group the following components can be replaced by a more efficient variant as follows:

- *Industry-standard asynchronous ac-induction motor* can be replaced by switched reluctance or brushless motors. They come with the advantage of a much-reduced inertia, improving response times, but also with better efficiency. The cost must include the control system and is significantly higher, [5]
- *The motor control system* with contactors and relays is replaced by inverter and microcomputers. By the variation in the frequency and drive voltage of the induction motor, the efficiency of the whole system is increased, [6]
- *Fixed flow pumps* can be replaced by efficient pumps with adjustable pumping capacity, with an integrated regulator or directly controlled by a computer, [7] [8]
- *Pressure* and flow indicators are replaced by digital transducers, acquisition systems and displays,
- *The pressure adjustment system is* improved by the addition of a pressure reduction valve, so that a control system can effectively regulate the pressure when needed [9],
- *The operator is* replaced by an intelligent, remote monitoring and self-diagnosing system [10] [11].

II.1 **Objectives of the doctoral thesis**

Under the conditions described above, manufacturers of hydraulic automation equipment are required to produce high-performance reliable equipment with low energy consumption, a low purchase price and requiring low maintenance and operating costs.

On the other hand, users are concerned about keeping the systems they have in operation for as long as possible. To be efficient in terms of electricity consumption, these systems need to be modernized, and this must be done at the lowest possible cost.

When choosing a group of energy generation often primordial is the cost of purchasing it. Therefore, groups equipped with fixed flow pumps are preferred. This equipment is much cheaper than one with adjustable flow. The latter is much more complex from a constructive point of view and requires a much more expensive manufacturing and assembly technologies. For a long time, also for economic reasons, this equipment was powered using an electric motor with constant speed.

On the other hand, using a group equipped with a fixed flow pump, the flow regulation in the system could not be done by the volume method, the only possibility being the resistive method. Although precise, the latter leads to significant energy losses in the form of heat, thus a low efficiency and consequently very high operating expenses.

The present paper aims to study the possibility and methodology necessary to improve a pumping group in the period of maturity, decline or even already out of use. It can also apply to new low-cost equipment. This equipment is inefficient and if not brought up to current standards of efficiency it becomes a burden for users. [12]

Power units are also intended to be transformed into intelligent structures capable of performing their function independently in the presence of disruptive factors. At the same time, this equipment is intended to be able to communicate with the control unit of the hydraulic system it serves, to receive information about the objective to be achieved and in turn to provide the control unit with real-time information on the evolution of the functional parameters.

Determining the density of a mineral oil used as a working medium in a hydraulic actuating system under certain concrete working conditions as well as the dependence of density with temperature and pressure are important problems for which a solution is still being sought. For this reason, the thesis aimed as a secondary objective to design and establish a stand that allows to determine experimentally the density of a mineral oil used as a working medium in a hydraulic system, as well as to identify a method for determining the influence of temperature and pressure on this parameter.

The stand shall be fully computerized and allow both the control of the actuator system and the acquisition and processing of measurement data.

To successfully achieve the proposed objectives, it is necessary to carry out a theoretical and experimental analysis of a hydraulic power generation group. Two possible situations are considered:

- the group under review exists physically,
- the group must be designed, purchased, and experimentally tested.

In both cases, a constructive-functional analysis of the group, the realization of a model, the realization of the mathematical model and the numerical simulation are required. Finally, in the first case, the optimal functional parameters of the system are determined, and in the second case the behavior of the future system is highlighted.

Experimental analysis involves the establishment of a testing methodology, the design of appropriate experimental stands and is completed with the realization of experimental determinations.

The next step is to study the theoretical and experimental results with direct implications for the constructive–functional optimization of the hydraulic energy generation group.

II.2 Intelligent hydraulic power units

Hydraulic power generation groups are reliable subsystems in machining tools and production lines. Maintenance performed at regular intervals has a high success rate for the prevention of malfunctions and implicitly the downtime [13]. The following structure is anticipated (Fig II-1 functions previously described.

All these systems have their own controller to implement the concept of decentralized

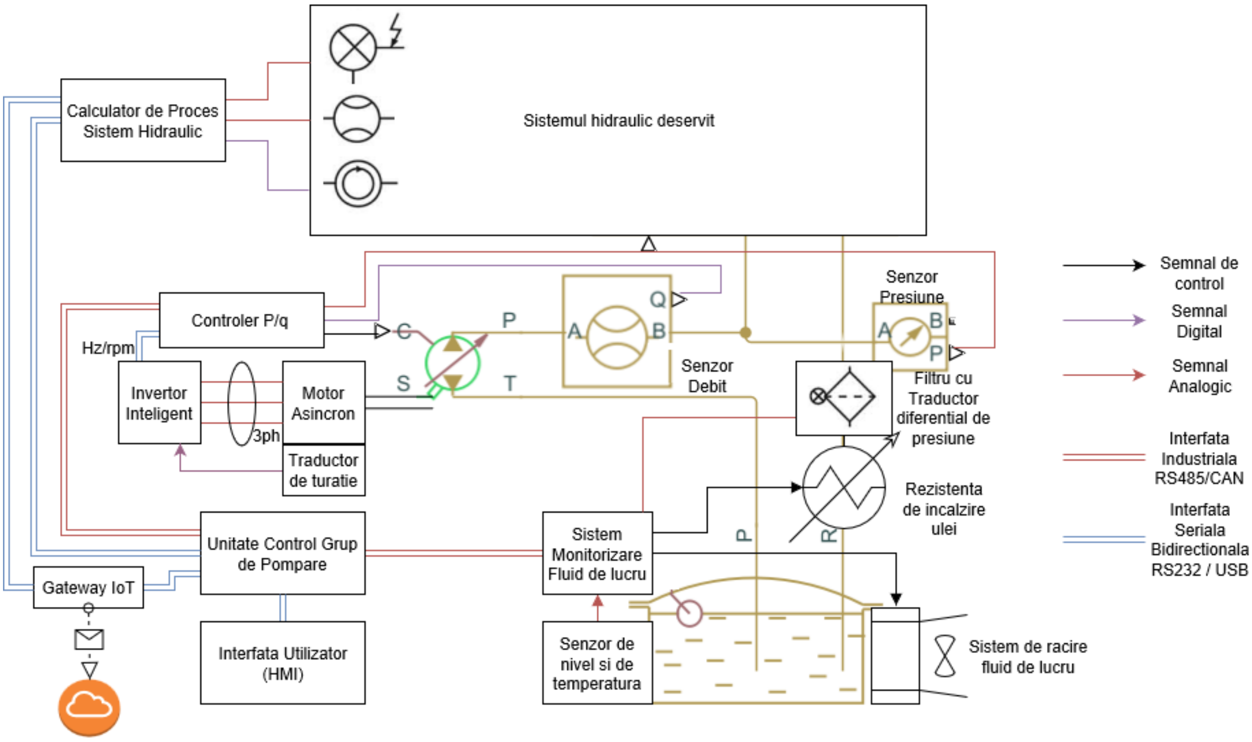


Fig II-1 Example Intelligent Hydraulic Group

intelligence and communication through a standard interface often used in industry (RS485, ModBus, CAN, Ethernet). Information read or received from other controllers is forwarded to the front panel and IoT monitoring system [14].

The system described is an ideal case to illustrate the level that can be achieved with decentralization, monitoring and artificial intelligence, integrating as many functions as possible. The units described below will tend towards this structure, while limiting the total cost by reducing the number of integrated components and controllers. Cost optimization will have no effect on the final functionality, however.

II.3 Existing hydraulic power generation groups to be upgraded into smart groups

The Department of Mechatronics and Precision Mechanics of the Polytechnic University of Bucharest has a few hydraulic power generation groups serving several hydraulic actuator systems.

The target is to achieve intelligent control of these groups by using various technical solutions to optimize performance.

II.3.1 Hydraulic power generation group with a power of 1.5kW

The first hydraulic power generation group has unknown background, the code on the electric motor indicates 1972 and the one on the tank indicates 1975 (Fig II-2).

Fig II-2 Rexroth Power unit– 1.5kW

The group exhibits a three-phase motor powered by the 380V electrical grid; stator windings can be star-triangle configured. The pump type is of external gear type and presumably has 8cm^3 of pumping capacity.

The components that will be described make up the hydraulic system (Fig II-3). A pressure transducer, a flow transducer, a 4/3 valve and an orbital hydraulic motor are mounted on the pump discharge circuit.

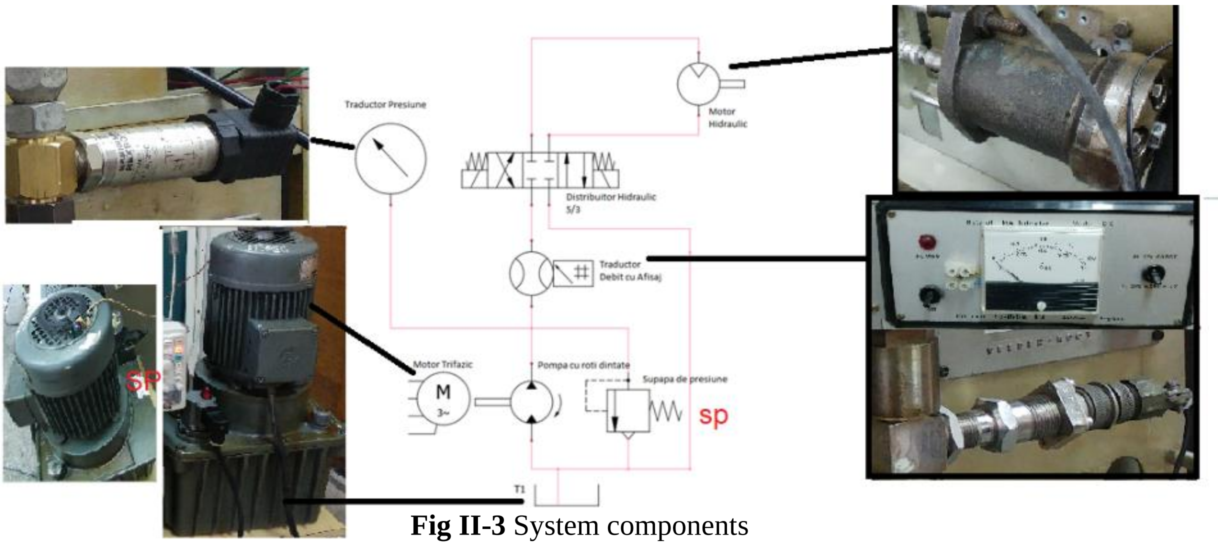


Fig II-3 System components

With an inverter, losses may be reduced if the speed of the motor that spins the pump shaft is varied to match the flow required by the load. The inverter with a power factor corrector further reduces the operating cost by avoiding the extra taxation on low power factor current usage. [15]

This system is a suitable example of hydraulic system that would benefit from a transformation into an intelligent equipment. The original structure of the group under discussion is representative of most hydraulic power generation groups currently in operation. Therefore, any change applied to it is universally valid on a wide range of relevant industrial applications.

II.3.2 Hydraulic power generation group with power of 4 kW

Currently this product is employed in a system for the regulation and control of hydraulic power, which is in the laboratory of Robotics, Actions and Precise Automated Systems within the Department of Mechatronics and Precision Mechanics. This is the group with the code ABSKG-60AL9/VGF2-016/112M-4-B produced by Rexroth.

The hydraulic scheme of the group is represented with standardized symbols in Fig II-4 is composed of:

- fixed-flow gear pump, P, [16]
- tank with a capacity of 60l, Rz,
- safety valve that opens at a pressure of 50 *[bar]*, S_{sig},
- manometer for monitoring the pressure drop on the filter,
- pressure gauge for monitoring the pressure in the system,
- 2 filters of different sizes on the circuit to the tank, F1, F2,
- classic hydraulic dispenser that interrupts or does not interrupt the power supply of the application- DH,
- electric motor for pump operation, [17]
- oil cooler – aluminum radiator.

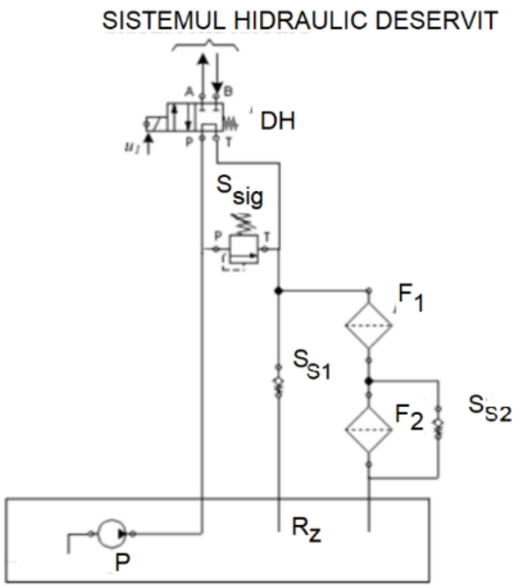


Fig II-4 Original structure

Changes to the pumping group were made that allowed control of the working fluid pressure and involve the existence of an automatic adjustment algorithm. Several elements have been added to the hydraulic circuit to achieve this goal: normally closed proportional valve S_{sig}, a pressure transducer T_p, a temperature transducer T_T .

The modified structure includes an electronic assembly. It has the role of generating: an analog control signal in the form of current i_1 in the range 0...800mA, for the control of a proportional electromagnet, a digital control signal in voltage u_1 with the values 0 or 24V required for the classic hydraulic valve DH. It also reads two analog signals (i_p and u_T) from newly attached transducers.

The purpose of these changes (according to the published article) is to adapt the pressure provided to the system according to the load carried by it, to modify the flow provided by the pump by the controlled variation of the motor shaft speed and to control the group by means of a controller. [18]

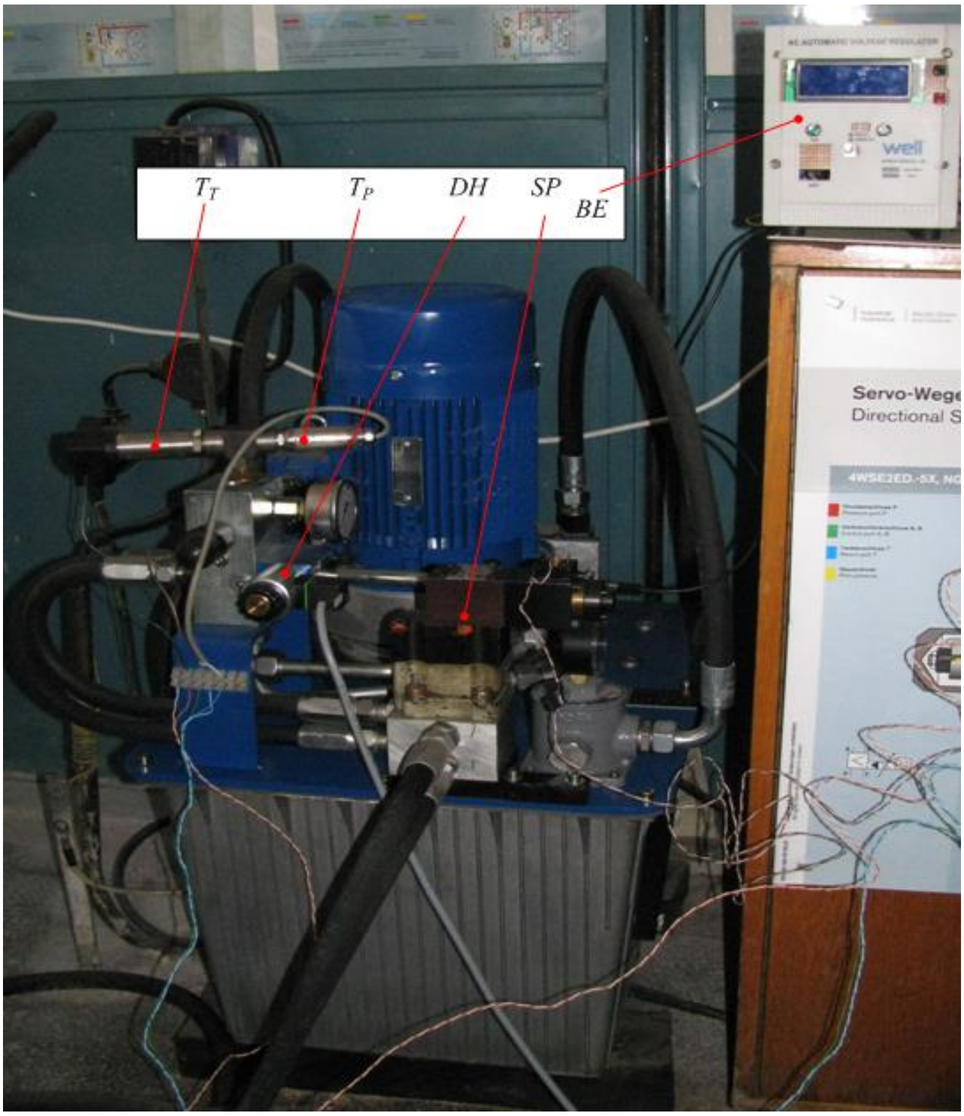


Fig II-5 Structura modificată , poza **[18]**

II.3.3 Hydraulic power generation group with 15kW power

The Department of Mechatronics and Precision Mechanics also has a very modern hydraulic power unit manufactured by Rexroth, model: ABMAG-160S-2X/A10VSO28DFR1/160L/A (Fig II-6). This includes several components, namely:

- pumping group type ABAPG-A10VSO28DFR1/160L-4-B1/SEABR,
- filter-cooling-recirculation oil group KOLP8N-1X/R-30F100-10-E/M,
- ABZMS-36-1X/0370M-k24 level sensor,
- thermostat AB31-14/7-1A2A3A4A,
- heater AB32-10/5 D 400.

The A10VSO axial piston pump has a variable flow rate obtained by the tilting of the rotating plate. It comes with a switch that indicates the position of 0 of the tilt (start assist).

To regulate the temperature of the oil the circuit contains a temperature controller, a fan (for cooling the oil) and a heater for heating it. Maximum performance is achieved if the system is used at the optimum temperature.

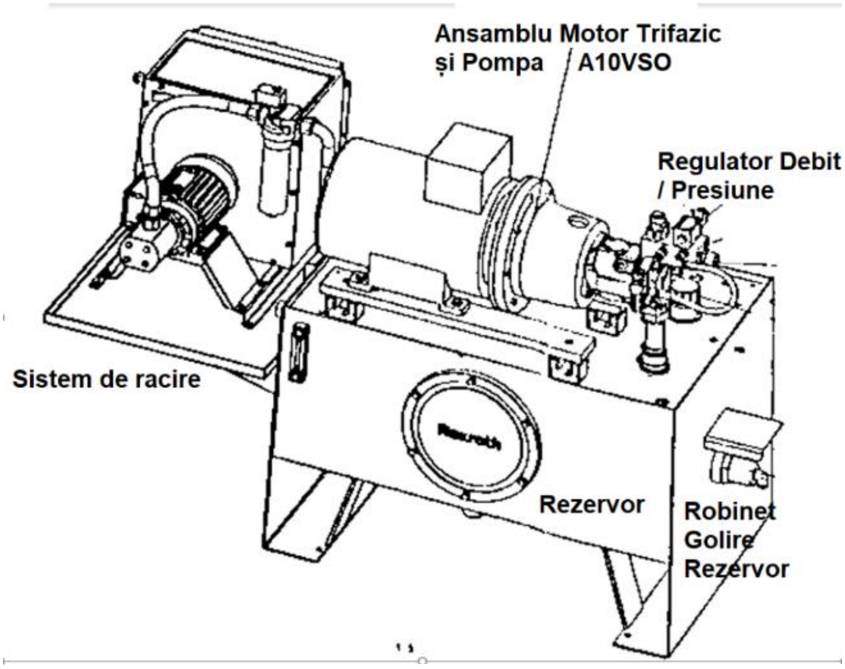


Fig II-6 Pumping group with 15kW motor

III. ESTABLISHING THE CONSTRUCTIVE MODELS OF INTELLIGENT HYDRAULIC POWER UNITS

III.1 Intelligent hydraulic power generation group with designed inverter – first variant

The objective pursued at this stage of the elaboration of the thesis was to transform the group presented in paragraph 2.3.1, an old group with modest technical characteristics, into a more efficient group with a certain level of intelligence.

The first step was to integrate an inverter into the circuit to increase efficiency, reduce the noise generated and start this group for the first time in a long time safely.

III.1.1 Designing the inverter

The inverter was designed in several variants according to the general structure shown in Fig III-1. The design process was iterative, the criteria being: miniaturization of circuits, reduction of costs, preparation for mass production and achievement of superior performance.

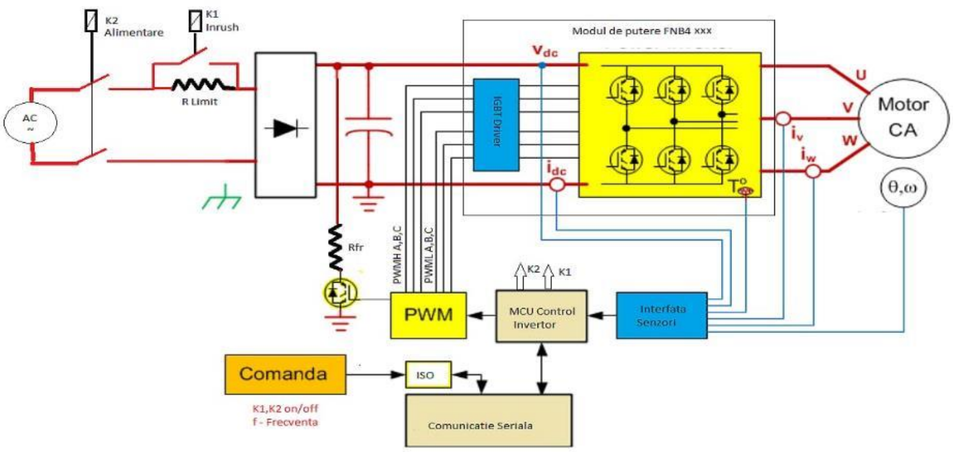


Fig III-1 Inverter structure **[28]**

The power side of the inverter was built around the hybrid integrated circuit FNB43060. The integrated circuit is supplied by ON Semiconductor and has been designed for use in household appliances.

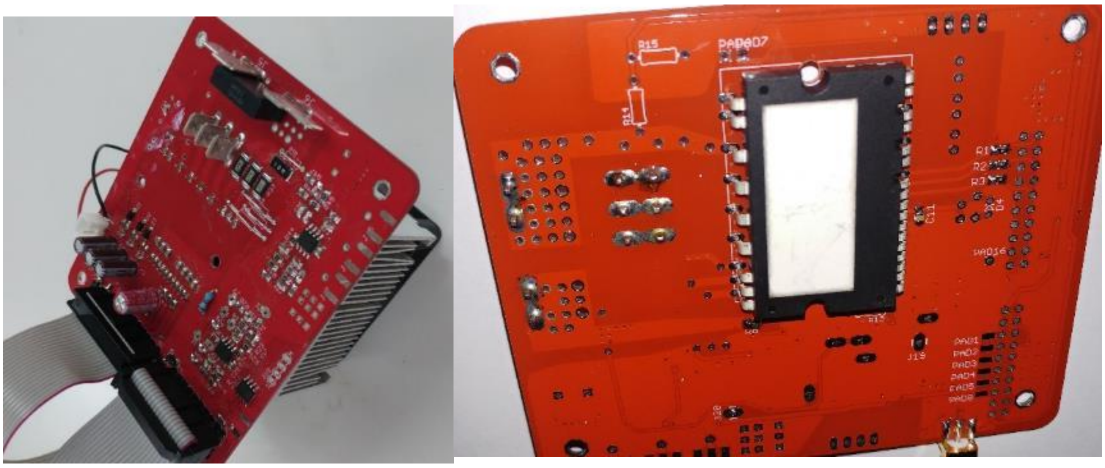


Fig III-2 PCB for power module

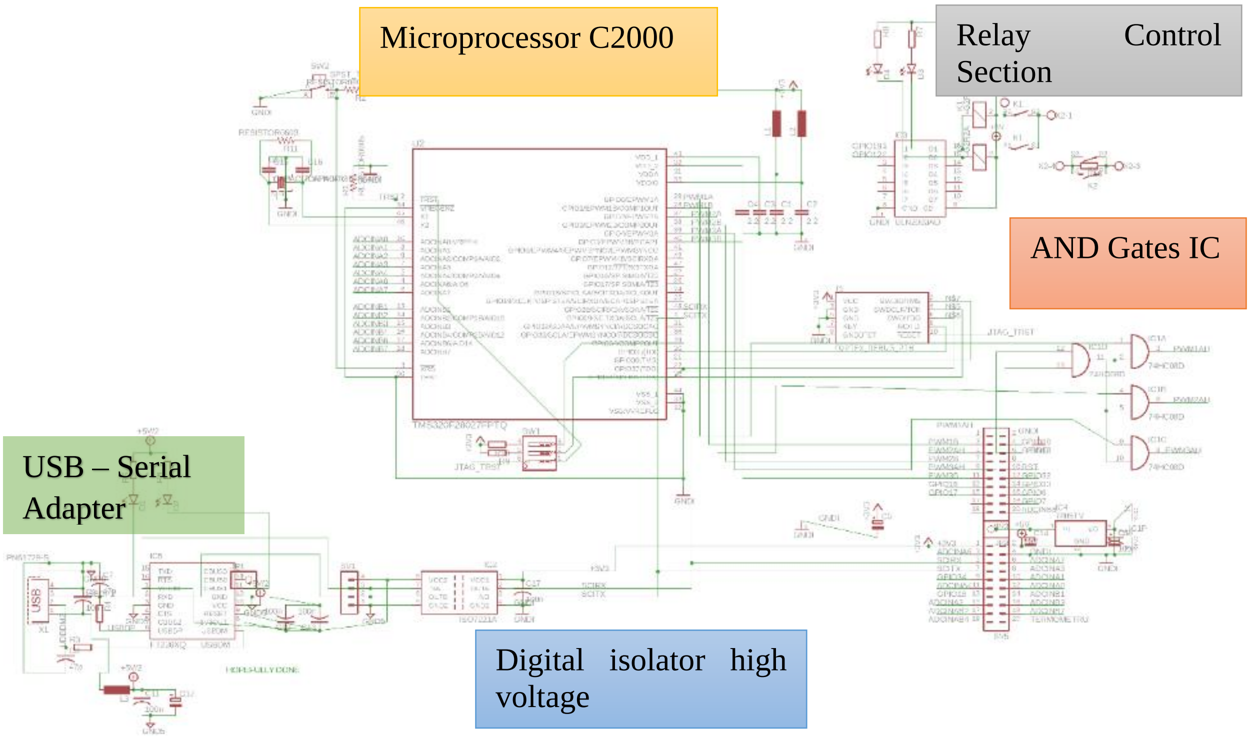


Fig III-3 Schematic processor board

The microprocessor has been selected based on the requirements: timer counter to simultaneously generate 6 pulses width modulated signals (PWM), standard communication interfaces (i2c/uart/can/lin), sufficient processing power to deploy control algorithms and fast and accurate analog-numeric conversion mode.

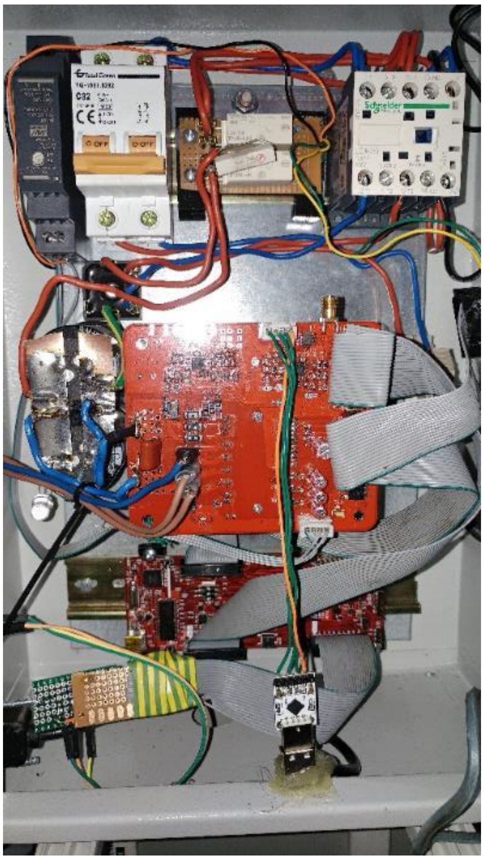


Fig III-4 In conjunction with F28069

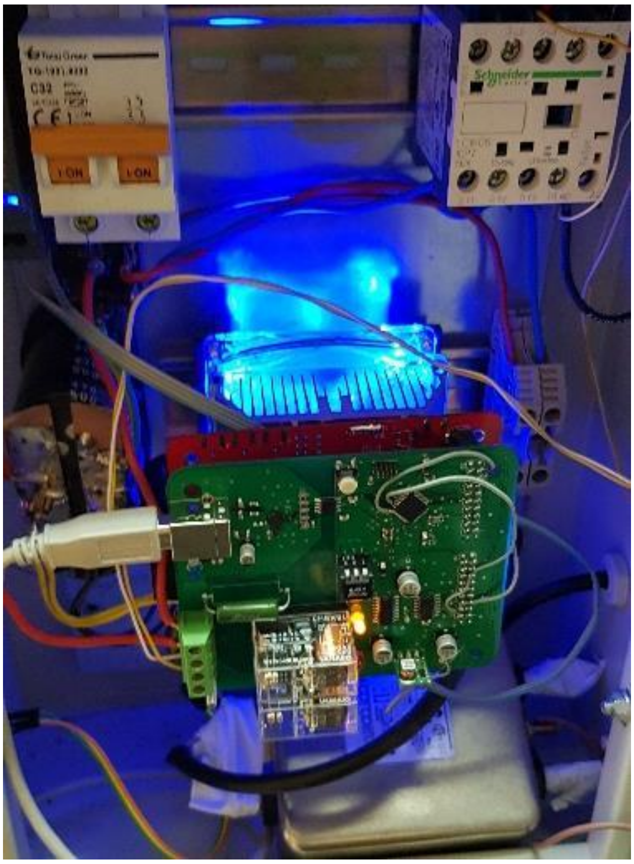


Fig III-5 New inverter and control board F28027

III.1.2 Developed acquisition and control board

Functional diagram is shown in Fig III-6 and the first prototype in Fig III-7.

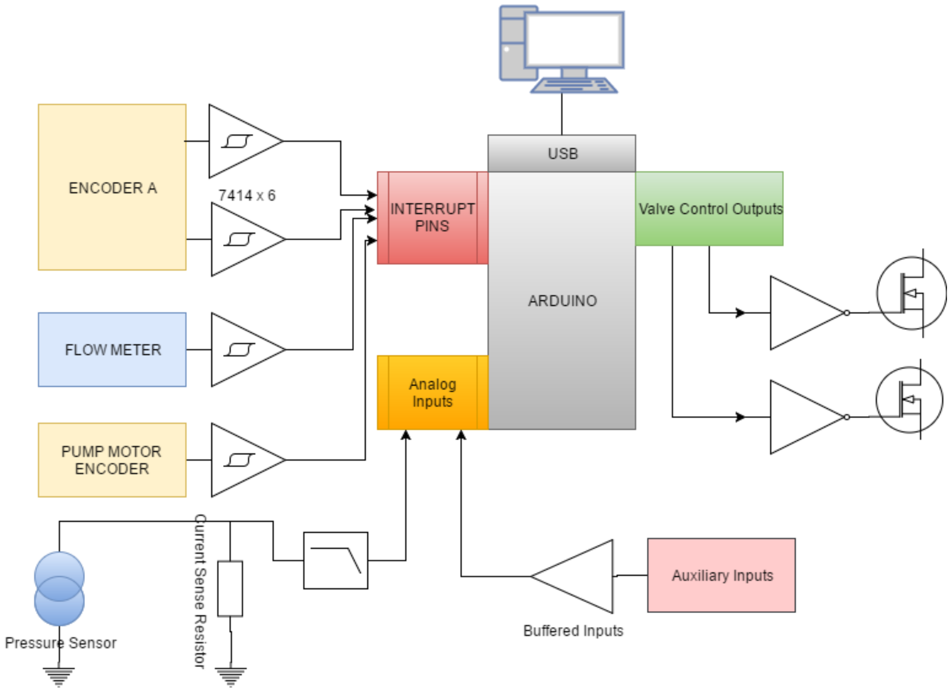


Fig III-6 Functional diagram **[33]**

Fig III-7 Prototype

Functional tests proved that the board should be redesigned (Fig III-8). The aim was to protect the microprocessor while adding new functions.

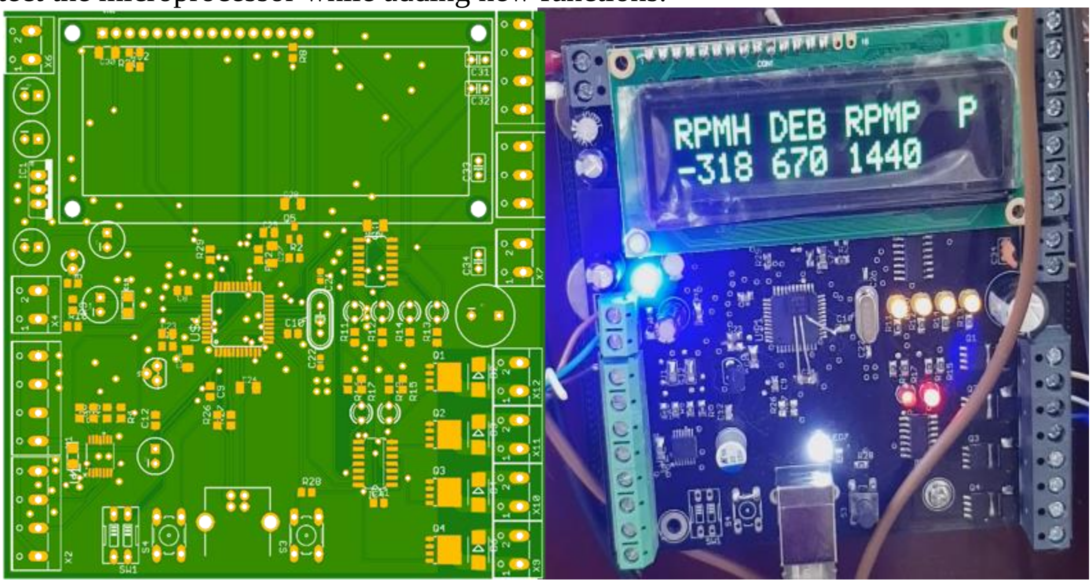


Fig III-8 Newly designed PCB

To determine the speed of the pump's electric motor, a 30-tooth encoder was designed in Solidworks (Fig Fig III-9). It was printed on a 3D printer with ABS filament.

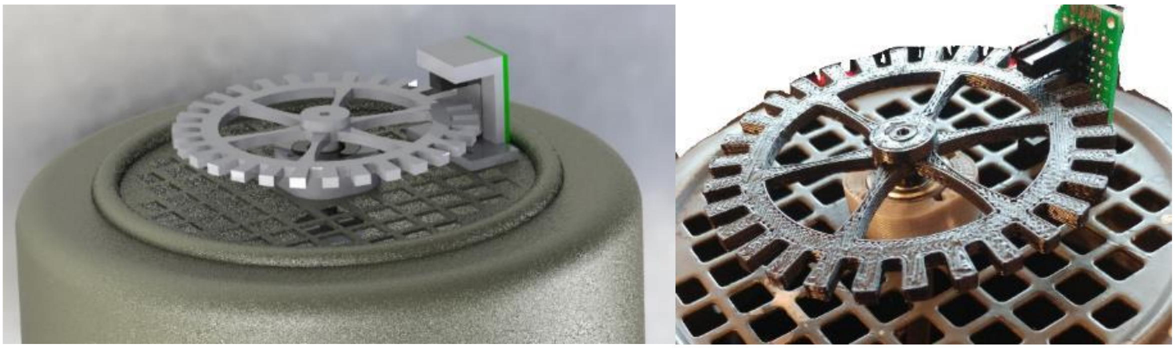


Fig III-9 Encoder as designed in Solidworks and manufactured

III.1.3 Principle of operation

The final circuit adopted is shown in Fig III-10 and allows a description of the principle of operation.

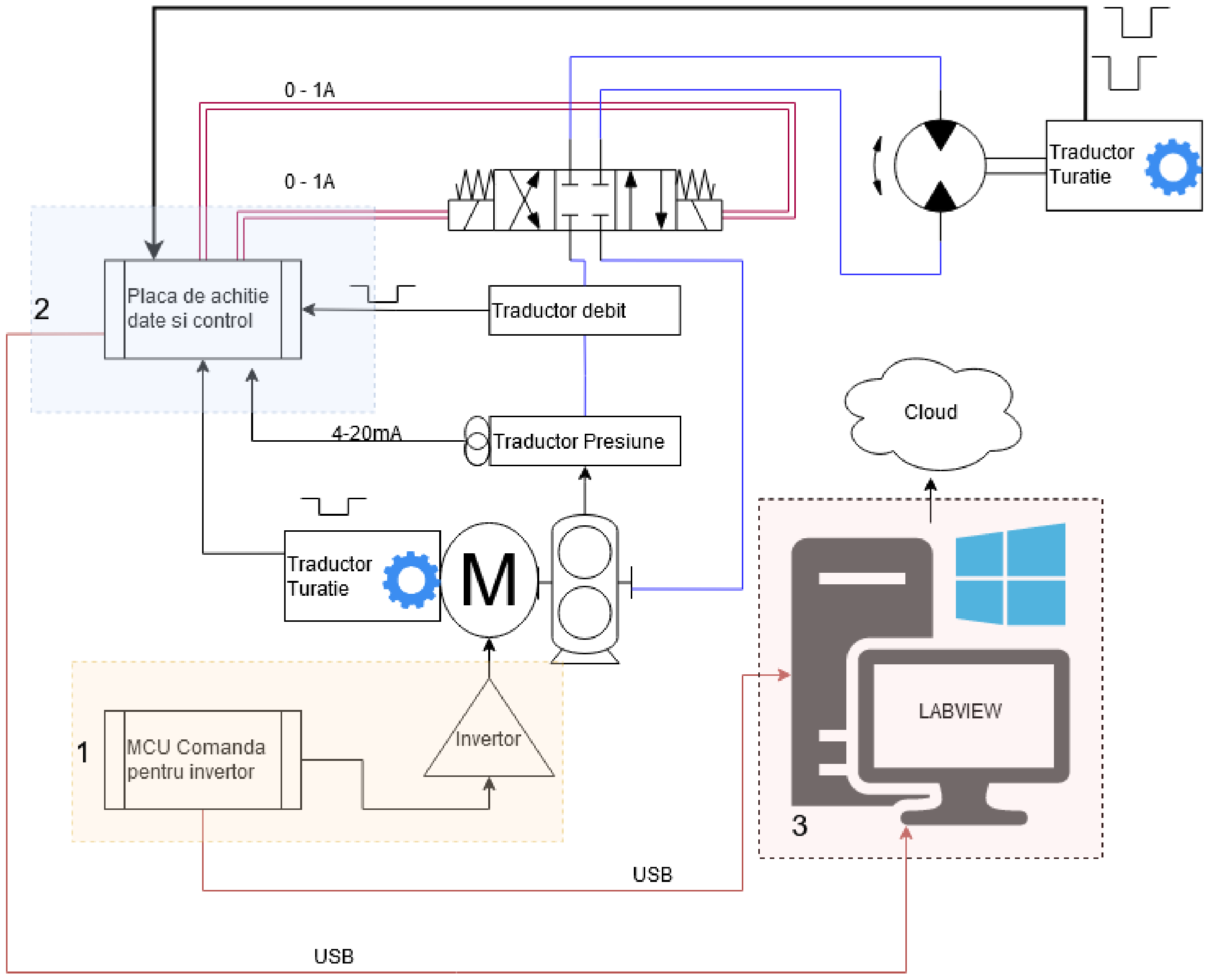


Fig III-10 Final command/control diagram

The main modules are highlighted with different colors and numbered to be described in the following paragraphs.

The first module, numbered **1,** is intended to generate a three-phase current with variable frequency and amplitude for controlling the speed of an asynchronous induction motor equipped with the pump. This module contains the **inverter** and **MCU** that controls the inverter.

The second module **- acquisition and control board** transforms process variables from electrical signals of different types into useful information for monitoring and control.

This board can measure signals from an industrial "current loop" sensor, 2 sensors that contain a Wheatstone bridge as well as signals from 4 frequencies. The information read from the sensors and transducers is displayed on the alphanumeric LCD display. The USB interface is used to send process information to the main process computer.

The **process calculator** numbered 3 in Fig III-10 manages the aforementioned components, ensures control, saves incoming data and processes them to ensure the safety and proper functioning of the system.

The program developed in LabView ensures that both boards are connected and work before allowing the motor to start. If both boards (inverter and acquisition) respond to commands, the program sends an order to the inverter to activate the main contactor and then waits for the capacitors present in the inverter to load slowly.

III.2 Intelligent hydraulic power generation group with typed inverter – variant 2

Unlike the 1.5kW pumping group, the modern group motor has a maximum power of 4kW, which is far too high for a single-phase power source of 230V. The design of circuits operating with a three-phase current source is difficult and dangerous so an inverter available on the market has been chosen.

The inverter has been integrated into the original structure resulting in a new structure (Fig Fig III-11) that includes the following components:

- two pressure transducers (9,10), one mounted on the pump output circuit and the other on the return circuit,
- a flow transducer (8) that monitors the flow in the system,
- a temperature transducer (11) to monitor the temperature of the working environment,
- a proportional pressure valve (7),
- a proportional 3-way valve (6) and the corresponding electronic control block (5),
- IoT gate (4) for remote access or laptop (3) for local data saving,

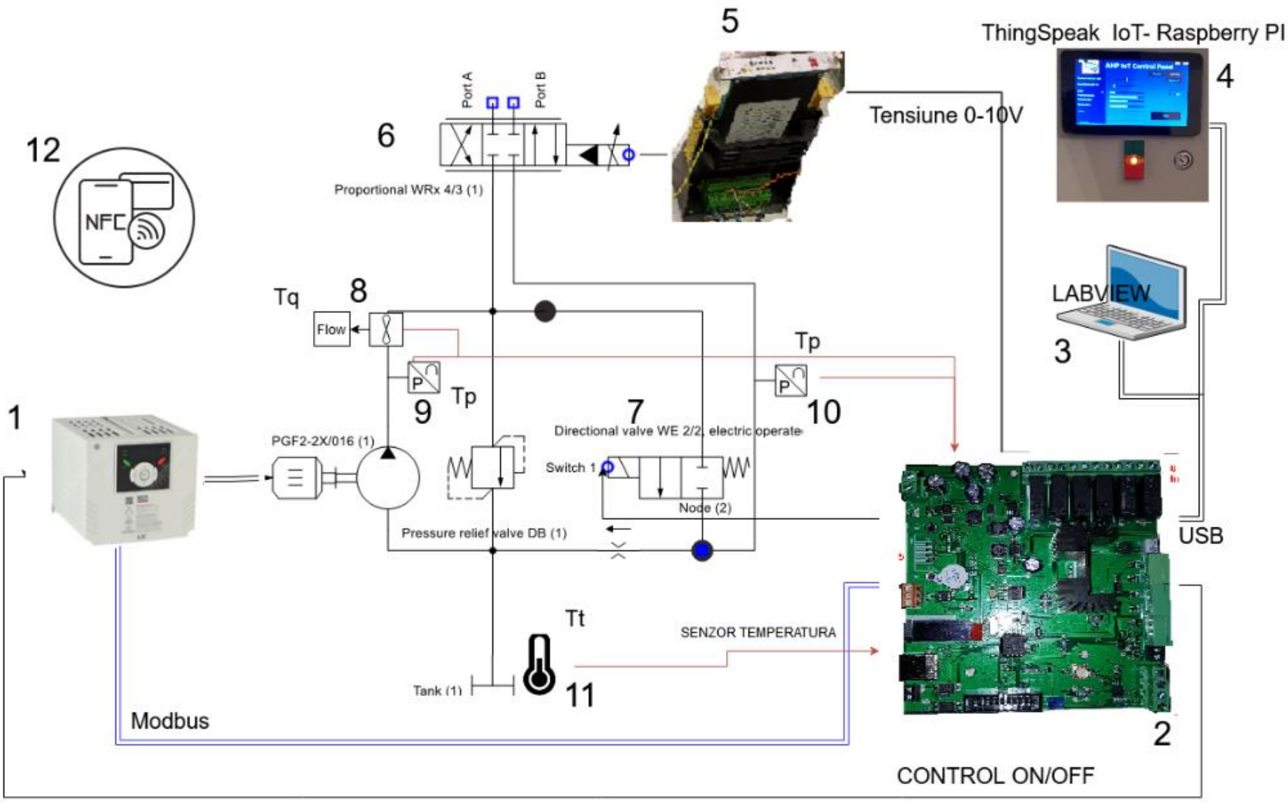


Fig III-11 Changes to the pumping group

- an NFC card (12) containing the IoT terminal address on the ThingSpeak platform for easy access to online information,
- control board (2) made specifically for this application.

From previous experience it has been concluded that an acquisition and control board is required, which will be described in the following paragraph.

III.2.1 Electronic acquisition and control board

The board has been designed to adjust the opening of a current-controlled pressure reducing valve to dynamically adjust the pressure in the system.

Valve and monitoring control board – variant 1

First variant (Fig III-12) has:

- 2 digital inputs (configurable),
- 4 analog inputs 0…20 mA,
- 2 analog inputs 0…10 V,
- 4 common transmitter outputs (24V or nothing),
- configurable voltage output: -10…10 V,
- constant configurable current output: 0-1A,
- OLED display,
- serial interface,
- USB interface.

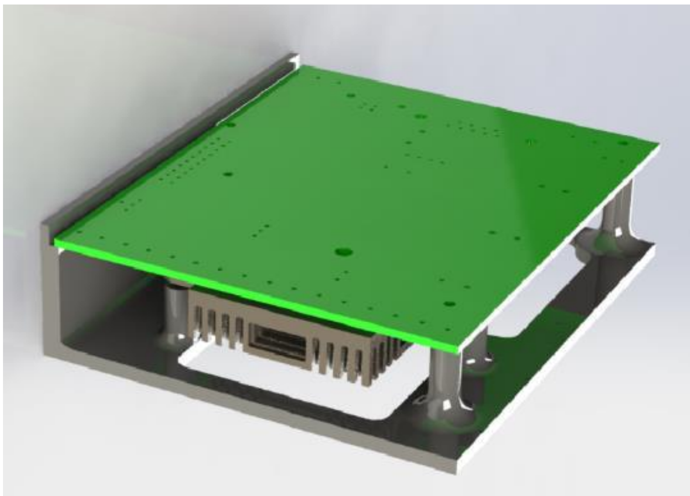



Fig III-12 Real PCB and 3d Solidworks model

The microprocessor used has many peripherals, is dynamic and has a low energy consumption; this variant is compatible with IoT solutions.

Control and monitoring board, variant 2

The circuit has been redesigned because of new requirements and to improve the possibility of mass production. It can be seen in Figure III-13 differs from the previous version by:

- 1 differential sensor input (K-type thermocouple or Wheatstone bridge) configurable,
- 2 digital outputs (24V or in the air),
- 6 N/O relay outputs connectable to any voltage,
- RS485 interface.

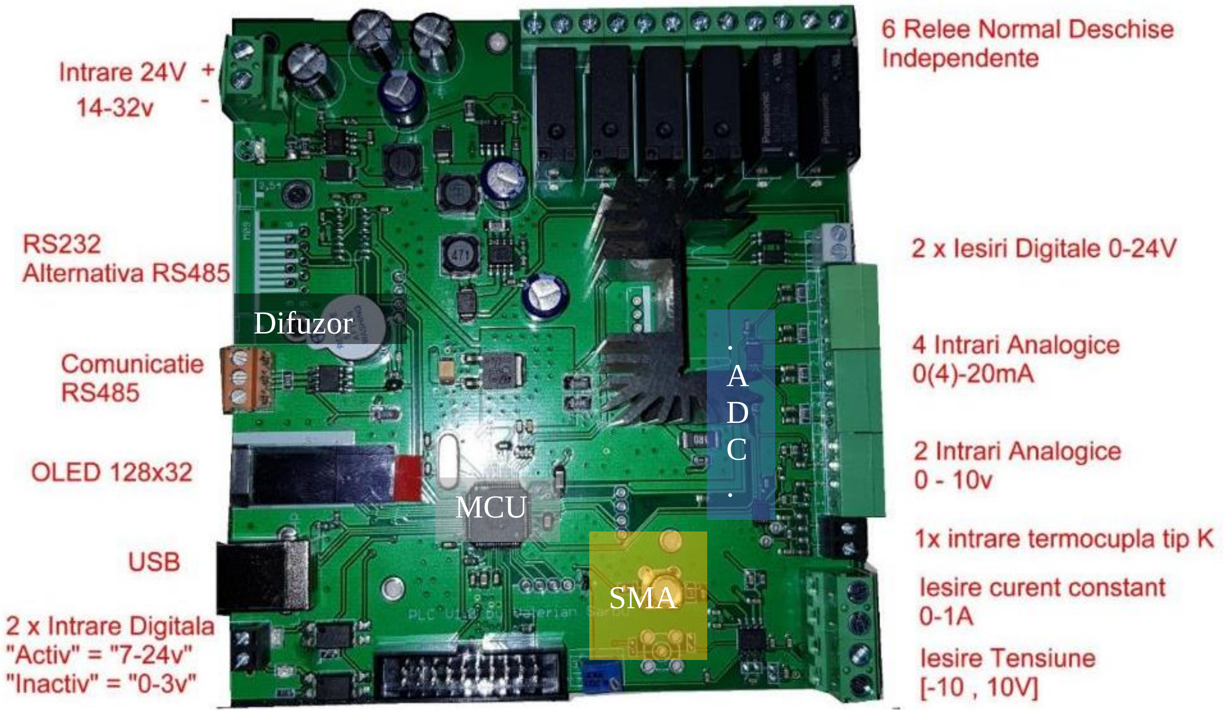


Fig III-13 Placa proiectată în varianta nouă

The new board was designed to also use an ATSAM L21 microcontroller (Fig III-13,MCU). In the new version the important changes are the emergence of new interfaces of type RS485, the addition of six relays and the use of an external analog-numeric conversion module of high resolution (the ADC integrated in the microcontroller has been replaced by an external one with superior performance). Two SMA connectors were also inserted to allow injecting of signals into the analogue block during testing.

III.2.2 Process calculator

First variant Fig III-14 was made using a Nextion branded LCD control module.

Fig III-14 Smart touchscreen version

Next one was made with a single board computer - Rasbperry PI. The obtained prototype in this case is presented in Fig III-15.

Regarding real-time data acquisition, experimentation, testing of other workflows and data processing, this variant is not ideal.

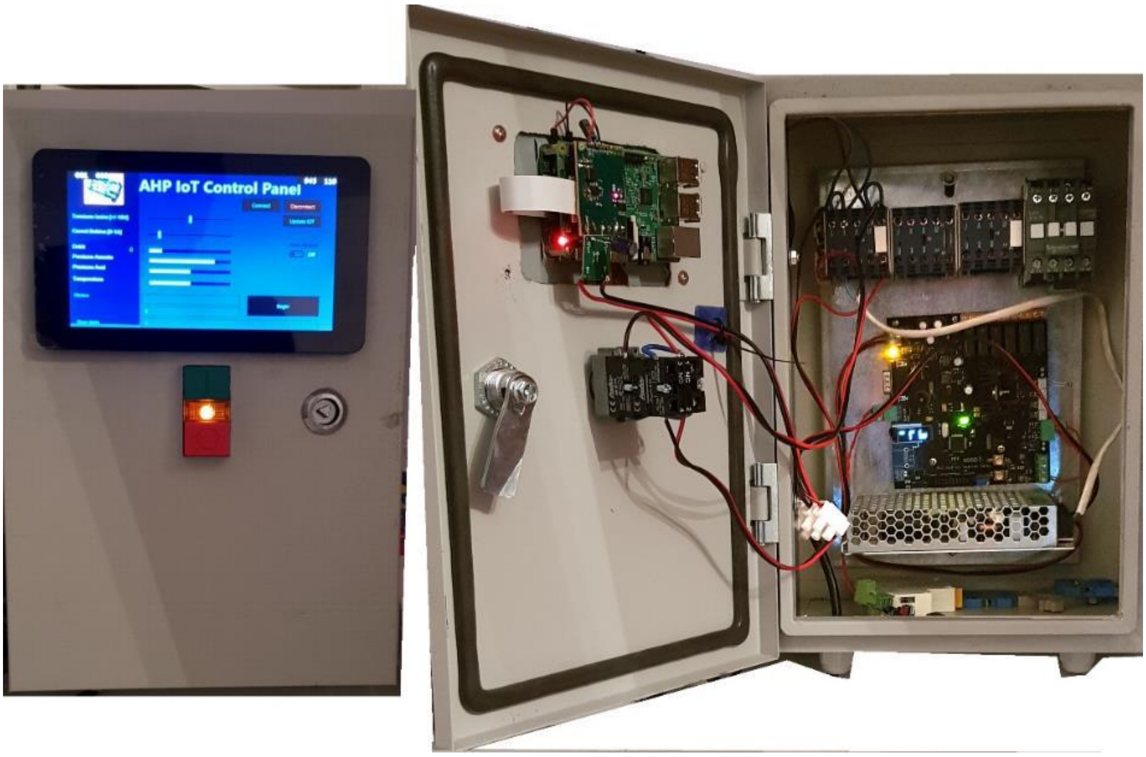


Fig III-15 Variant with secondary control computer, display and IoT gateway.

The optimal variant - **variant 3** (Fig III-16Fig III-16) requires a complete computer or laptop. This solution is expensive but the performance (the ease of modifying workflow and the possibilities of processing acquired process information) are highly competitive. It is preferable in the research phase, under laboratory conditions.

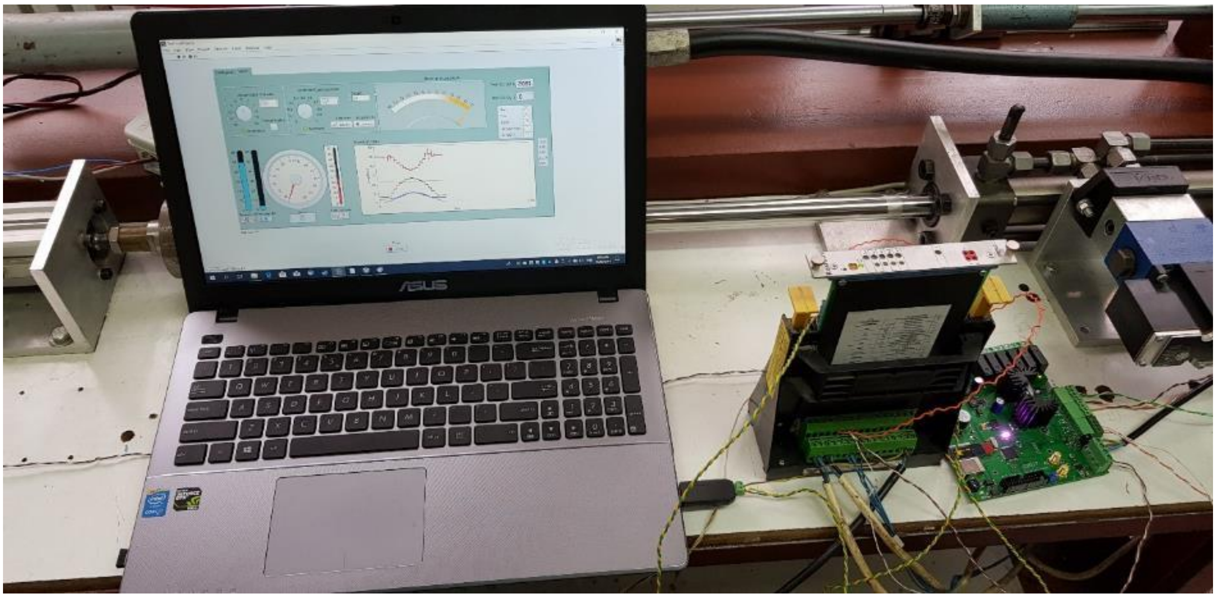


Fig III-16 Variant with computer / laptop and LabView.

III.2.3 Examples of hydraulic systems in which the hydraulic power generation group designed and carried out has been integrated

The intelligent hydraulic power generation group shown in the preceding paragraphs serves several experimental stands, existing in the laboratory " "Acționări, automatizări și robotică" in the Department of Mechatronics and Precision Mechanics. Our focus is on:

- Precision hydraulic positioning system,
- Speed adjustment system of a Danfoss rotary hydraulic motor,
- Hydraulic stand for experimental determination of working fluid density.

In Fig III-41, a functional diagram is presented which highlights the three hydraulic systems mentioned above. The required hydraulic energy is provided by the intelligent hydraulic power generation group GGEHI which is coupled with the loads by means of the RP (pressure supply) and RT (for connection to the tank) and r_i valves, one for each load.

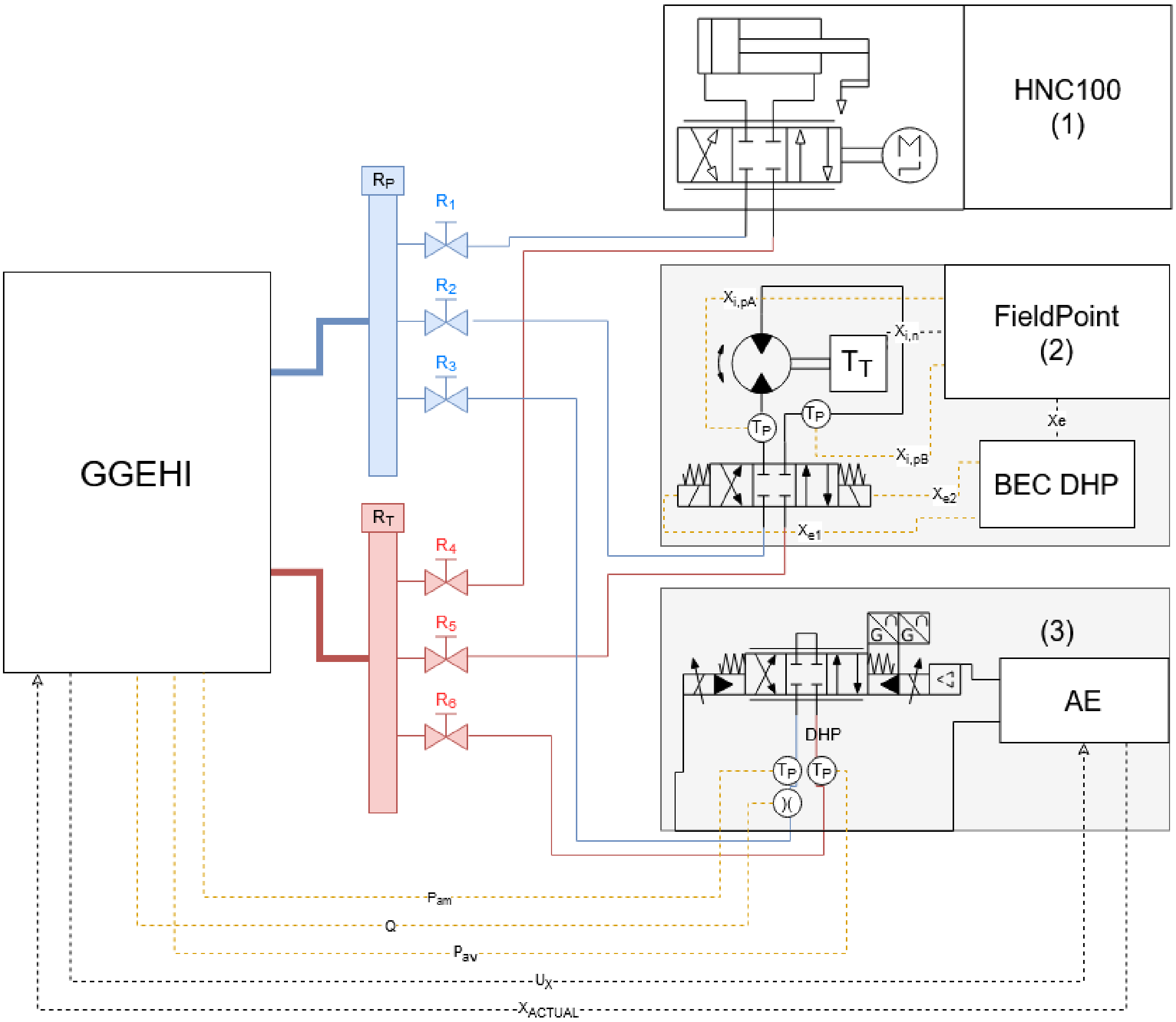


Fig III-17 GGEHI loads

The three systems powered by the smart pumping group have the didactic role of highlighting the variety of loads that can be attached to it. The first two operate independently of GGEHI following their own algorithms, the difference between them being given by the controller used, as follows:

- the system (1) uses a dedicated controller for hydraulic actuators (PLC),
- system (2) uses a modular programmable automatic coupled to a computer,

- the system (3) is hybrid, divides the control board with that of the GGEHI for the hydraulic amplifier control (AE), and in turn the serviced system contains all the transducers necessary for operation; this architecture is unconventional but necessary to ensure the accuracy of the measurements in this case.

1. Precision hydraulic positioning system

This system (Fig III-18) contains in addition to the mentioned group, a structure provided by East Electric (as representative Rexroth Romania) consisting of the following equipment:

- a programmable and configurable controller, model HNC100 (1),
- a linear hydraulic motor (2) with dual action and bilateral MHL rod,
- a position transducer T_{POZ} (3),
- a proportional hydraulic distributor DHP (4), position reaction and related electronics integrated into its construction.

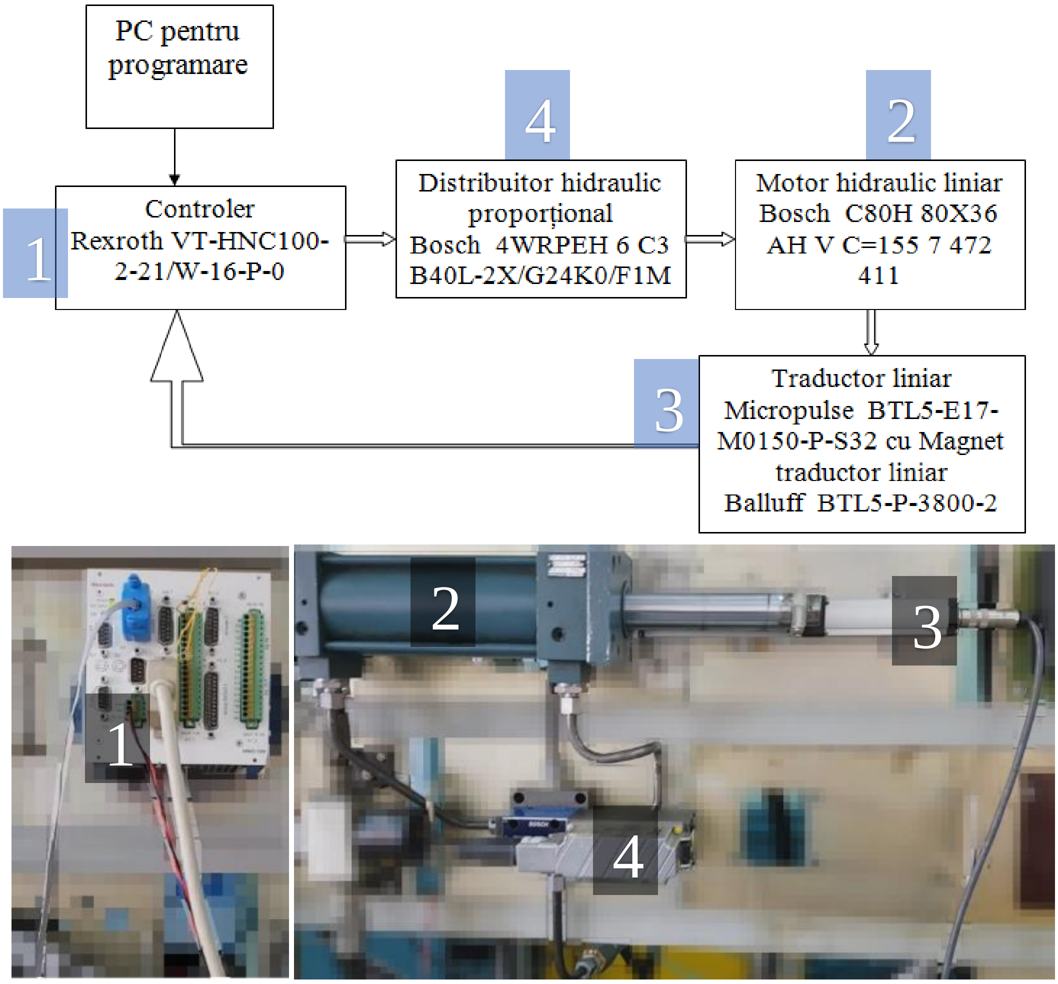


Fig III-18 Hydraulic positioning system
(1) HNC100 controller, (2)piston, (3)position transducer, (4)hydraulic valve

- **Danfoss rotary hydraulic motor control system**

The functional diagram is shown in Fig III-20. The following equipment can be identified in this structure:

- *MHR* – rotary hydraulic motor,
- *DHP* – proportional hydraulic dispenser,

- T_{pA}, T_{pB} – pressure transducers,
- T_n –rotation speed sensor,
- T_q – flow transducer.

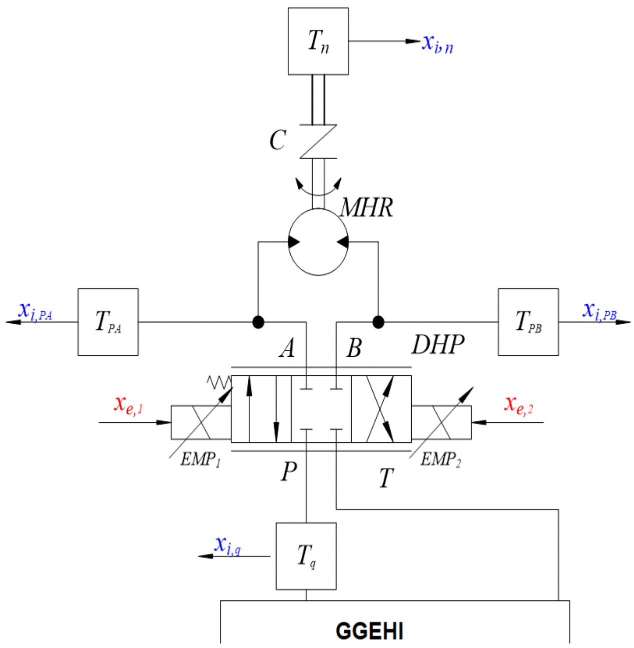


Fig III-20 Structure of the system **[26]**

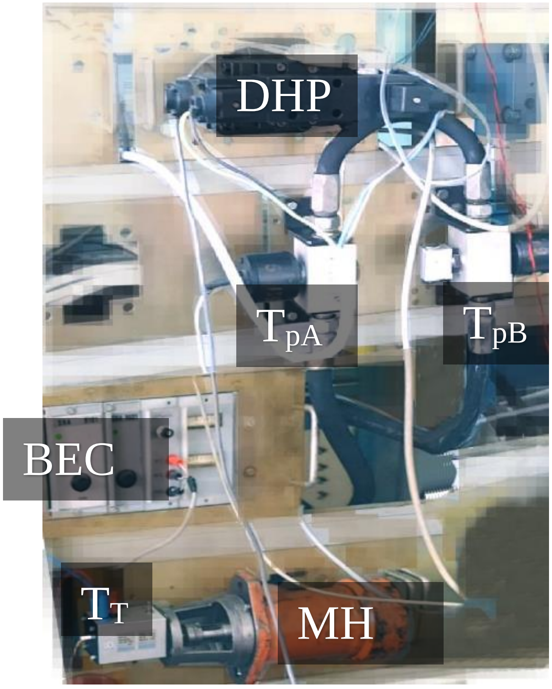


Fig III-19 Speed adjustment system of a rotary hydraulic motor

The stand (Fig III-19) is also powered by this power unit. The hydraulic circuit is simple, consisting of a hydraulic valve DH proportional to the load to whom a hydraulic motor (MH) is connected, with two pressure transducers (T_{pA} and T_{pB}) one on each line. The hydraulic motor has a T_T speed transducer on the shaft and the hydraulic dispenser is controlled by the electronic control block BEC. [19]

2. Hydraulic stand for experimental determination of working fluid density

In order to be able to experimentally determine the density of mineral oil, used as a working medium in hydraulic systems, an experimental stand presented as a functional diagram in Fig III-21 was realized and manufactured.

The proposed stand shall consist of the following equipment:

- proportional valve, SP,
- 3/2 preferential position and electronic control distributor, DHC,
- proportional distributor DrP,
- t_q flow transducer,
- pressure transducers T_{PAV} and T_{PAM},
- T_T temperature transducer,
- BEAC acquisition and control system.

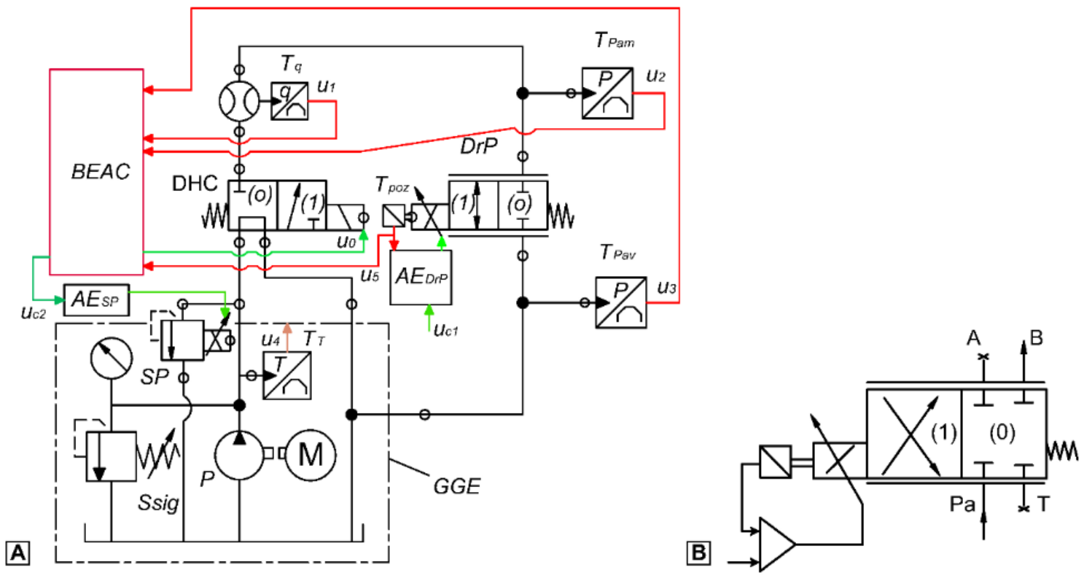


Fig III-21 Experimental stand structure (A); proportional valve (B)

III.3 Intelligent hydraulic power generation group with 15kW power

This group is a modern and highly efficient one, which puts its mark on the purchase price. It is equipped with a flow and pressure regulator and operates independently, as a classic hydraulic control system. An electronic block is required for optimal operation to power the power supply as well as several protective functions.

The manufacturing company also makes the related electronic part available to customers, but due to the fact that the budget allocated at the time for the acquisition of the hydraulic power generation group was not sufficient, it was decided to design the electronic part with its own resources.

There are three large electrical loads in the circuit who need power contactors to control them, namely:

- a 15kW power electric motor and star-delta start,
- a 1kW electric motor for the auxiliary recirculation and cooling pump,
- a 700W oil heating resistance also supplied by three-phase current.

Fig III-22 shows an image of the 15kW motor connection solder that drives the pump shaft. The six terminals are the ends of the three coils in the motor stator; the coils are rated U, V and W. Each coil terminal has index 1 or 2 representing its extremities.

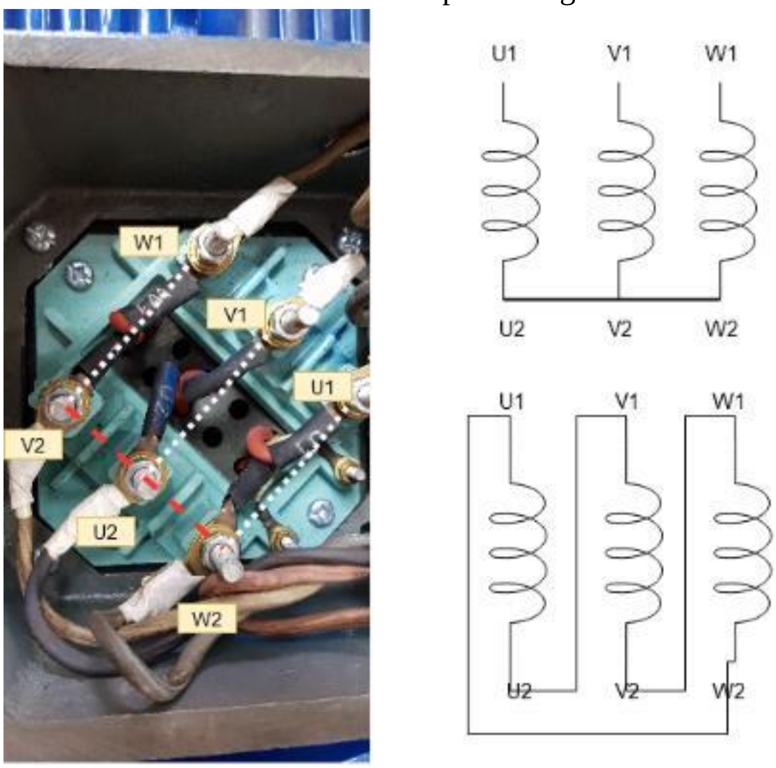


Fig III-22 Bornele de alimentare

The motor supply must be carried out with the correct phase sequence (U-V-W) applied to the terminals of the U1, V1, W1 coils to have the correct direction of rotation. Their pairs U2, V2, W2 must be configured for star layout (marked in red dotted on the figure) or delta (in white).

The control scheme can be carried out in several variants: with relays, with microcontroller with programmable plc automatic or with a computer and a acquisition card. The schematic in Fig III-23 shows the minimum power circuit required to start and stop the pumping group and accessories, in the variant where a programmable automatic control has been chosen. In the following figure (Fig III-24) the detailed electrical diagram is presented to be implemented initially in order to be able to start/stop the pumping group.

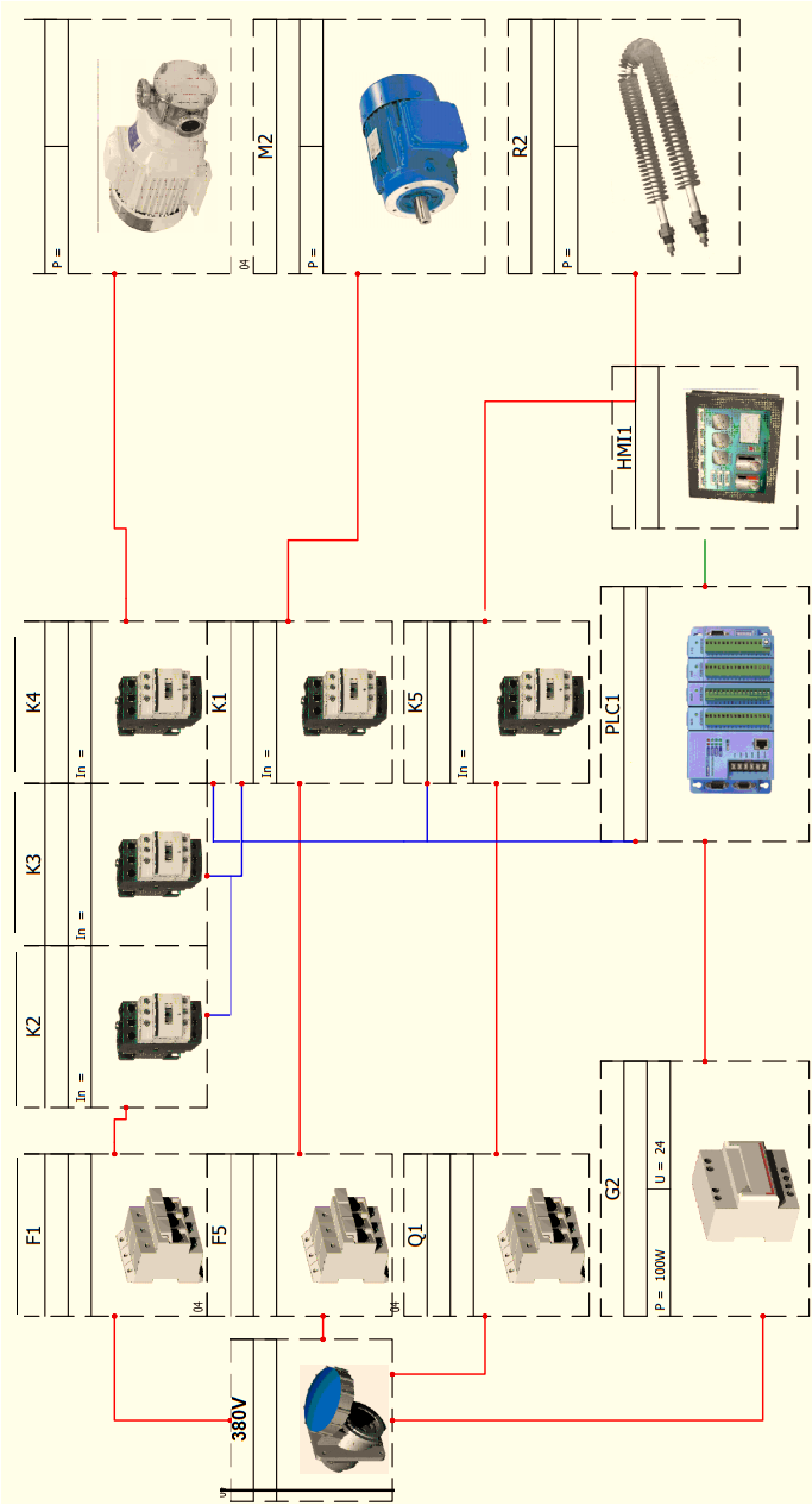


Fig III-23 Proposed Simplified Control Chart

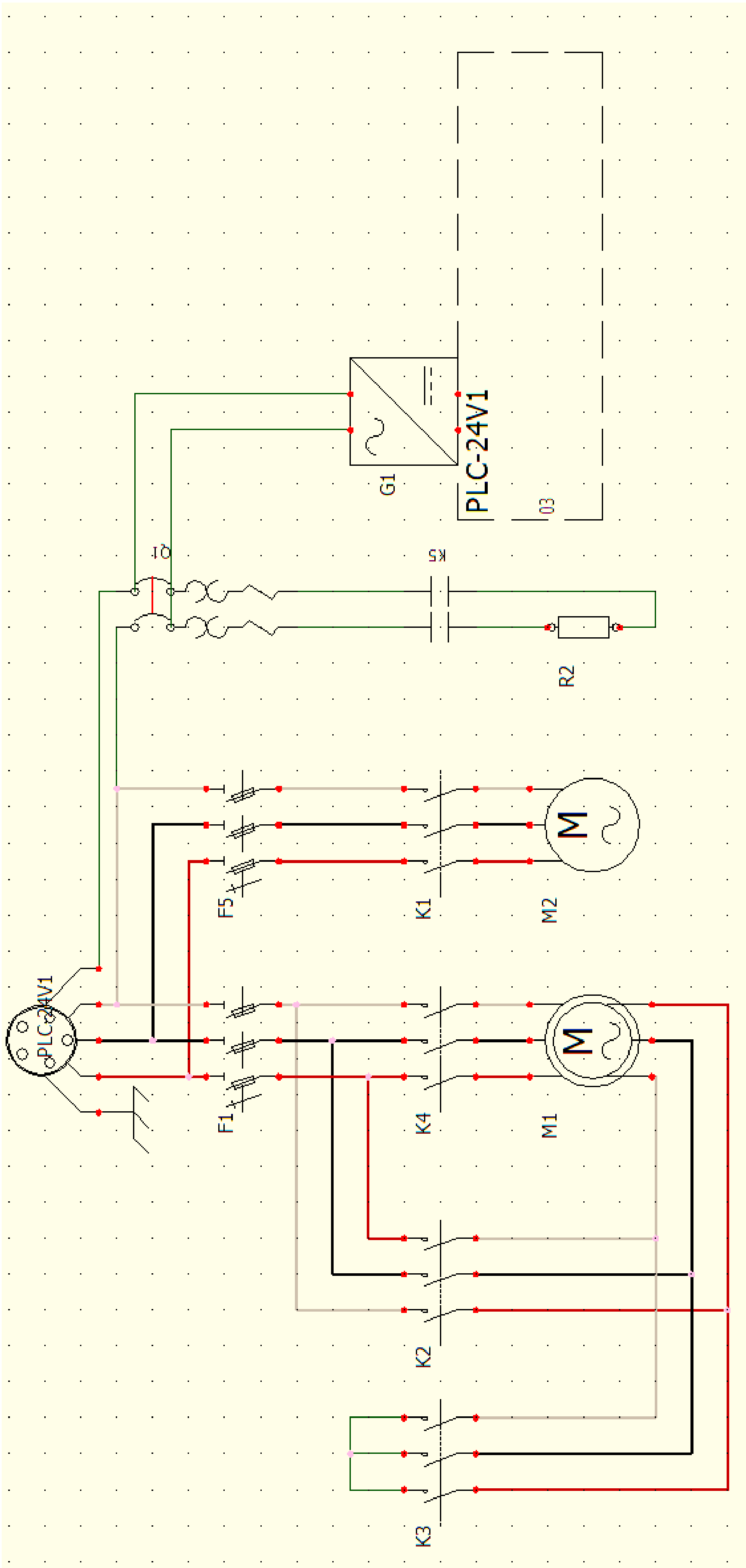


Fig III-24 Electrical schematic for the interface with the power elements

IV. THEORETICAL RESEARCH OF INTELLIGENT ENERGY GENERATION GROUPS

IV.1.1 Determining the pump capacity

As already mentioned, the pump integrated into the structure of the modified pumping groups is with gears. The first group has a pump with external gear and the modern one has the pump with internal gear arrangement.

For the second group the pump technical specifications are available, being newer as opposed to that of the first group. The original manufacturing company, Bosch, was unable to provide concrete data, just a technical sheet of a similar pump that we consider a reference, after long searches in the archives.

Thus, in the following, methods have been researched and developed to determine the size of a pump, if a few constructive parameters are known by simple dismantling. These methods are original and have already been published [20] [21].

Several methods of theoretical determination of the pumps specific volume have been identified to be presented below. Depending on the it, the instantaneous flow of the pump can be calculated with the following relationship:

$$q_p = 10^{-3} \cdot V_{gP} \cdot n \text{ [l/min]}$$

where n is the speed of the drive motor shaft, expressed in [rot/min].

- **First method**

The method involves calculating the volume using the equation:

$$V_{gP} = \left(2 \cdot V_g - V_{min}\right) \cdot z$$

$$V_{gP} = 2 \cdot \pi \cdot 10 \cdot 3^2 \cdot 12 = 5654\ mm^3 = 6.785\ cm^3$$

- **Second method** involves calculating the area by adding the areas of simple geometric shapes

Variant 1. A function was implemented in the Matlab programming environment that returned the following results: V_d = 347.2504 mm^3, V_g = 442. 8759 mm^3, V_{gP} = 8.8575 cm^3.

The second calculation variant assumes that in the case of the first variant the division of the tooth into n elements of volume ΔV_i. For n=2000iterations the following results were obtained:

V_d = 291,716 mm^3, V_g = 366.723 mm^3, V_{gP} = 7.3345 cm^3.

The third variant involves calculating the section of a tooth (fig. IV-1) as follows:

$S_d = 2 \cdot (S_1 + S_2 + S_3)$

Using this method the following results are obtained: V_d = 350. 1388 mm^3, V_g = 439. 9875 mm^3, V_{gP} = 8. 7997 cm^3.

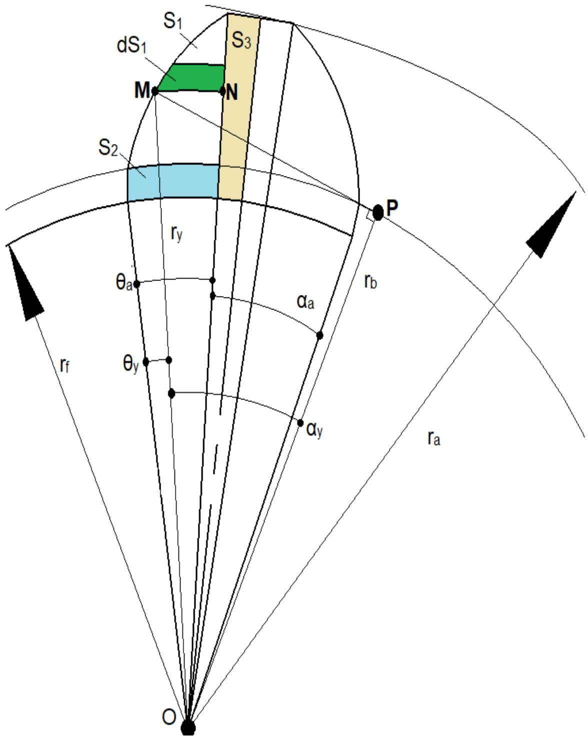
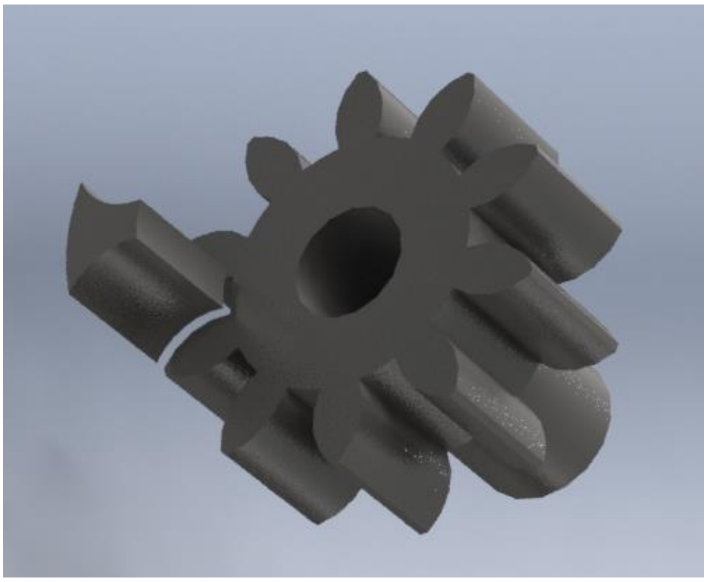


Fig IV-1 Variant 3

- **Third Method**

This method involves the construction of a tooth wheel for which the geometric elements are as specified in Table 1 in the computer-assisted design (CAD) environment (CAD). In Fig Fig IV-2 the 3D model obtained, for which you can determine the surface of a tooth and the volume of a void. In this case the result is 442.898 mm^2.



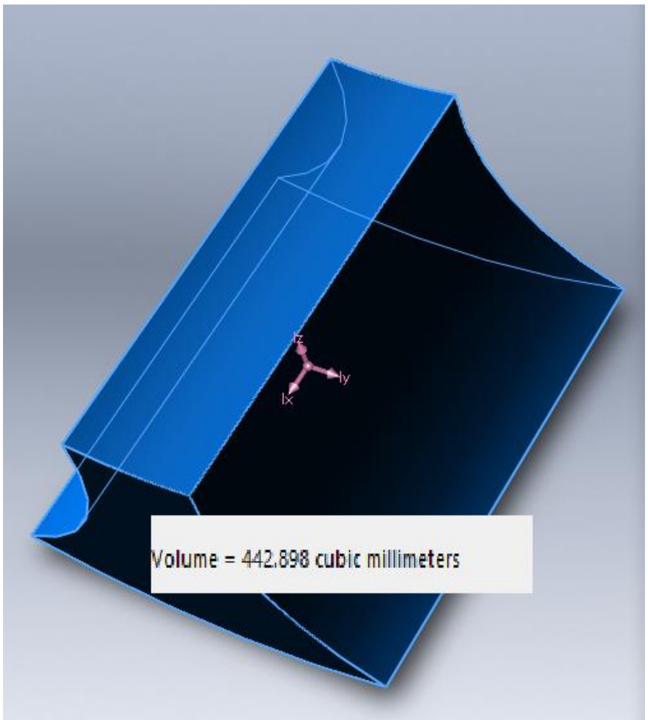


Fig IV-2 Determination of the section with SOLIDWORKS

- **Method 4**

The following will refer to the scheme of principle in Fig IV-3. In this figure the driver pinion *1* engages in rotational motion, in the figurative sense, the driven pinion *2*. The point of contact of two teeth is at some point in *M*.

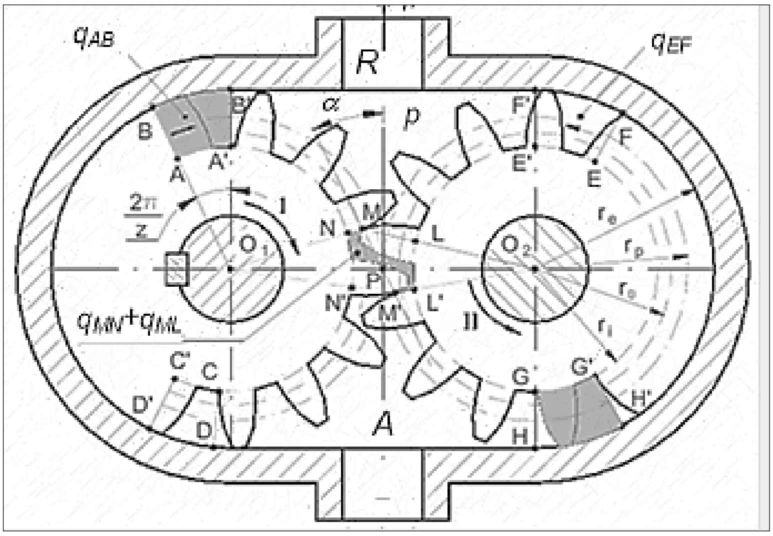


Fig IV-3 Schema de principiu

Debitul instantaneu refulat se calculează cu relația:

$q_i = q_{AB} + q_{EF} - q_{LM} - q_{MN}$

The average flow rate has been calculated in the thesis as being:

$\overline{q_P} = 1.5081 \cdot \frac{2 \cdot \pi \cdot n}{60} \left[\frac{cm^3}{s}\right] = 9.4757 \cdot n \left[\frac{cm^3}{min}\right]$

So, it can be said that for this pump the specific volume has the value of $9.4757\ cm^3$.

- **Method 5**

It was decided to design an original experimental stand, which involves: a stepper motor for moving the gears, a camera to capture images, image processing in Matlab, their interface being made with a single-board computer of type Raspberry Pi (Fig IV-4).

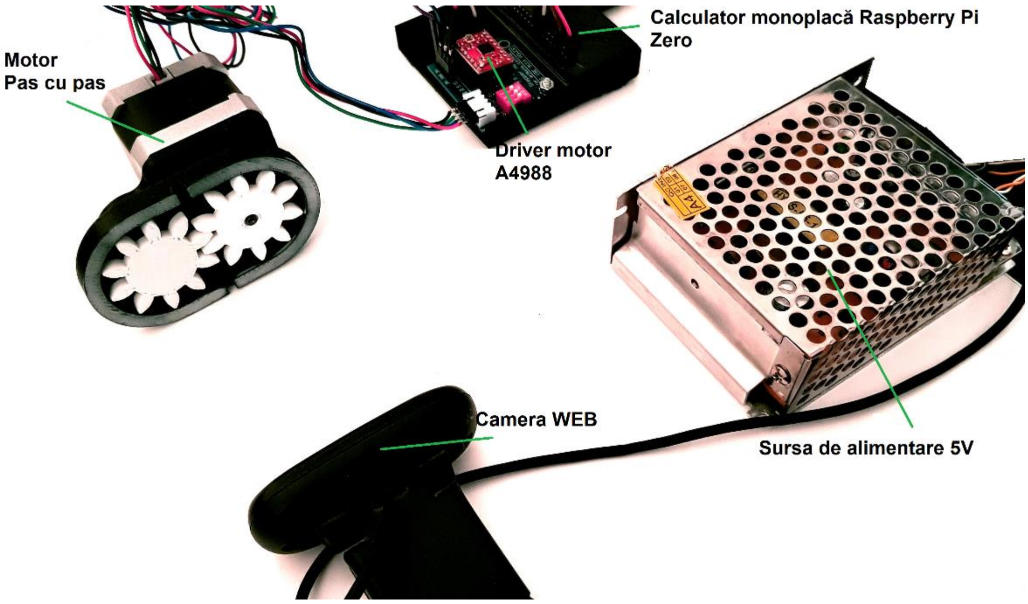


Fig IV-4 Stand experimental procesare imagine **[21]**

The pump can be partially disassembled to film the movement of the toothed wheels directly, or a pump with identical geometric parameters can be created on a 3d printer. Images received are processed to make analysis of active volumes easier. At first the first image is cut out to exclude elements irrelevant to the study. The step-by-step motor then receives the continuous rotation control at constant speed and begins the actual capture of the movement of the toothed wheels.

All images are then processed similarly to Fig IV-5, cropping, then the area of interest is converted from color image to black and white, followed by combining images.

Fig IV-5 Etapele parcurse de algoritm **[21]**

The selected point of interest is used by the program to perform the "Fill" operation of black and white images. Then the result is passed through the operation of Or Exclusive (Xor) with the original image to record the differences.

This matrix applies the Matlab "nnz" function (number of non-zero items) that counts all boxes with a value other than 0; this array is also used as a "mask" to graphically display the result of the (Fig IV-6).

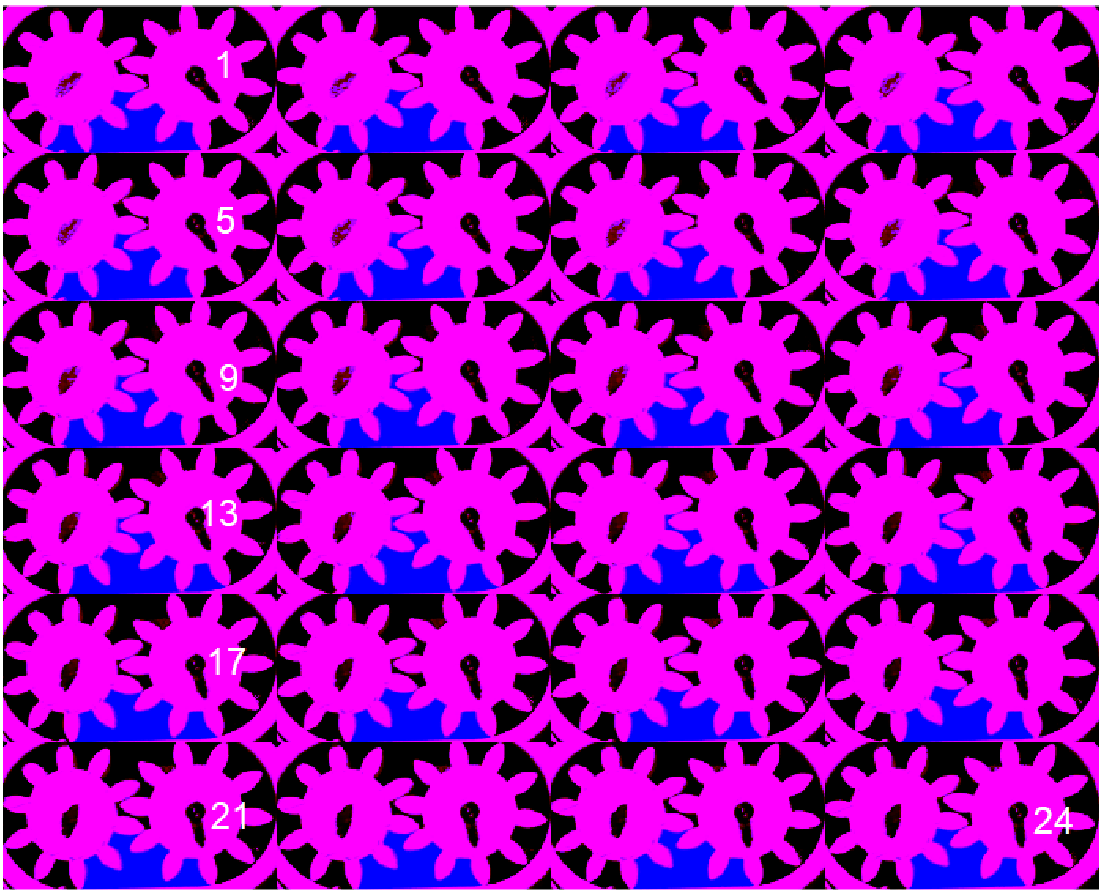


Fig IV-6 Rezultatul grafic obținut **[21]**

The number of pixels obtained is then multiplied by a constant representing "pixels per square mm" in order to have the result in the form of an area in mm2.

Subsequently multiplying this area by the width of the flank of the teeth, a volume is obtained. The result obtained is visible in Fig IV-7 the normalized volume on the right.

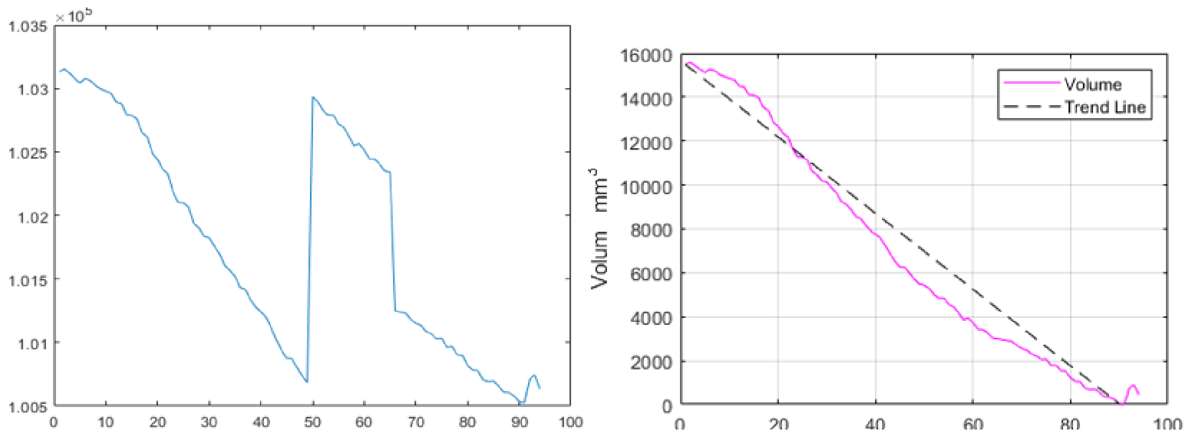


Fig IV-7 Results a) number of pixels b)volume change with trend line as reference **[21]**

The study of the volume between two consecutive teeth is also achievable without changing the algorithm. The graphic result is shown in Fig IV-8 right side.

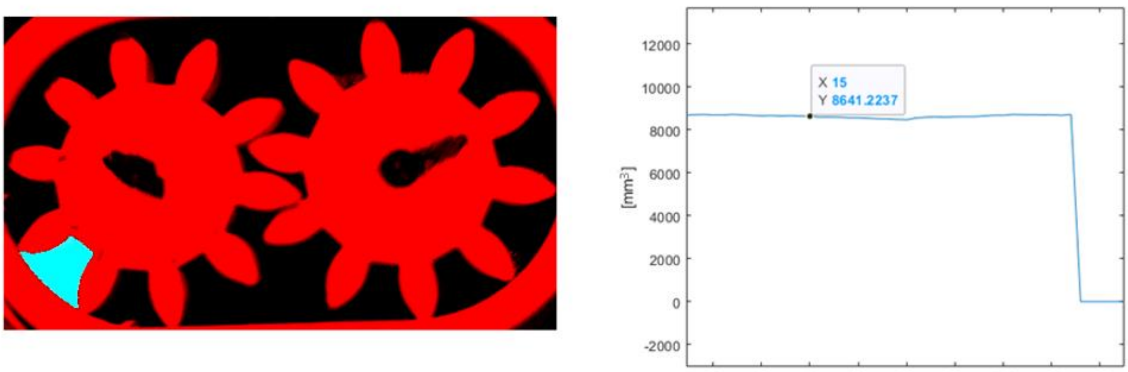


Fig IV-8 Volume between two consecutive teeth and the resulting estimate of the displacement **[21]**

- **Method 6**

An original algorithm was written in Matlab to draw the complete gear using only specific mathematical equations and a special algorithm. Determining the volume of gaps between two consecutive teeth with the previous method is interactive and getting the same effect was desired also in the case of mathematical determinations.

The result of the algorithm can be seen in Figure IV-9. The algorithm determined the volume occupied by a tooth to be 253.06 mm^3 respectively the value of 8.51cm^3 is calculated for the displacement.

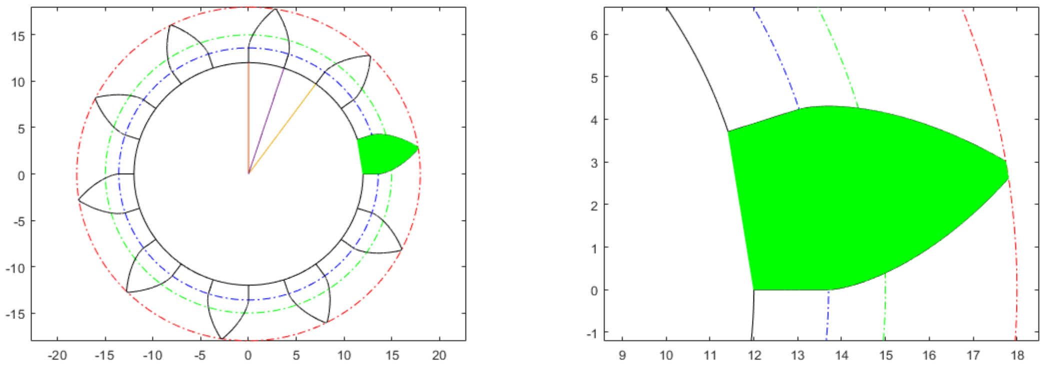


Fig IV-9 Graphic result(in the green area there are numerous rectangles, their areas being added)

➢ Conclusions

The results obtained by the methods presented are centralized in Table IV-1.

The values obtained by the six methods are close to that provided by the manufacturer, 8.6 cm^3, also determined experimentally.

Tabel IV-1

Method	Tooth volume $V_d[mm^3]$	Tooth-gap $V_g[mm^3]$	Size $V_{gP}[cm^3]$
Method 1	-	-	6.785
Method 2			
- V1	347.2504	422.8759	8.8575
- V2	350.0588	440.0675	8.8013
- V3	350.1388	439.9875	8.7997
Method 3	350.1323	439.9940	8.7999
Method 4	350.244	442.898	9.4757
Method 5	-	428.7	8.574
Method 6	253.0656	425.5176	8.5104

IV.1.2 Elaboration of the mathematical model

The aim was to develop a mathematical model as complete as possible, avoiding as far as possible the use of simplified hypotheses. The mathematical model was established in Fig IV-10.

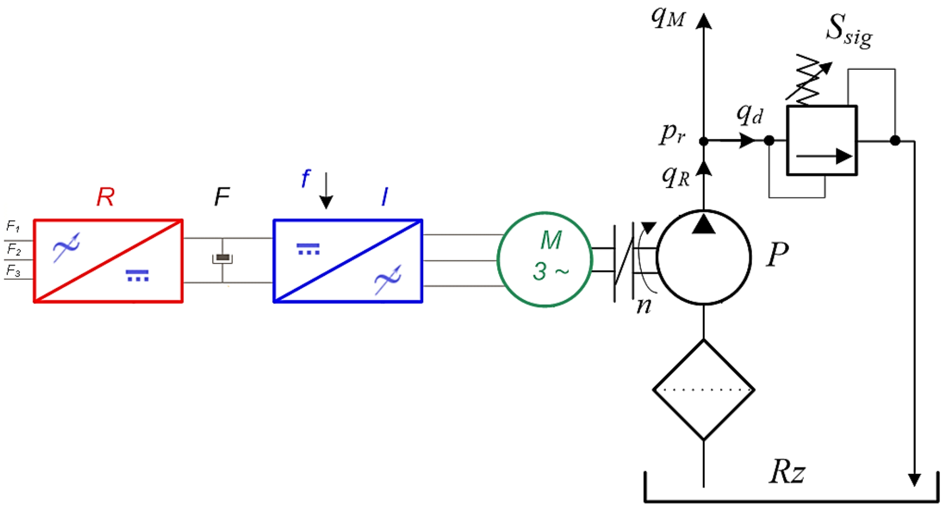


Fig IV-10 Schema de principiu a grupului hidraulic de pompare

IV.1.3 Numerical simulation of group operation

Matlab Simulink and Amesim simulation media are used for numerical integration of the mathematical model. In the figure IV-11 is the block scheme of the program carried out in Matlab Simulink.

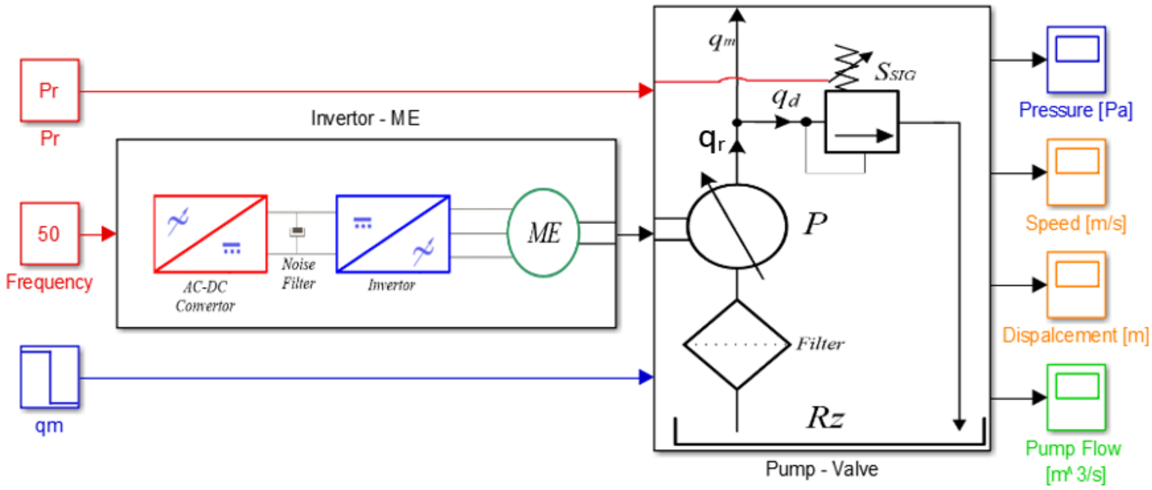


Fig IV-11 Simulink simulation scheme

The program was carried out modularly and contains:

- mode "input parameters"; this module allows the setting of the *adjusted* pressure Pr, the flow rate of the motor q_m and its frequency *f* control for the inverter;
- module "Inverter-Motor Electric" (fig.IV-12);
- module "Pump-Safety ValveBlock" (fig.IV-13);

- module "Parameters of interest"; this module allows you to view the parameters of interest for simulation: pressure, pump flow, speed and valve displacement.

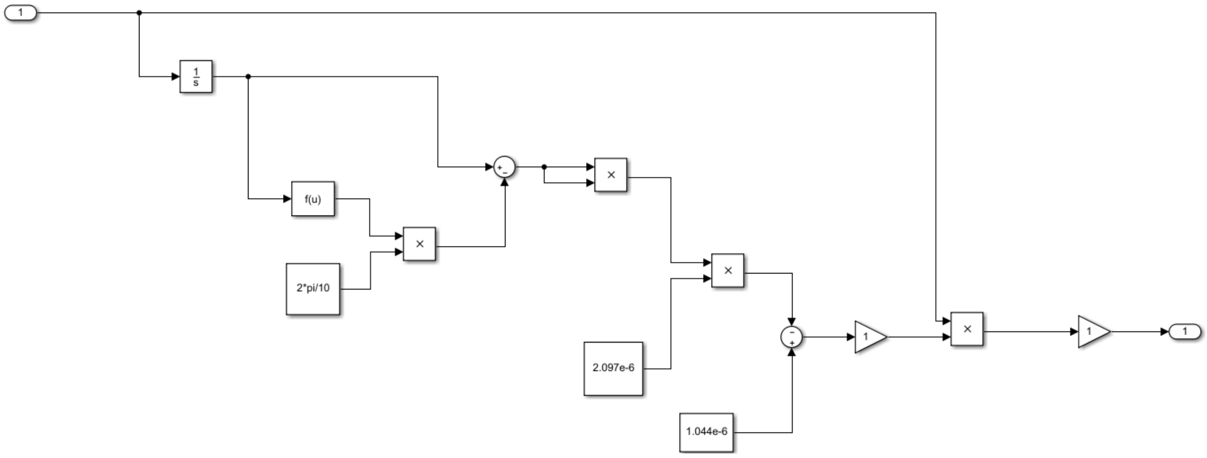


Fig IV-12 Detail – inverter block and electric motor

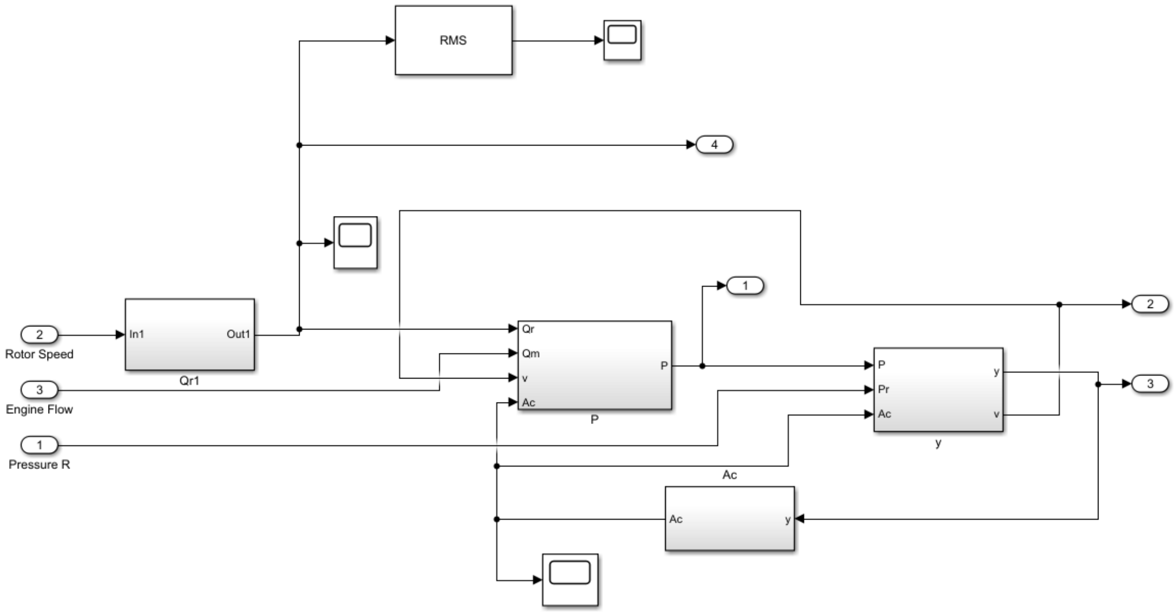


Fig IV-13 Detail – safety valve block

In parallel, for the validation and consolidation of the proposed mathematical model, a simulation model was also developed in the Amesim environment (fig. IV-14).

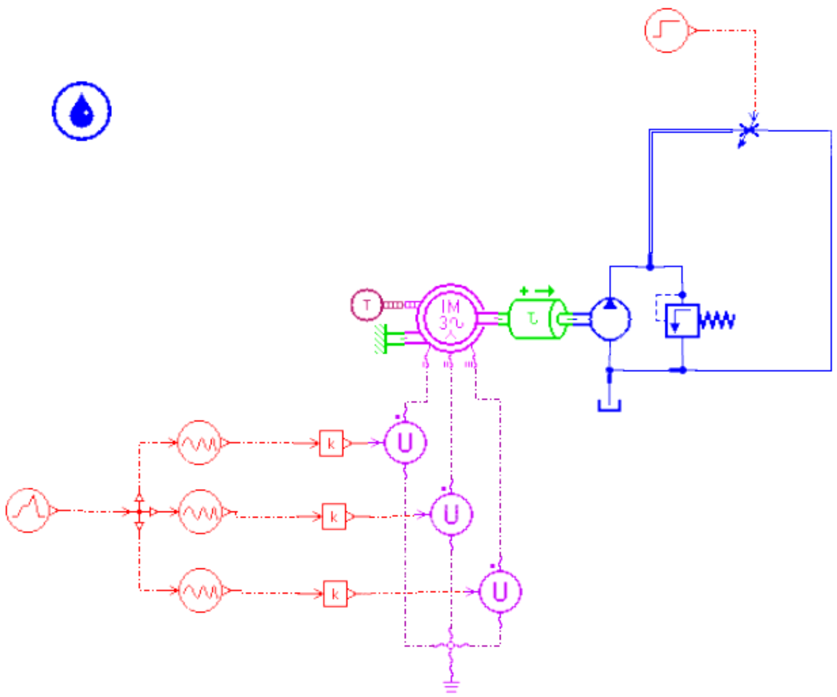


Fig IV-14 Amesim diagram

Model obtained using Mathworks Matlab-Simulink

Another possibility to simulate the functioning of the proposed group models is the use of the Simscape extension of the Matlab-Simulink programming environment.

The model obtained (Fig IV-15) allows to verify the effect of inserting an inverter motor into the circuit.

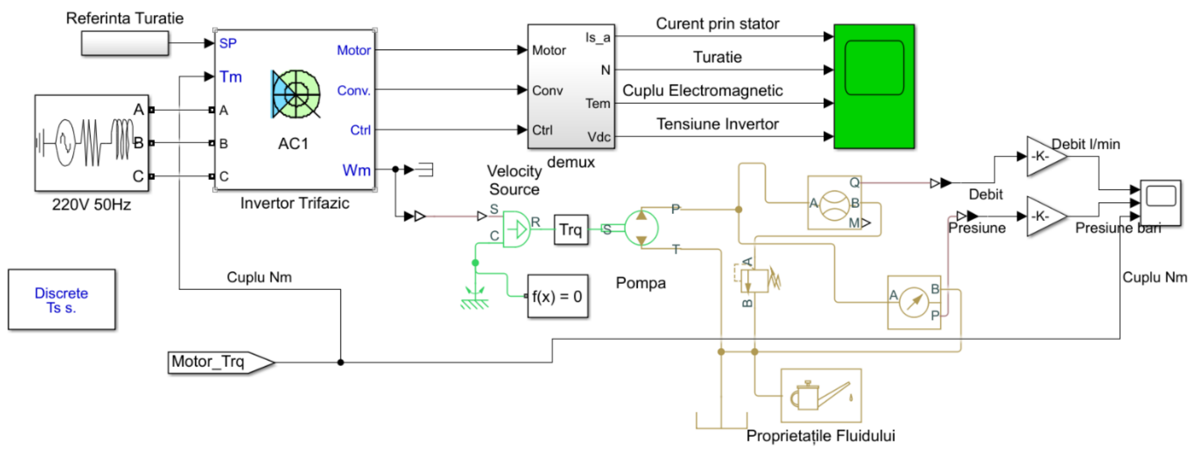


Fig IV-15 Simulation in Matlab Simulink with Simscape extension

The theoretical analysis of the energy generation group consisted in the elaboration of its mathematical model. This model has been numerically integrated using both the Matlab Simulink, Matlab Simulink-Simscape graphics programming environment and the Amesim environment.

The results obtained show that the integration of the inverter allows to control the speed of the pump drive shaft by means of the frequency of the power supply. By adjusting the speed of the asynchronous electric motor, the hydraulic flow values were adjusted to the hydraulic pump with external cylindrical gear and the variation of hydraulic power was obtained by the volume method.

V. IMPLEMENTATION OF MODELS DEVELOPED IN INTELLIGENT HYDRAULIC ACTUATORS

V.1 Speed adjustment system of a rotary hydraulic motor

Characteristic of this system is the fact that the speed of the hydraulic motor is controlled by means of the flow of the pump, thus by the volume method. This system has been analyzed in both theoretical and experimental terms. The following are the results obtained. [22]

V.1.1 Theoretical analysis

The theoretical analysis was carried out using the Amesim simulation medium and presents two scenarios of interest: the response to a step signal and a sinusoidal variation of the command [23]. The model obtained is shown in Figure V-1. These are composed of graphic blocks, each with a well-defined purpose based on mathematical computational relationships, which together form a hydraulic system close to studying.

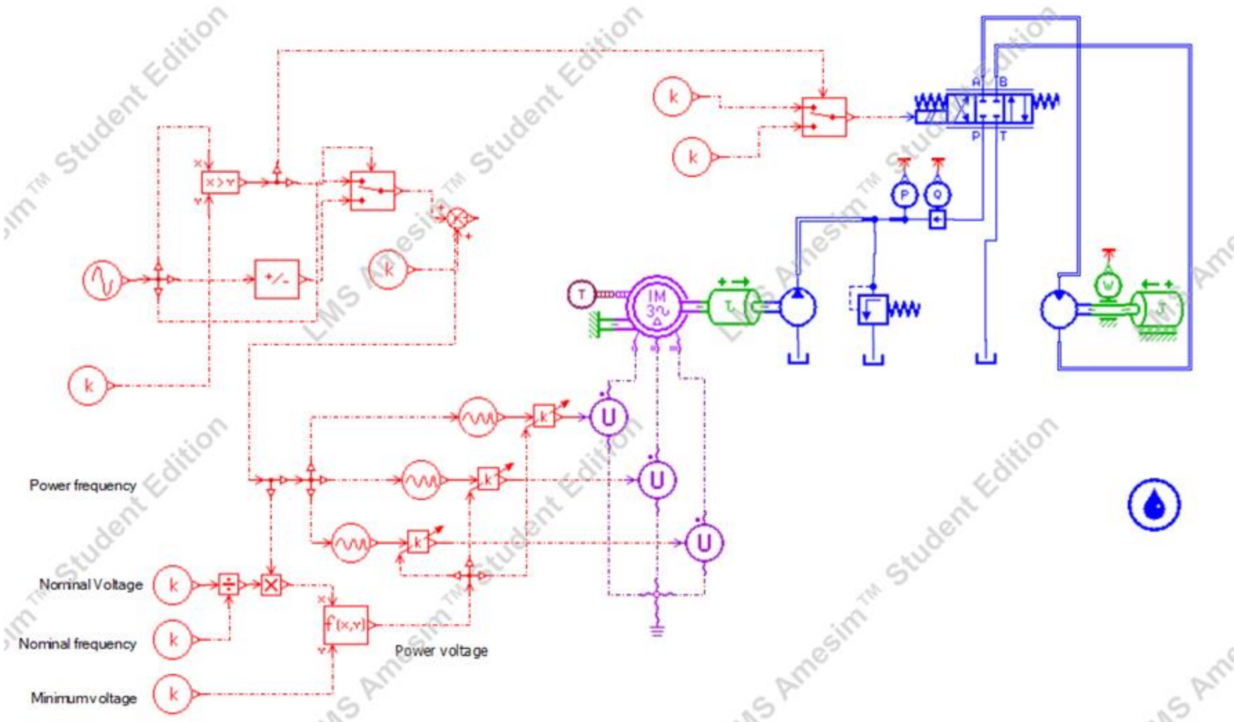


Fig V-1 – Simulation of Group 1

in Fig V-2 results from the simulation are presented.

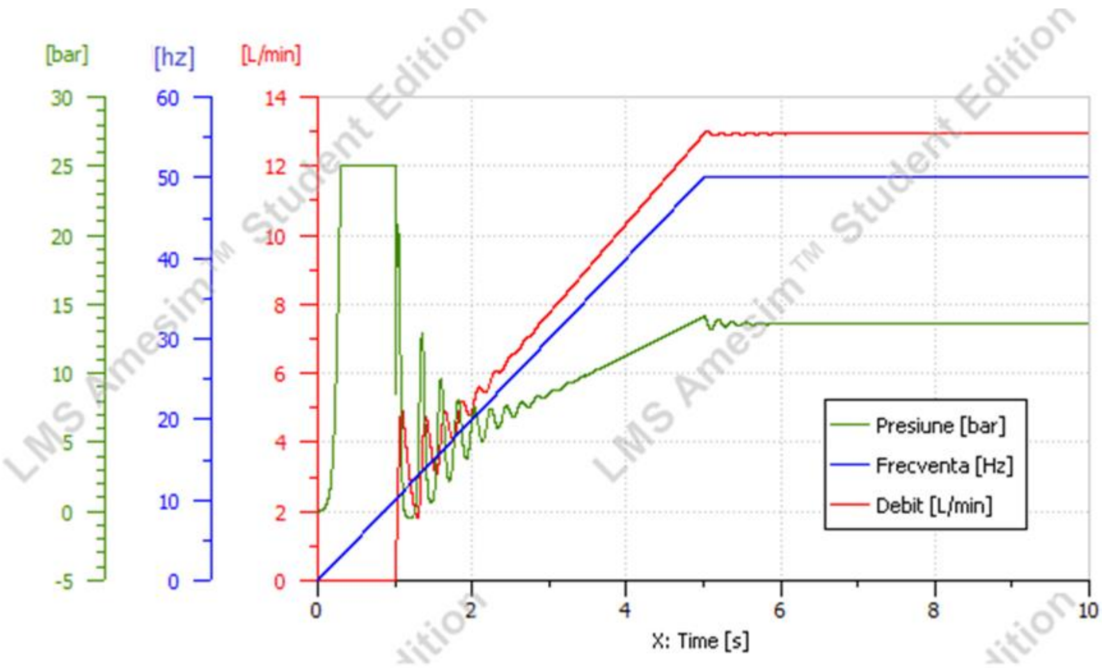


Fig V-2 Amesim Ramp and Startup Simulator with classical valve initially closed

Fig V-3 shows the results obtained when the frequency variation is sinusoidal. In this case the frequency varies between 15 and 50 Hz after each cycle the distributor being switched and thus reversing the direction of rotation of the hydraulic motor. The figure shows the two revs, the speed of the electric motor and the speed of the hydraulic motor respectively.

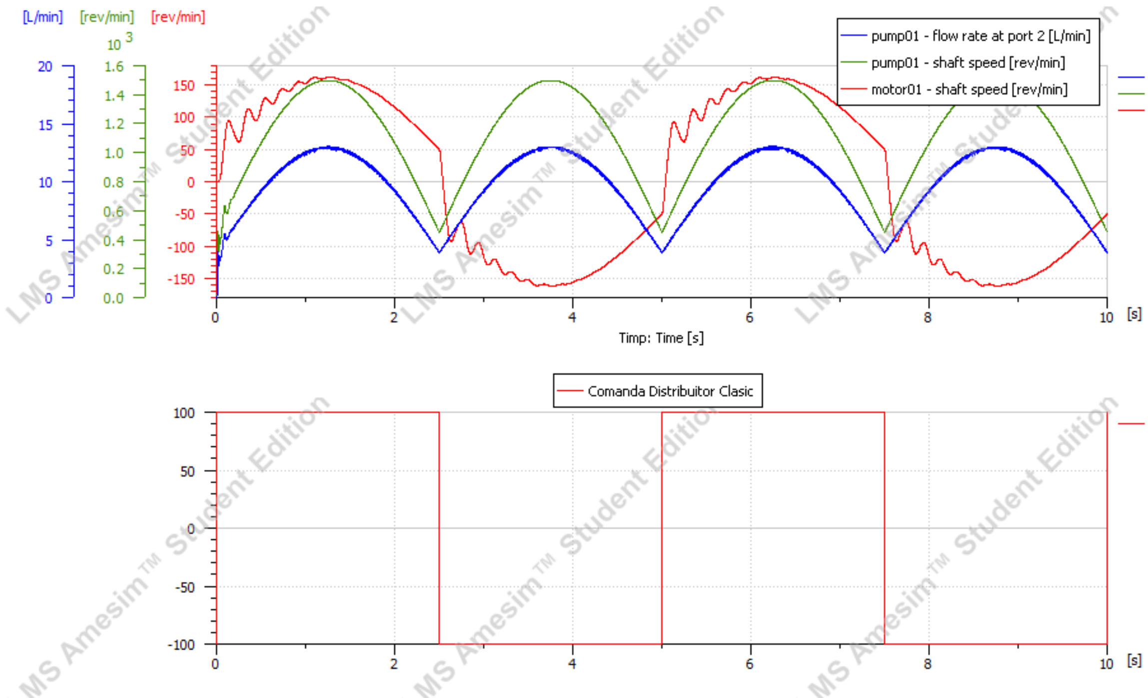


Fig V-3 Sinusoidal signal response graph

V.1.2 Experimental analysis

For experimental testing of the system, the stand described in paragraph II.3.1 was used, and this involved the implementation of a work flow in the form of firmware and software. The software allows the control of the inverter, the valve, and the gathering of data from the transducers present in the system.

Started with the creation of a graphical interface in LabView to control the first variant of the inverter, i.e. the one in which there was no separate acquisition card (Fig III-4). This variant is very simple, and has the following elements: start button (Power) and limited running current (Inrush), a rotational frequency set button (Desired frequency), button that achieves an automatic drop (auto-decrement), stop button and five graphic displays: Pump motor speed (RPM), Measured pressure, voltage on the capacitor bank in the form of a dial and in the form of a graph, inverter temperature in the form of a graph.

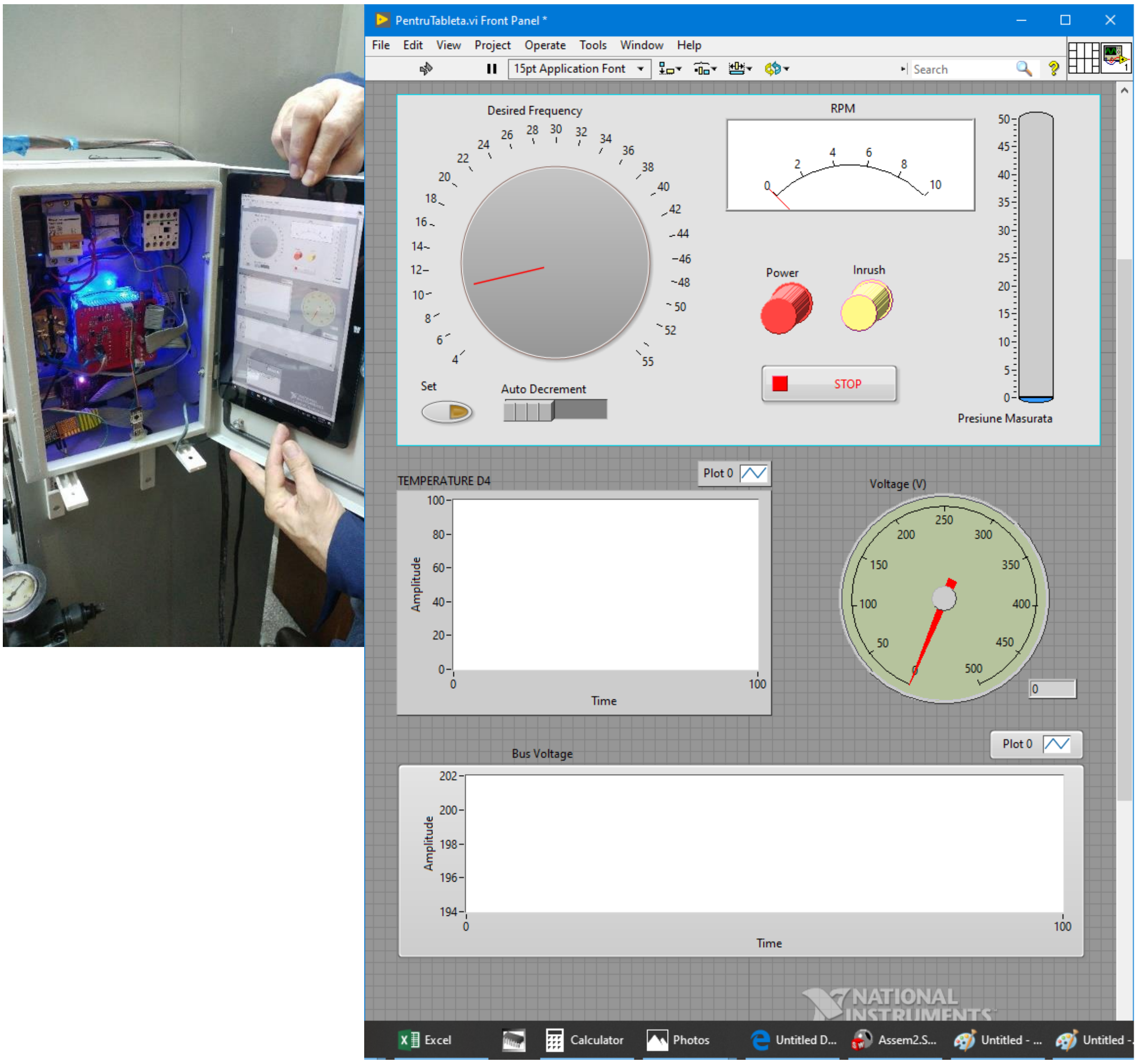


Fig V-4 Graphical Interface

The results of the descending ramp test are shown in Fig V-5. The graph has two y axes, the one on the left serves the set frequency and pressure and the one on the right only the hydraulic motor speed.

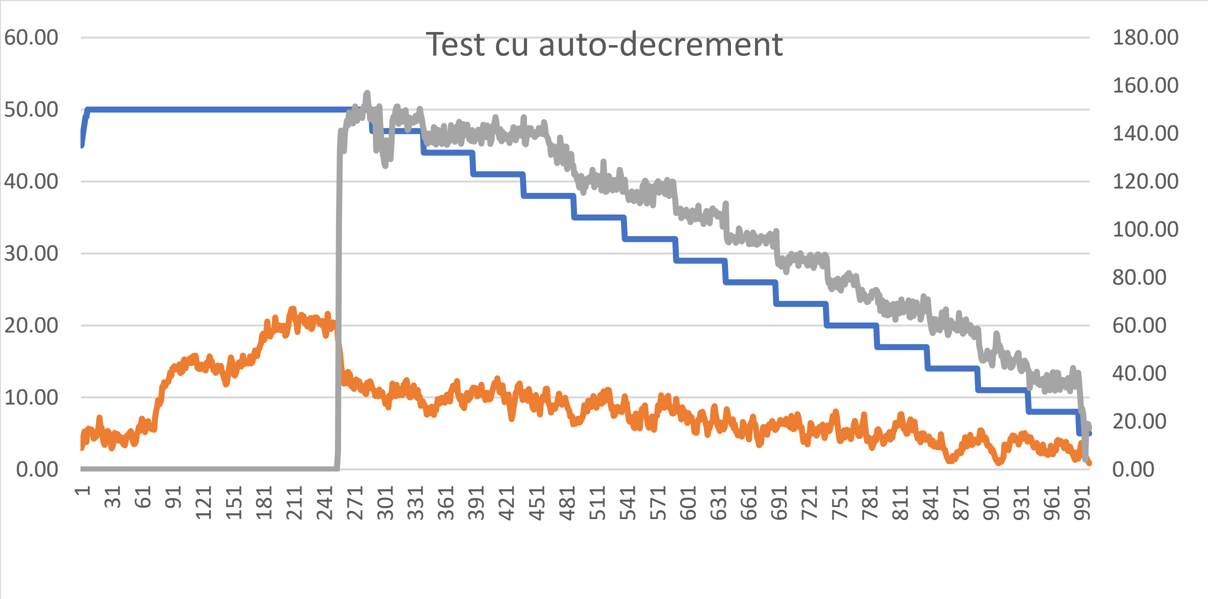
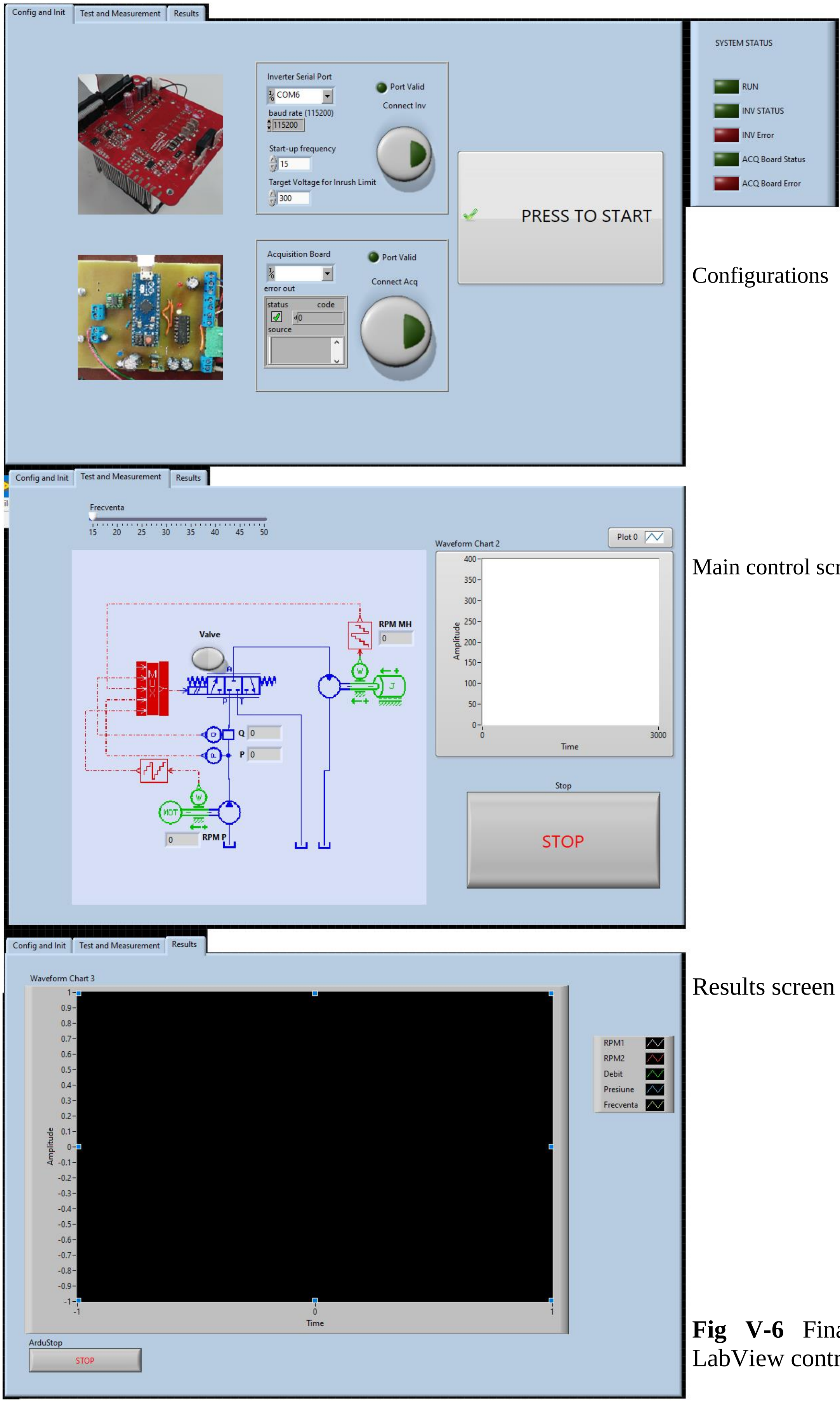


Fig V-5 Descending ramp result

The new version of the work schedule (Fig V-6) is significantly more complex and includes multiple screens, display elements and indicators for the two boards. It also includes a test to evaluate the system's response to a sinusoidal frequency variation.

Serial communication channels (speed, interface number) are configured on the first screen: in the case of the inverter, the starting frequency and voltage at which the escape current limiter is disconnected can be changed. After validating the configuration of the two boards, by pressing the buttons related to them, you can press the start button (PRESS TO START). The visible screen changes automatically with the second; in this screen you can change the work frequency, order given to the 4/3 distributor, and retrieve the process variables. The last screen provides the user with a graph to study all process variables but also to save them as a text file. The "Stop" button with the "ArduStop" label has a dual function, stops data acquisition, and then saves stored data, processed as an Excel table.



Configurations

Main control screen

Results screen

Fig V-6 Final version of LabView control panel

The block diagram behind the graphical interface is significantly more complex and has large dimensions. The simplified diagram is shown in Fig V-7.

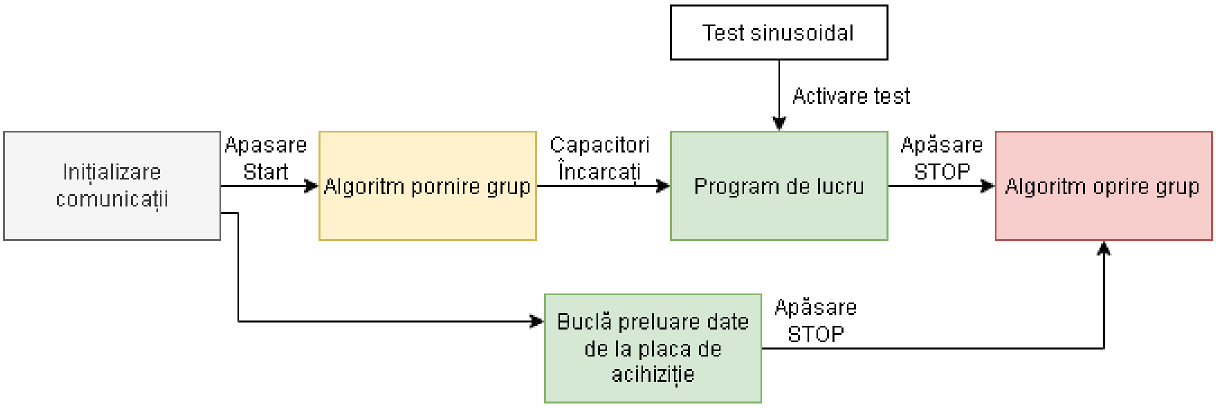


Fig V-7 Simplified Process Chart

The software made in LabView allowed experimental results to be obtained for two control waveforms: trapezoidal with configurable ramp but also sinusoidal.

Fig V-8 highlights the results obtained with the trapezoidal version of the input signal.

The tests in this figure show the response of the parameters in the system to a trapezoidal variation in frequency in two distinct cycles. The first has a slope of 4Hz/s and the second of 2Hz/s. The frequency varies in the range 15…50 Hz per cycle and in the graph in Fig V-8 parameters followed, namely:

- for pressure [2, 8] bar
- for flow [4, 10] l/min
- for pump shaft speed [450 , 1480] rpm
- for hydraulic motor shaft speed [50 , 150] rpm

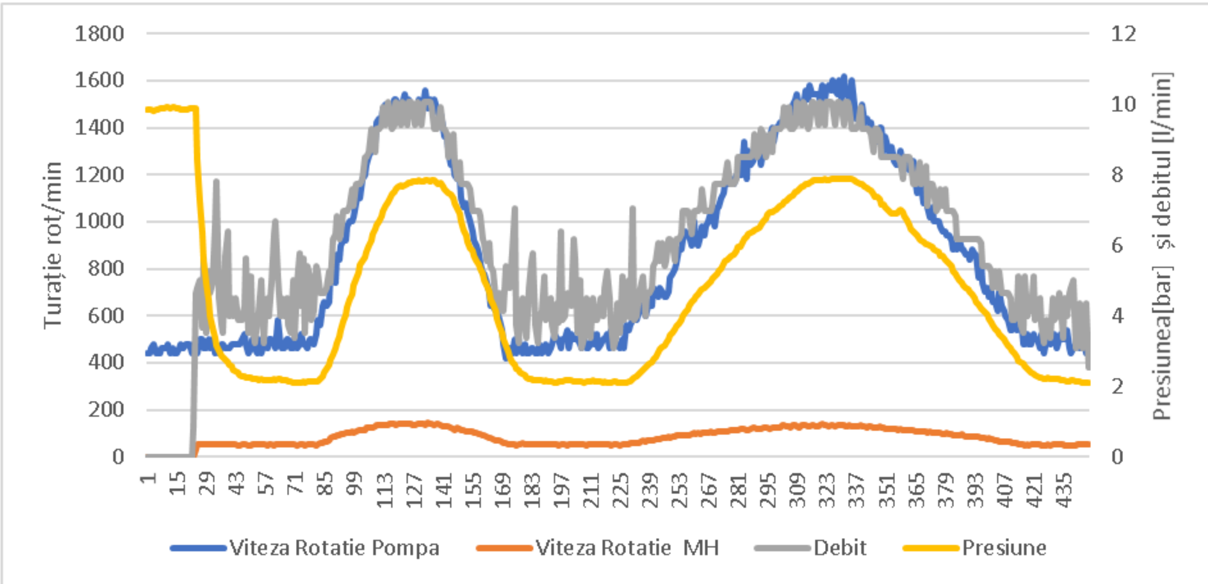


Fig V-8 Experimental ramp test result

The following figure Fig V-9 shows the sinusoidal test and the very good linearity between the given control frequency and the speed of the hydraulic motor, regardless of the direction of rotation.

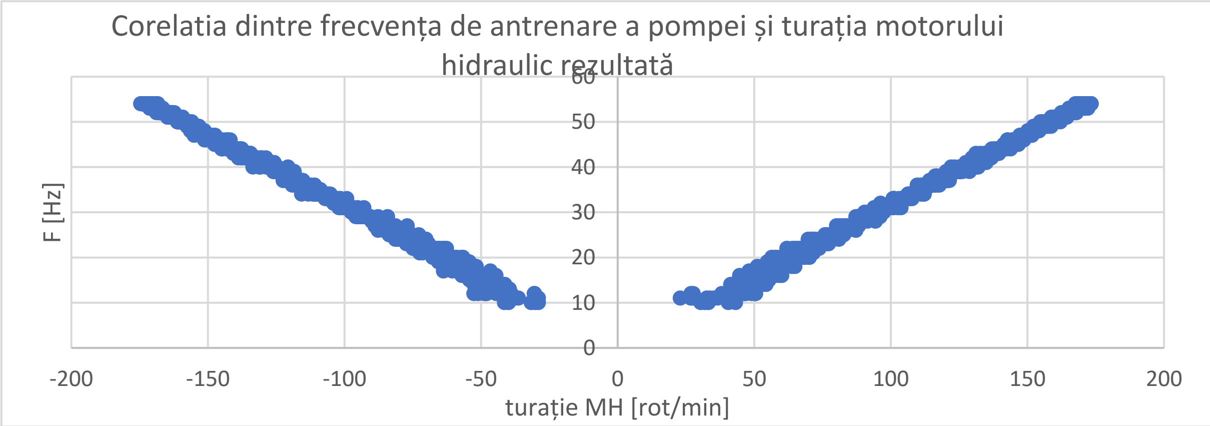


Fig V-9 Correlation between pump drive frequency and hydraulic motor speed

In Fig V-10 two graphs are observed; in the first (a) there are the speeds of the two motors in the system: the one that drives the pump and the hydraulic rotary one; the second graph contains the functional parameters of the system. After each cycle in which the inverter receives control in frequency within 10-54 Hz with sinusoidal variation, the direction of rotation of the hydraulic motor is reversed. For this reason, its graph has an almost perfect sinusoidal appearance.

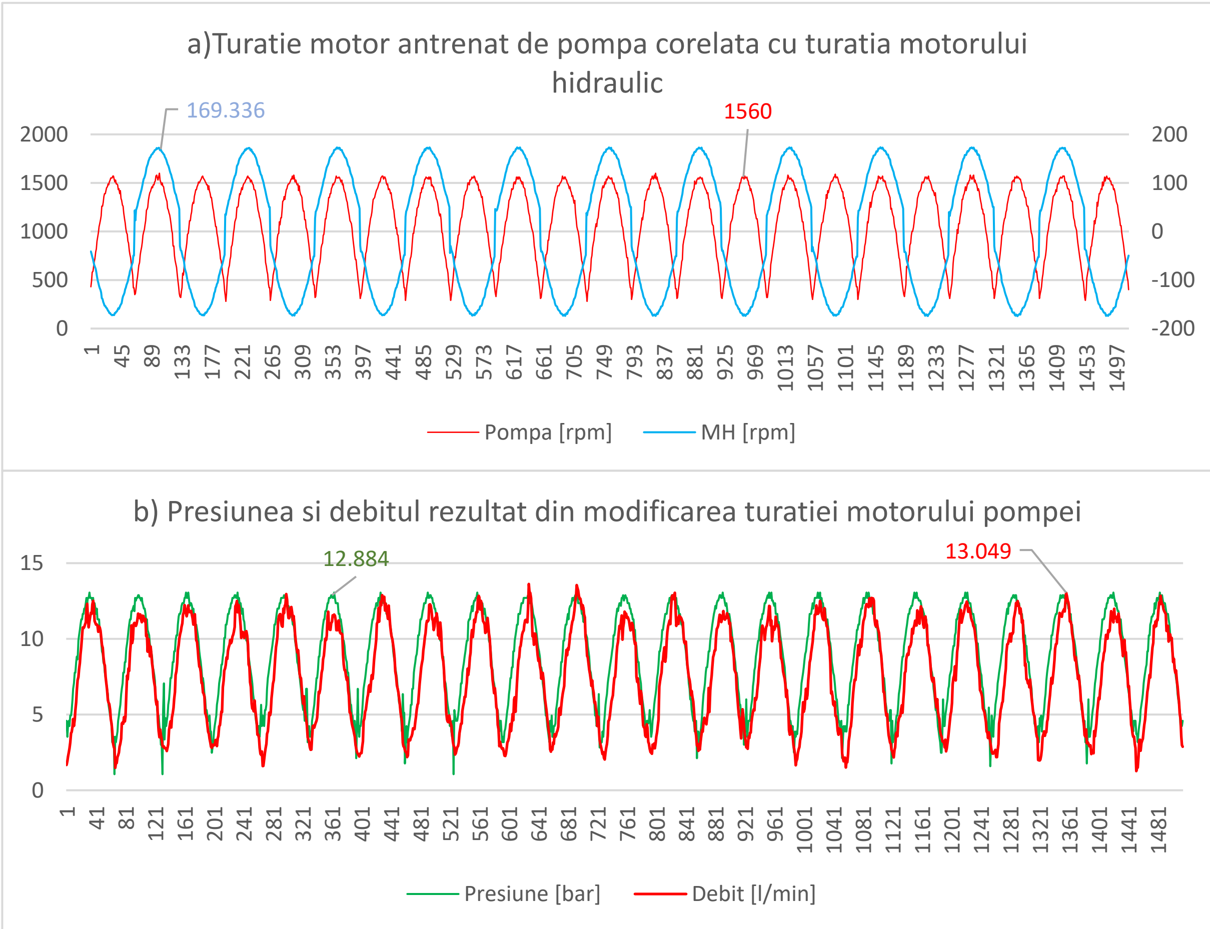


Fig V-10 a) Rotational speed with frequency, b) Pressure and flow with frequency

The following graph in the same figure has the working parameters of the system, namely flow and pressure. They vary simultaneously this time without having a great delay. The pressure shall consistently reach the maximum value of 12.8 bar and the flow rate exceeding the nominal value of 12.4 l/min (obtained with the unchanged group, for a constant speed of the drive electric motor shaft of 1500 rpm) at each peak of the cycle, the maximum frequency being in fact 54Hz. In this way, by using the inverter, the nominal flow rate increases by 8%.

V.1.3 Comparison of theoretical and experimental results

The results of the sinusoidal test obtained by both the theoretical and experimental method have been processed so that they can be easily compared without interfering with the measured values. Finally, the results presented in Fig V-11 were obtained. The experimentally obtained data were limited to two complete cycles, as is in the numerical simulation; the measured values were represented on the same scale and cursors were added to assess the results numerically.

On the representations in Fig V-11 a) the cursors (1) and (2) were added and the process values measured in those positions were added to the right side of the figure. Experimental results are processed in Excel and points of interest (peak ones) are marked on these

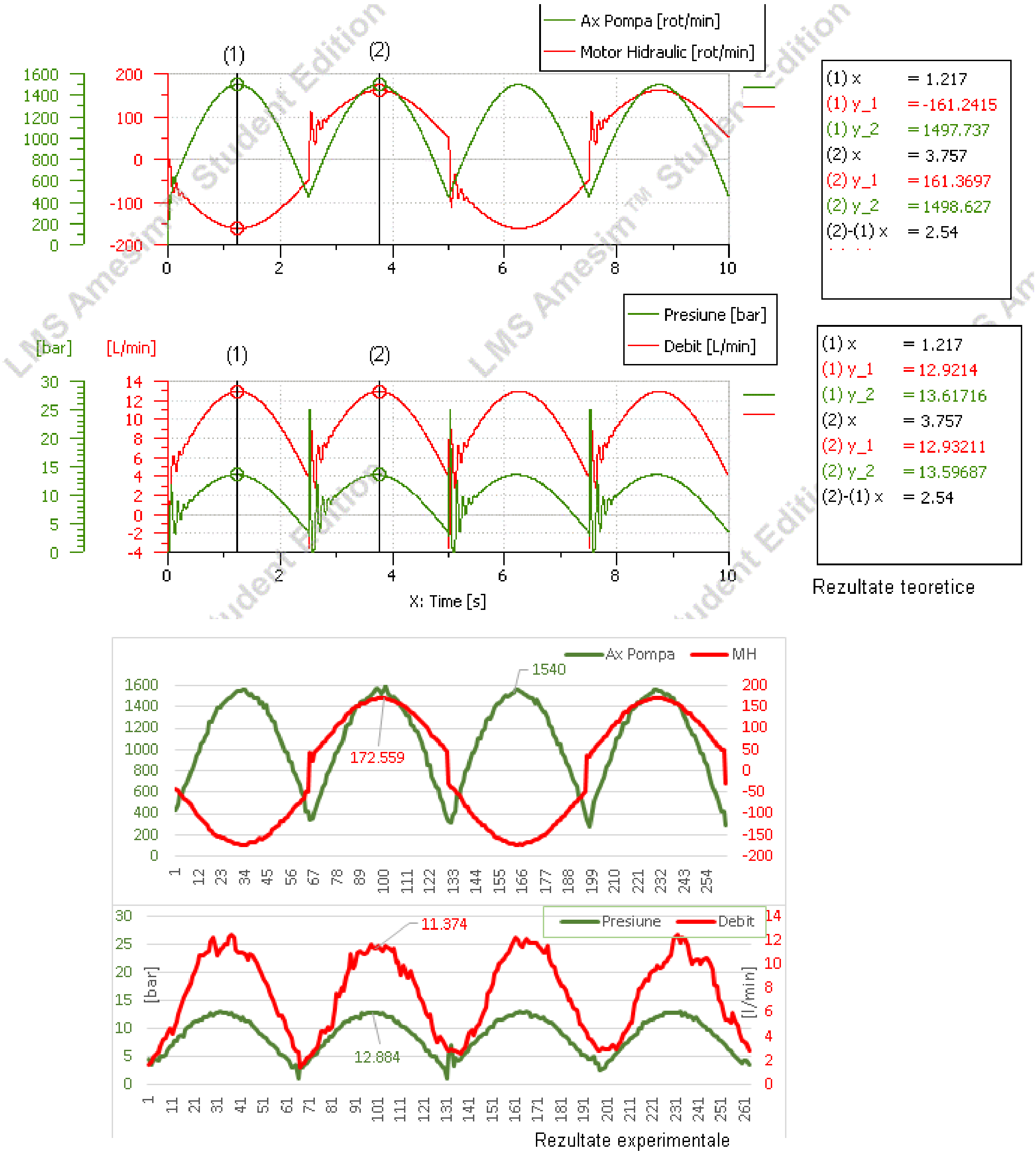


Fig V-11 Rezultate teoretice și experimentale prezentate succesiv

representations. The pressure values are similar with a peak of 13.5 bar in the theoretical case and 12.9 bar practically close enough given the resistive moment and other internal frictions difficult to determine in the case of the hydraulic motor.

For the pump integrated into this group was considered the theoretical displacement value 8.6 cm^3. Based on experimental determinations (see paragraph IV.1.1) for a frequency of 54 Hz, the flow rate of 12,226 l/min was obtained and the pump shaft speed of 1540 rpm was obtained. In this case, the experimentally determined displacement can be calculated by dividing the flow rate by speed and the value of 0.00793 or 7.93 $cm^3$is obtained.

It is noted that the two values of displacement (theoretical and experimental) are close, the theoretical displacement being greater than the experimental one, which is also stated in the literature.

For the ramp waveform, the existing experimental data had a negative slope, and a positive slope was provided in the simulation. In order to be able to effectively compare the results for this type of command signal, the simulation has been modified to have a negative slope and the results are given for comparison in Fig V-12.

V.1.4 Concluzii

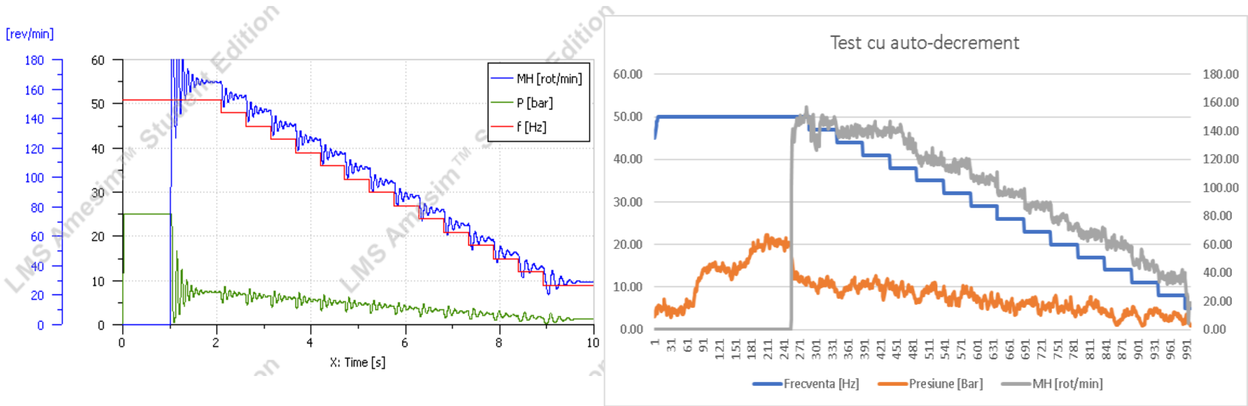


Fig V-12 Theoretical and experimental results for ramp signal

Experimental and theoretical results are close enough to validate both systems. The speed of the hydraulic motor and the pump motor shall vary linearly with the control frequency and is predictable as observed in Fig V-13. Between the two speeds the equation can be established. $n_{MH} = 0.1115 \cdot n_{axPompă} - 2.1432$

The hydraulic power generation group thus developed can be integrated into efficient hydraulic systems where the flow is controlled by the volume method. Dynamic performance has been experimentally tested with an acceleration ramp from the minimum speed allowed by

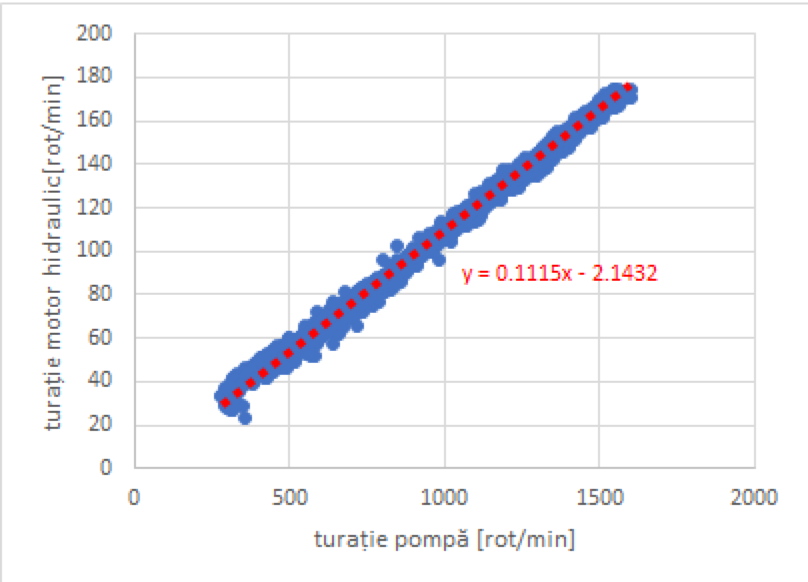


Fig V-13 Linearity of the command and result the pump to the maximum speed reached in 3 seconds, sufficient for normal hydraulic processes that are characterized by high forces/couples offered at low speeds/speeds. The results also show an additional function already tested by the inverter, the possibility of exceeding the frequency of 50 Hz with a maximum of 5 Hz, obtaining a flow rate of approximately 10% higher than conventional systems powered directly from the electrical grid.

V.2 Hydraulic power generation system with integrated pressure regulator

The hydraulic power generation group shown in paragraph II.3.2 has been upgraded by the addition of the control board and an inverter. The control board shall take on the role of the pressure regulator it replaces in order to provide the energy required for the hydraulic systems served as listed in paragraph III.2.3.

The pressure adjustment shall be made by adjusting the opening of a pressure valve proportional to the electrical control in the form of current within limits of 0…1[A]. In the absence of control, the valve sends all the flow generated by the pump back to the tank. The flow to the load is thus controlled by the current running through the proportional electromagnet of the valve and varies according to pressure, the temperature of the environment and the speed of the pump shaft.

The operation of this regulator will then be simulated under the conditions to which it will be subjected in the existing circuits by studying the step signal response as well as the response to a stair signal.

V.2.1 Theoretical Analysis

The first simulation (Fig V-14) was performed in the Simster software produced by Rexroth.

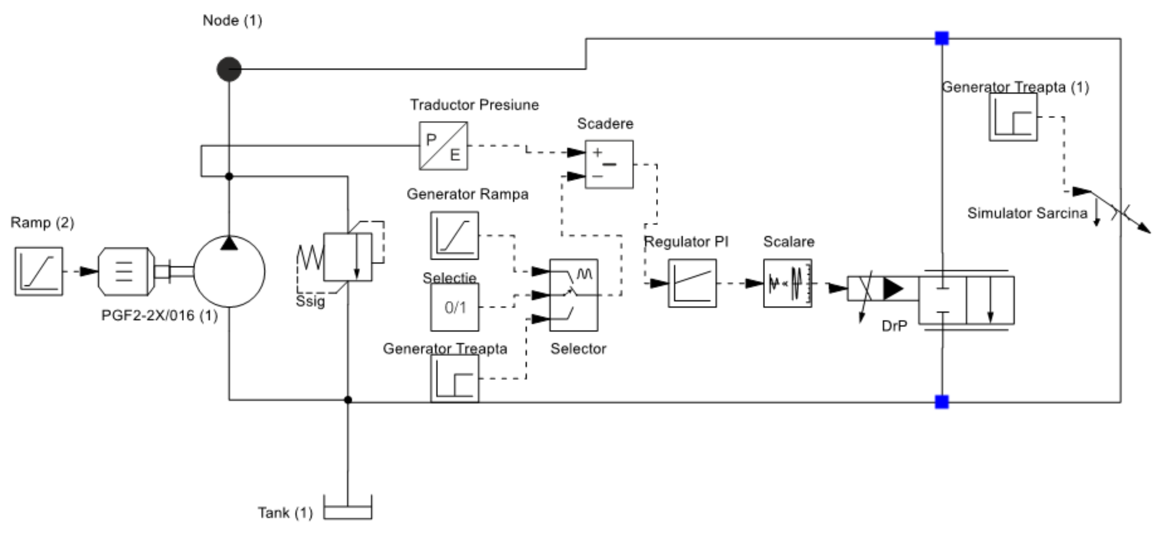


Fig V-14 Regulator de presiune simulat în Simster

The results of this simulation are presented in Fig V-15 following the scenario: the pressure set to 10 bars in the first three seconds and then raised to 25 bars; the flow area is doubled 5 seconds after starting the simulation.

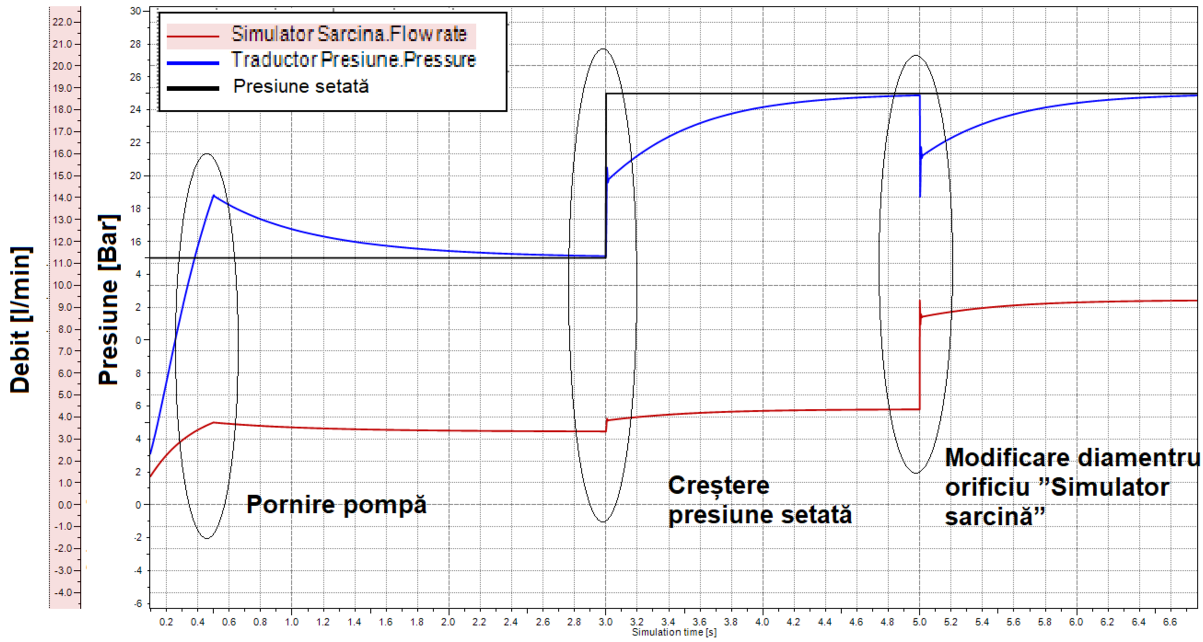


Fig V-15 Simulation of the pressure regulator

The second simulation was carried out in LMS Amesim, produced by Siemens, software that has already been described in previous paragraphs.

The mathematical model in Fig V-16 complements the one done in Simster by studying the behavior of the pressure regulator based on the algorithm used in the work environment density determination stand (paragraph V.4).

.

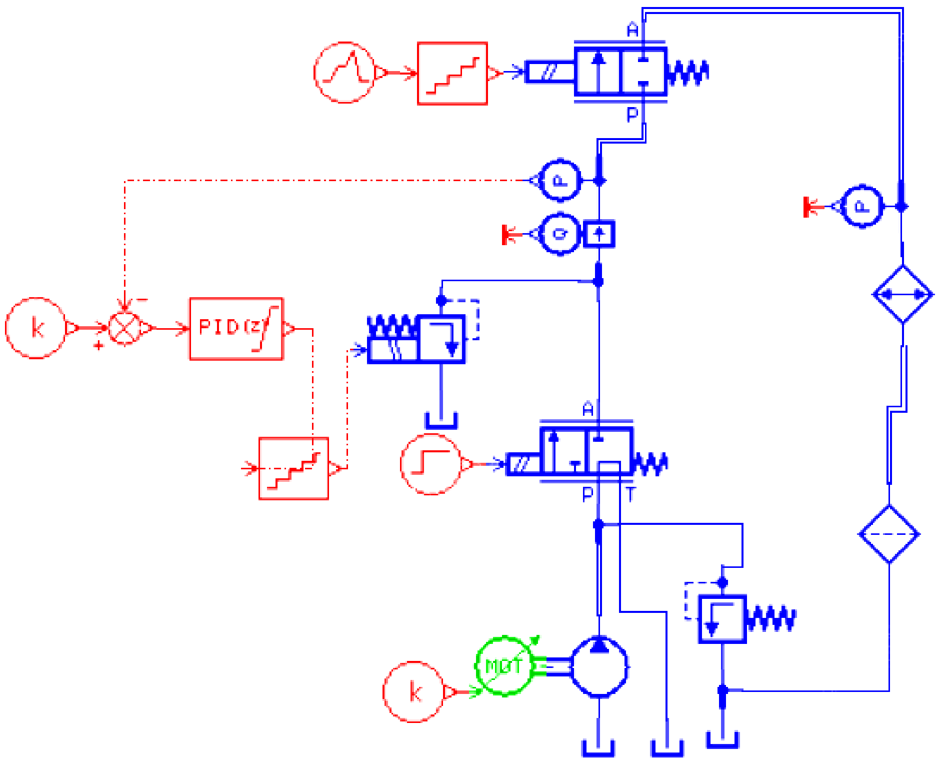


Fig V-16 Simulare regulator de presiune

The result of this simulation is in Fig V-17; the upstream pressure, with blue, is the focus of this test and it is stable throughout the test.

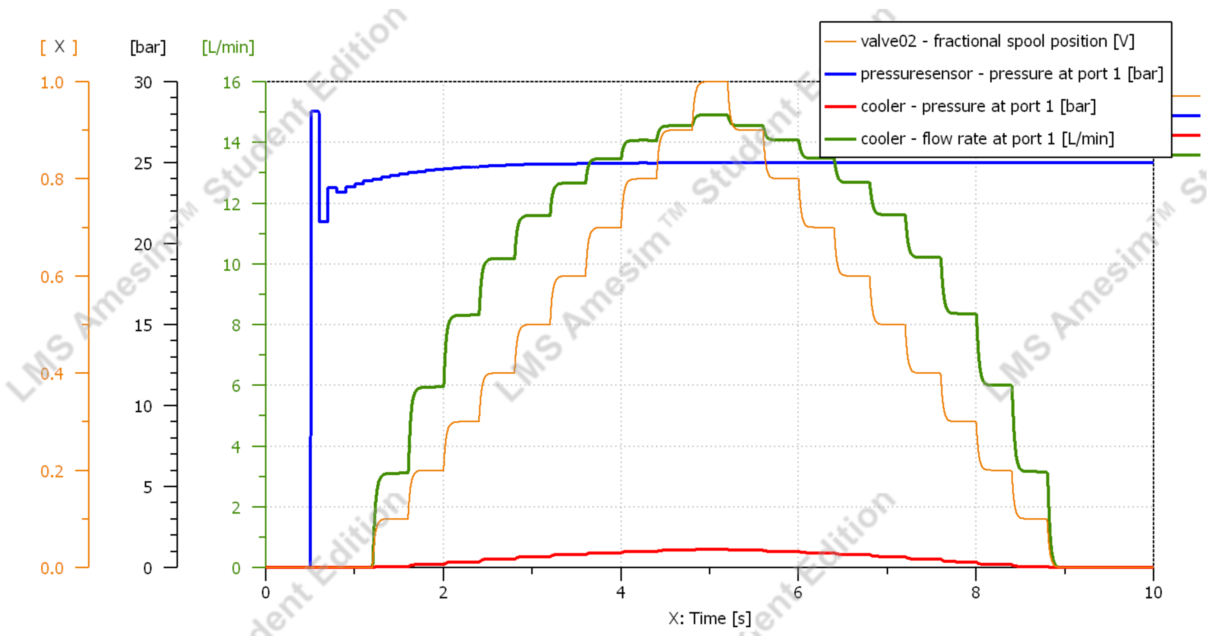


Fig V-17 Amesim pressure regulator during density determination tests

The pressure regulator is activated at the time t=0.5s, at which point the pressure rapidly climbs to the set value, temporarily exceeding it and reaching the value of 28 bar where it oscillates slightly until it finally stabilizes at the set value of 25 bar at the time t = 2 s.

Throughout the test cycle defined for this stand the pressure remains constant even though the flow varies between 0 and 15 l/min.

V.2.2 Experimental analysis

The regulator has been integrated into a complex program to be described in paragraph V.4 in its entirety but the section responsible for generating constant pressure within that program is shown in V.4Fig V-18

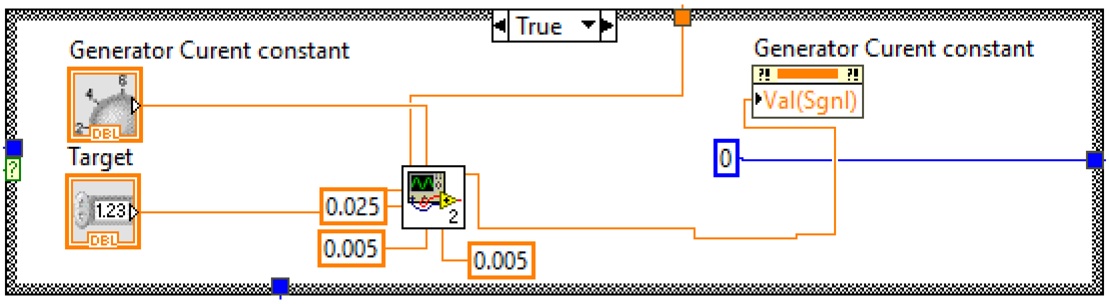


Fig V-18 Implementare în sistem

It was made in the form of a block in LabView (Fig V-18, icon numbered with suffix 2), and its contents are highlighted in Fig V-19.

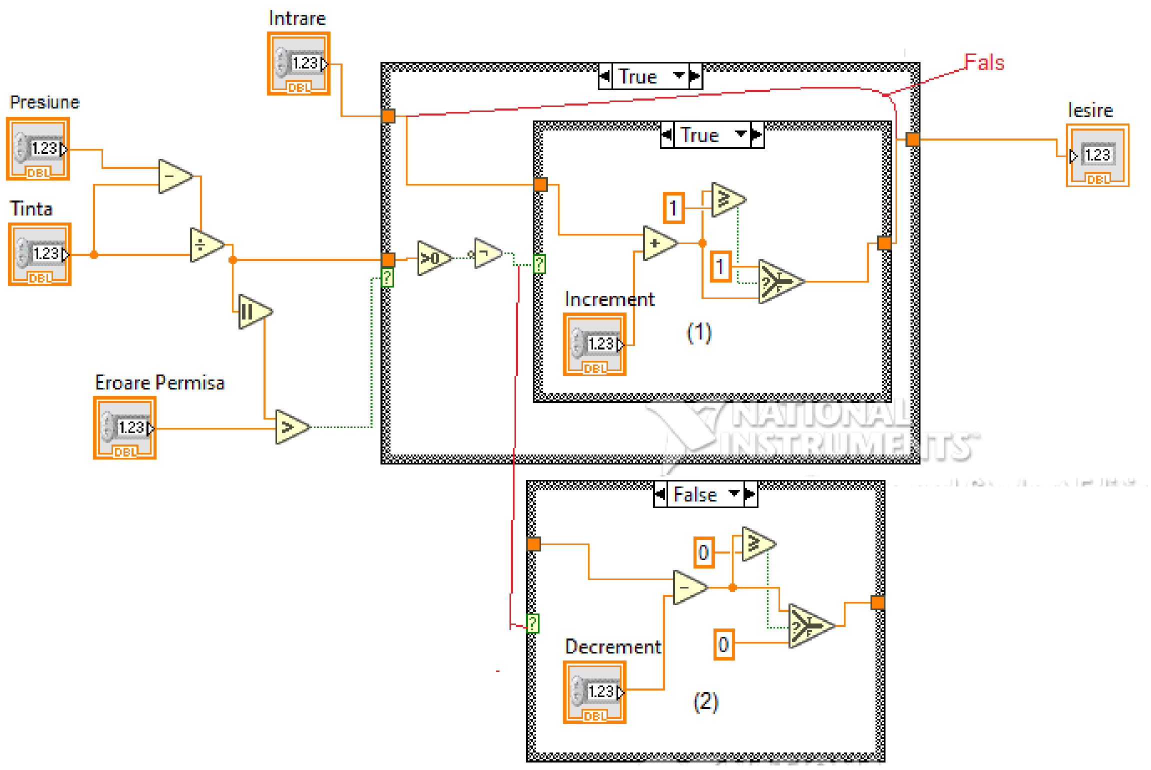


Fig V-19 Regulatorul de presiune din Labview

The regulator was tested on an experimental stand consisting of a linear hydraulic motor. It was programmed to perform movements from one end to the other at full speed to check the stability of the adjustment loop at a variable load.

The result of this experiment is shown in Fig V-20. The pressure is set to 30 bar and in the figure is drawn in red. Sudden variations in pressure, both positive and negative, are observed, caused by the sudden stopping of the piston at the end stops, the stationing for a while, followed by the continuation of the movement in the opposite direction. These peaks are small, reach 35 bar for a very short term and negative ones do not fall below 26 bar.

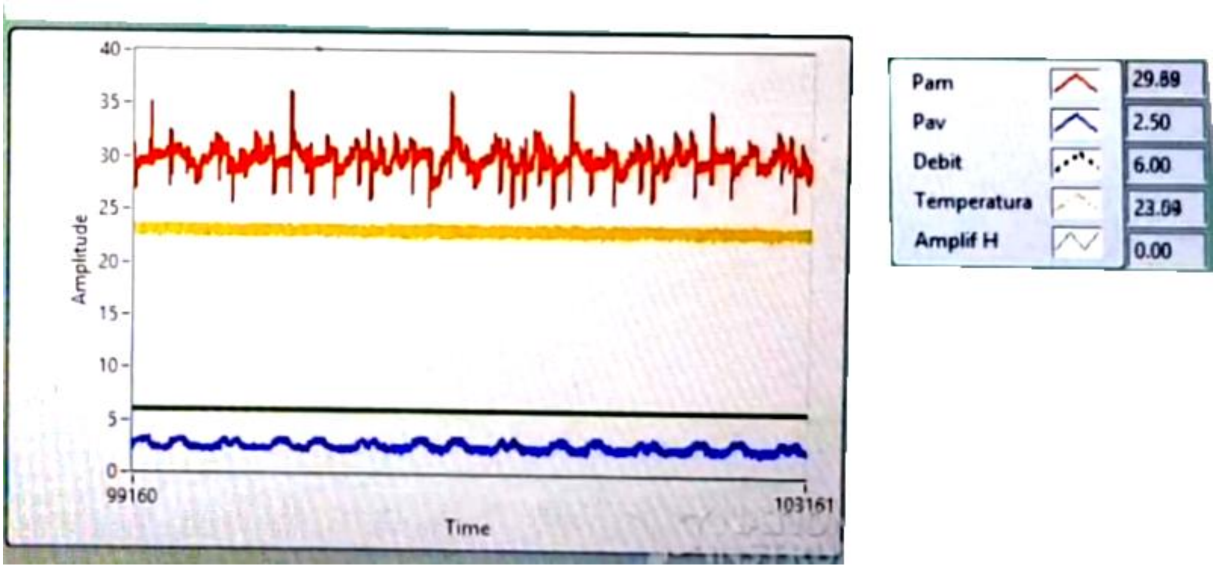


Fig V-20 Stability of pressure during transient load

V.2.3 Conclusions

The pressure regulator is simple and efficient and the theoretical and experimental results validate the concept, safety and precision of the algorithm used. Performance is sufficient for common applications in this field and the following theoretical and experimental stands depend on its proper functioning.

V.3 **Hydraulic positioning system**

This system has been described in paragraph III.2.3. As a positioning system it was decided to carry out a work program involving the movement of the piston on the ends of the race but also at an intermediate position. It was also implemented on the physical controller, HNC100.

V.3.1 Theoretical Analysis

Almost all the components that make up the structure of the hydraulic system are produced by Bosch-Rexroth. It was therefore decided to use the software they produced for simulation.

In Fig V-21 the model implemented in Simster is shown. It contains the components used in the structure of the realized test stand. The block called the "NC *Program"* contains a list of positions in the form of coordinates. The *"HNC100* simulator" is actually the PID regulator similar to the one in the physical controller.

The simulation resulted in the graph in Fig V-22. The position of the piston accurately tracks the set position; had to change the scale to be able to distinguish the graphs of the two signals had to change the scale for the vertical axis. The position transducer used converts the piston position in relation to one of the ends from 0…140mm to 0…10V, the "NC Program" block has the reference positions also stored in the form of 0…10V voltages.

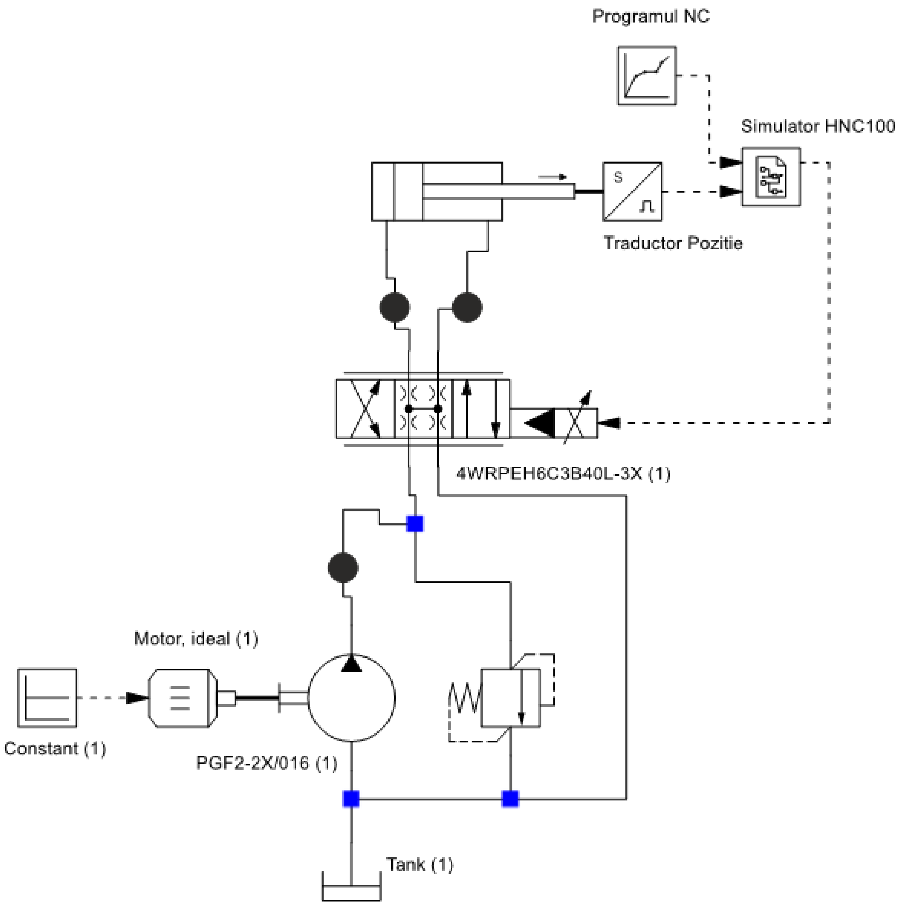


Fig V-21 Positioning System - Simster

The pressure shows small oscillations during piston movement, with a value of approximately 2 bar, from the relative position of 0 to 10V and shows small pressure falls of 1-2 bar during the remaining test cycle, especially during rapid movements.

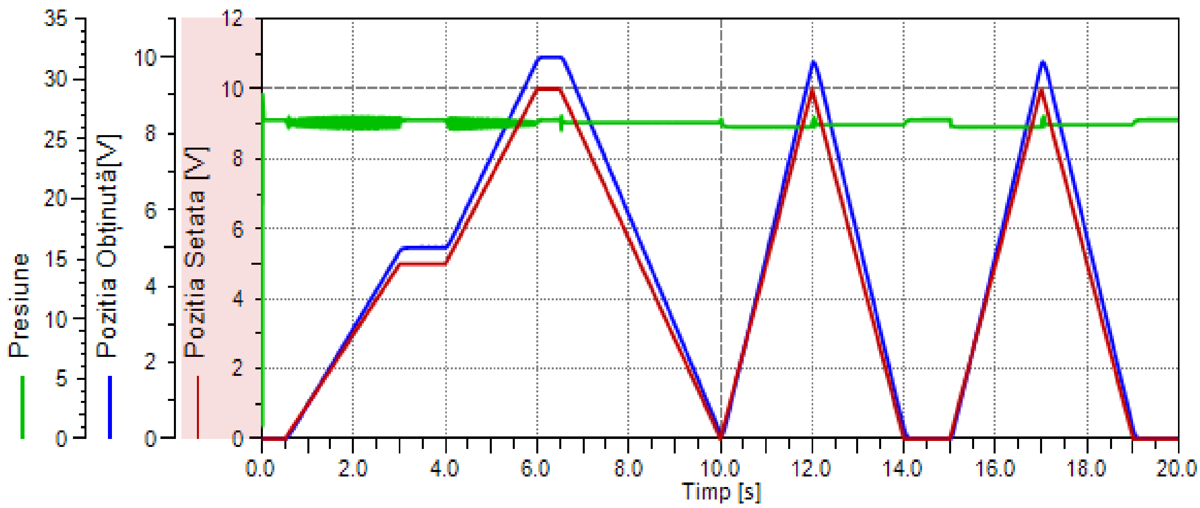


Fig V-22 Simulation Results

V.3.2 Experimental Analysis

The program for the HNC100 controller is presented below.

```
; R200 = poziția țintă
; R201 = Accelerare
; R202 = Decelerare
; R203 = Viteza
; R204 = viteza traversare (0)
;===============================================================
M33
G62
JMP L100

L100
G01 XR200 IR201 JR202 FR203 R204
G04 F1
G01 XR200-650 IR201 JR202 FR203 R204
G04 F1
G01 XR200-1300 IR201 JR202 FR203 R204
G04 F1
G01 XR200-650 IR201 JR202 FR203 R204
G04 F1
G01 XR200 IR201 JR202 FR203 R204
G04 F1
G01 XR200-1300 IR201 JR202 FR203 R204
G01 XR200 IR201 JR202 FR203 R204
G01 XR200-1300 IR201 JR202 FR203 R204
G04 F2
JMP L100 ;Sari inapoi la L100
M02 ; Sfârsit program
```

Experimental and theoretical results are shown for comparison in Figure V-23. The results have an almost identical waveform. The performance of the precise positioning system was not adversely impacted compared to the unmodified group.

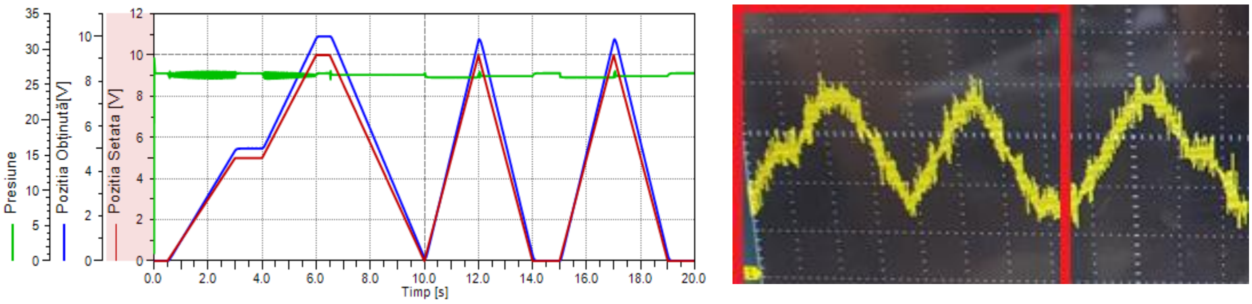


Fig V-23 Theoretical and experimental results

V.4 Stand for determining the density of the hydraulic work fluid

The completed stand is fully computerized and allows both the control of the actuator system and the acquisition and processing of measurement data. In the structure of this stand the central element is a microcontroller. For the measurement of different physical sizes are used high-performance transducers that provide electrical signals at the output.

The completed stand has been described in paragraph III.2.3in point 2 the experimental results and programs developed will be described below.

V.4.1 Theoretical analysis

For determining the density of the hydraulic environment Simster software was useful to simulate the operation of the stand and to obtain preliminary results. In the simulation (Fig V-24) the motor that operates the pump has constant speed, therefore the flow rate provided by the pump is constant. The proportional electromagnet integrated in the construction of the proportional distributor 4/3 is ordered with a special stair wave form. The signal climbs in increments of 1V from 0V to the maximum limit of 10V and then descends with the same increment until it reaches the minimum limit of 0V. This protocol will also be followed at the experimental stage.

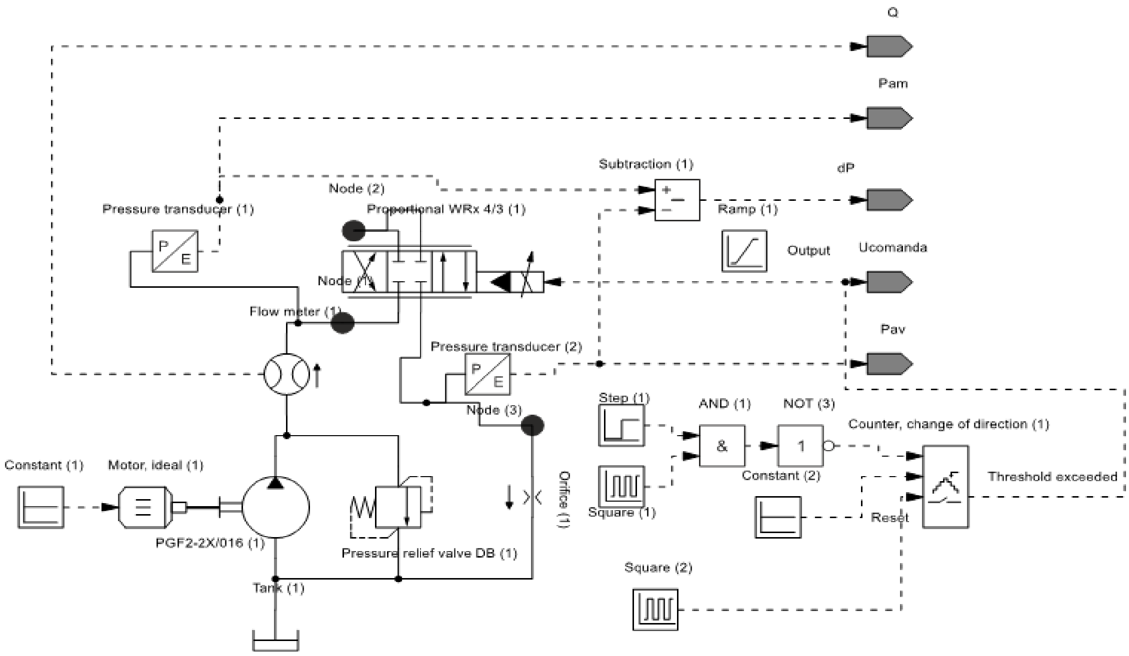


Fig V-24 Simulation with Simster stand for determination of hydraulic medium density

Fig V-25 is the result of the simulation with the designed algorithm. When the previously defined signal is applied to the system entry, the proportional distributor spool moves in relation to the zero position (X signal) and generates the flow section through the valve. Through this section a flow will pass, highlighted on the representation in the figure (red color).

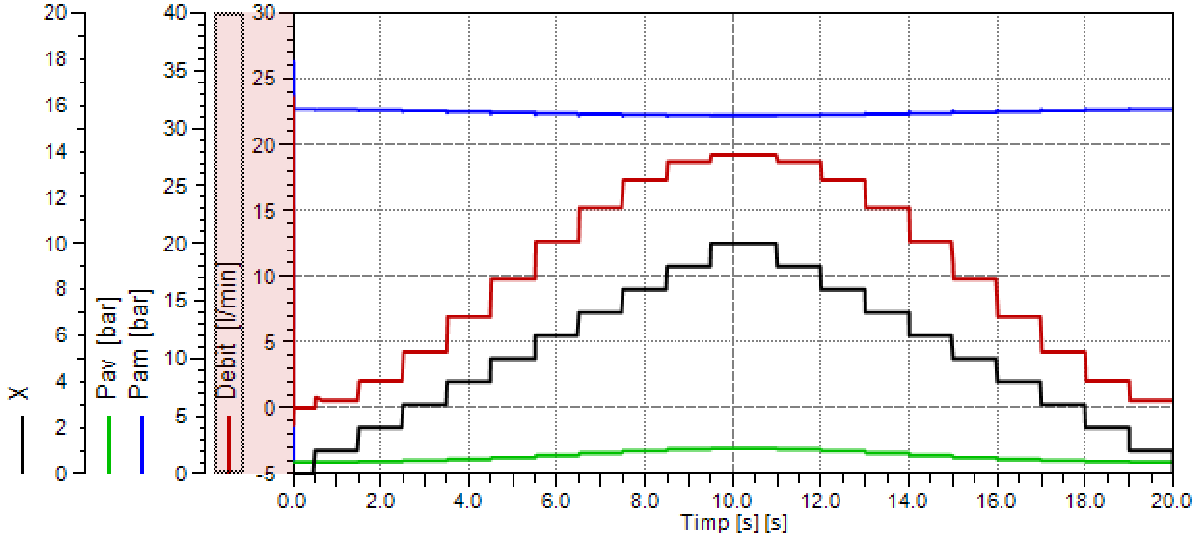


Fig V-25 Result simulation stand for determining the density of the hydraulic environment

V.4.2 Work algorithms developed

To control all devices attached to the control board and to save and process data gathered from the system, a program was designed in LabView.

This program has three screens named: "Settings," "Values," "Save." The first screen is shown in Fig V-26 and allows the entire system to be configured and checked. On this screen, you can select the serial port to which the control card in the "VISA resource name" is attached.

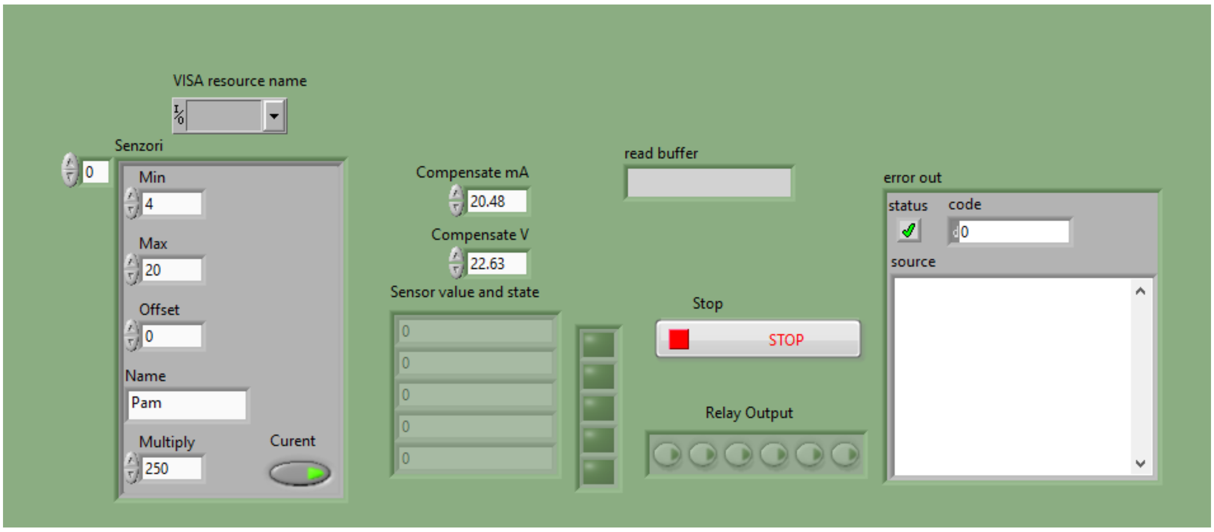


Fig V-26 Ecranul de configurări

The "Sensors" section configures the type of signal provided by a particular sensor, its range of variation and the maximum value of the measured physical size. This window is particularly useful when running the program. In the "Sensor value and state" area you can see the values provided by the sensors and for the sensors in the current loop can determine whether they are physically connected correctly and whether they are functional. Also, here (Relay Output), for testing, can be connected or disconnected existing relays physically on the board.

In the second screen (Fig V-27values, as follows:

- Pressure In – pressure upstream of the proportional hydraulic distributor DhP,

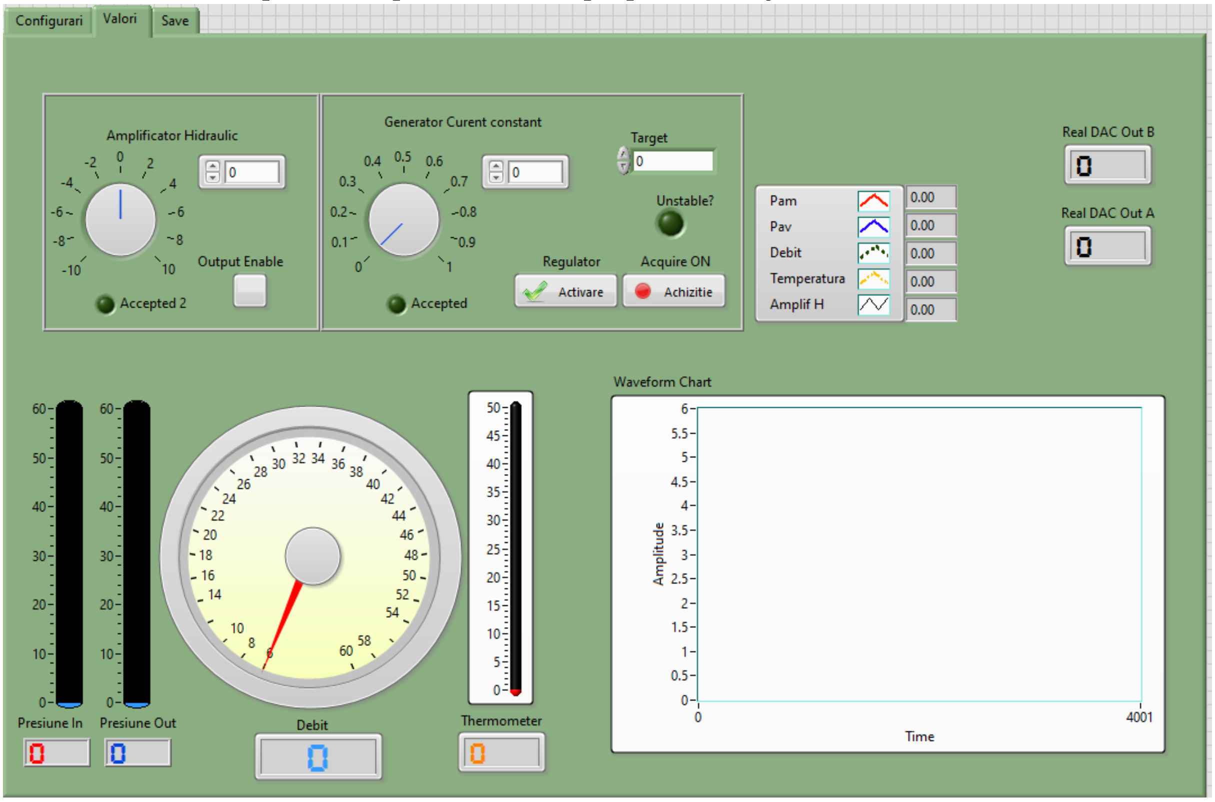


Fig V-27 Ecranul 2 – Valori

- Pressure Out – downstream pressure of DhP,
- Debit – flow through the system,
- Thermometer – temperature of the working environment,
- Waveform Chart – graph that includes the parameters listed above, and contains the position of the spool "Amplif H".

At the top are two separate sections "Hydraulic Amplifier" and "Constant Current Generator".

The main loop of the completed program is shown in Fig V-28

V.4.3 Experimental results

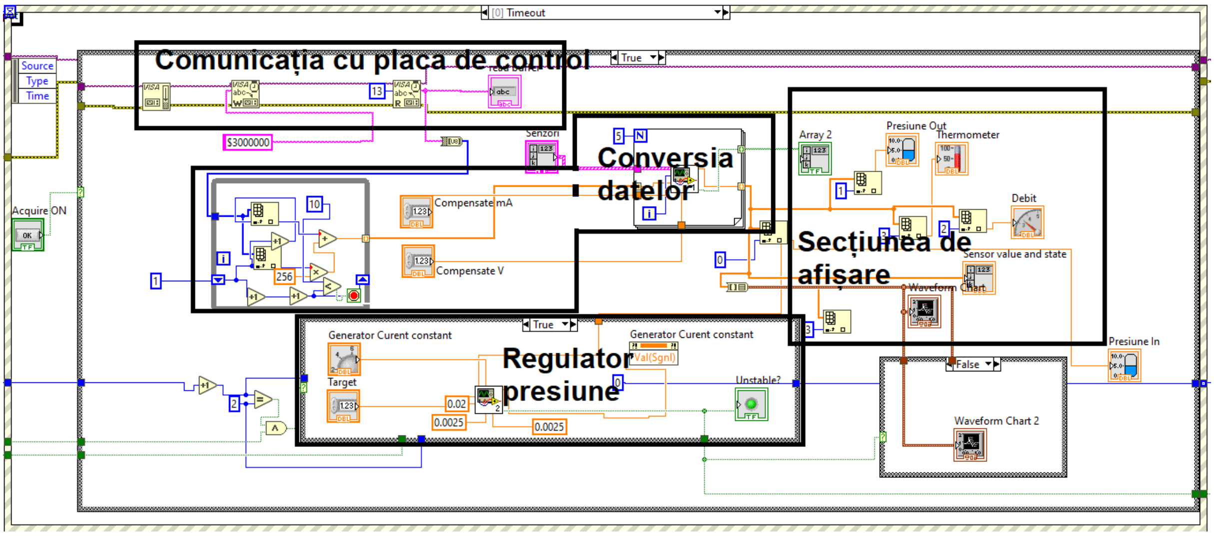


Fig V-28 Diagram of the completed program

The position of the drawer signal varies in a ladder waveform type as well as the existing control signal at the entrance to the electronic amplifier of the proportional valve DrP. In the 4 figures the measured flow reaches maximum pressure values of: 14.5 l/min at 15 bar, 18 l/min at 20 bar, 21 l/min at 25 bar and 24 l/min at 30 bar.

The amount of data obtained from the experiments is very difficult to process, each test cycle (at a single pressure) can have around 7000 values. A program was written in Matlab to retrieve and process the measured values; then, based on the established formula, the program calculates the density of the working environment.

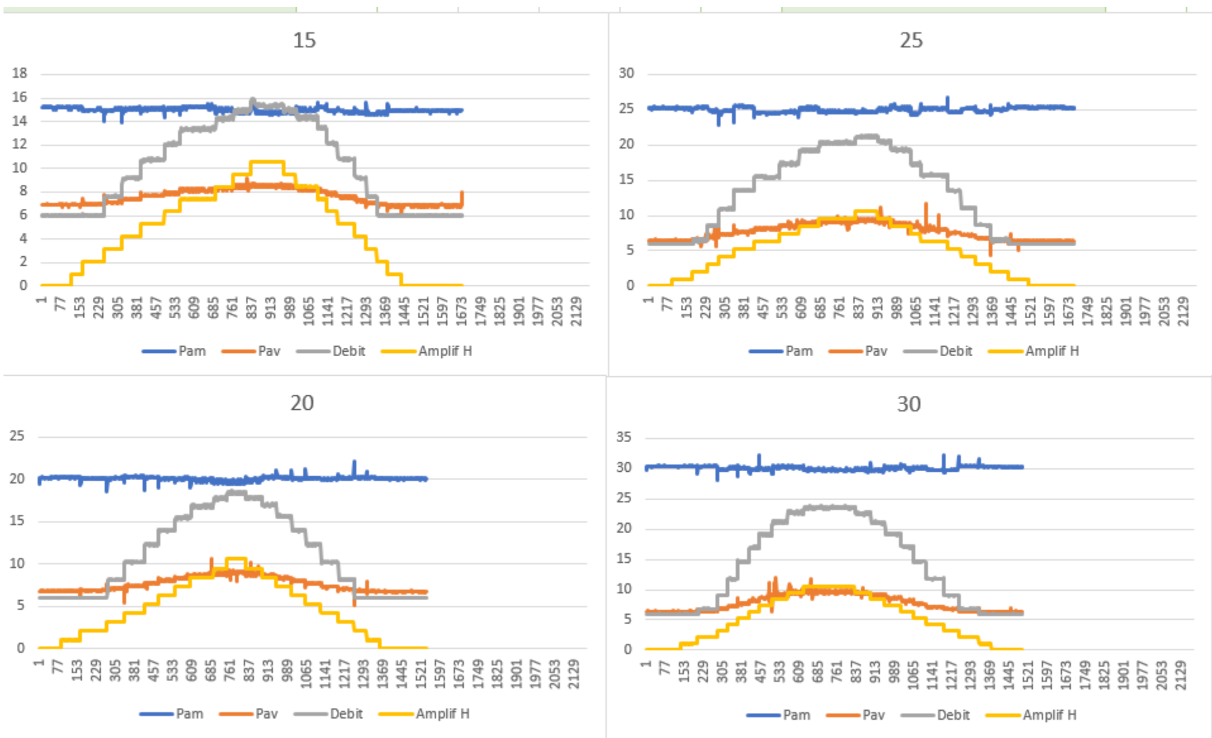


Fig V-29 Rezultate experimentale la 15 , 20 , 25, 30 bari

.

The data shall be processed to show the variation in the relative density measured according to the pressure difference. This variation is shown in Fig V-30 the range of variation being [0.94 ,1], which means a 6% variation in the density of the hydraulic environment.

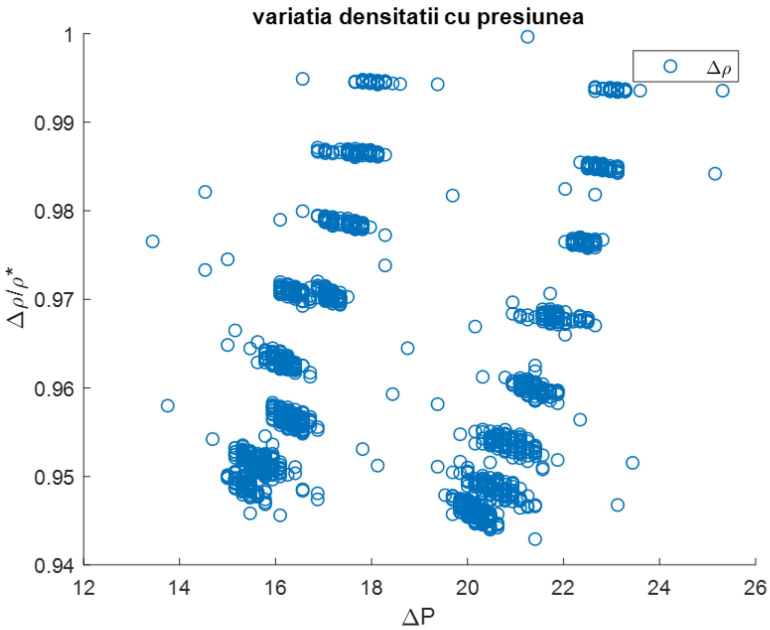


Fig V-30 Variația densității cu presiunea

V.4.4 Comparison of theoretical and experimental results

There are differences between the experimental and theoretical results that can be explained either by the presence of a quantity of air in the installation or by calculation or measurement errors.

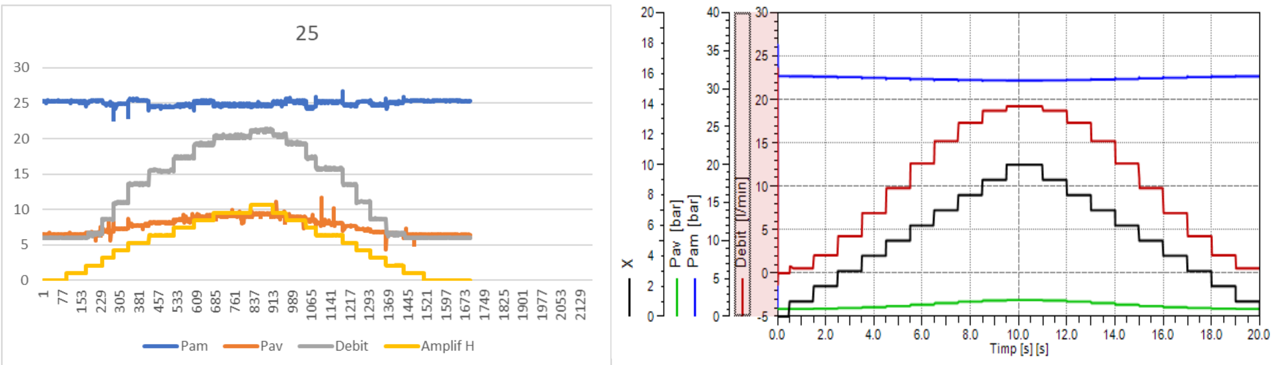


Fig V-31 Comparison between experimental and theoretical results

In conclusion, determining the density of a mineral oil used as a working medium in a hydraulic actuating system under certain concrete working conditions, as well as the dependence of density with temperature and pressure, is an important problem for which a solution is still being sought.

The experimental stand designed and made is an effective solution for solving the problems mentioned above. This stand represents, through its hardware and software structure, a complex system of experimentation and testing, to which all the activities carried out are assisted by the computer.

One of the facilities of the system is that the experimental results obtained can be both viewed directly on the calculation system monitor, even during measurement, which is a great advantage in experimental research, and stored in memory in the form of text files, with a view to further processing of data and printing it in the form of test/experimentation bulletins, without the intervention of the human operator.

V.5 Thermal analysis of the proposed intelligent hydraulic power generation groups

As mentioned in paragraph III.1, a thermal chamber has been integrated into the 1.5 kW hydraulic power generation group to monitor temperatures in several areas of the group.

This thermal chamber (Fig V-33) is an original design and was made from the module produced by Panasonic AMG8834 (Fig V-32). A SAM3S2 microcontroller is used to read camera information and transfer it to a 320x240 resolution LCD screen to display the image. The case was designed and printed on a 3D printer.

Fig V-33 Camera termală realizată

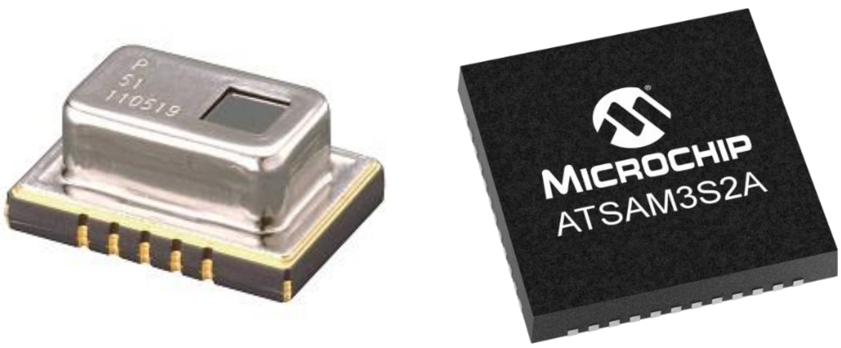


Fig V-32 Modulul AMG8834 **[30]** și Microcontroler ATSAM3S2A **[29]**

The connection with the computer is made through the USB port and the data is processed using the LabView environment, the aim being to generate alarms and trigger the system shutdown in cases where this is necessary.

In the memory of the microcontroller there is memorized the work program, written specifically for this application, which automatically performs an interpolation of the pixels read to increase the resolution of the camera and display a better qualitative image (Fig V-34). The information transmitted via USB is in the rough, each package sent thus contains 64 values, representing each pixel.

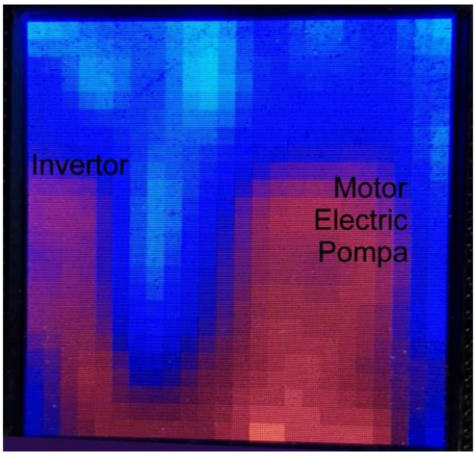


Fig V-34 Imagine obținută

For the second group, the 4kW group, a thermal analysis was performed using a thermal camera with much higher resolution, 206x156 pixels, produced by Seek (Fig V-35). The analysis involved taking several catches from different areas of the group under concrete operating conditions. As a first step, areas of interest were established based on experience gained over time and recommendations identified in peer-reviewed journals. This was intended to identify the main sources of energy losses existing in the system during operation.

Fig V-35 Camera Seek din seria Compact pentru telefoane mobile

Fig V-36 clearly highlights the areas in the system that after a while of operation have warmed up. To better visualize this phenomenon in the first image is shown the group in the non-functioning state (when its temperature is the temperature of the environment regardless of the area of interest). The third image (on the right) was obtained by overlapping the two images obtained under the conditions shown above (the non-functioning group and the group after a running time). This image highlights that the motor's windings and rotors have warmed up quite quickly; this fact is known from the literature, in inductive motors if the speed is reduced by an inverter, the motor heats up and the cooling system is required to be supplemented. [24]

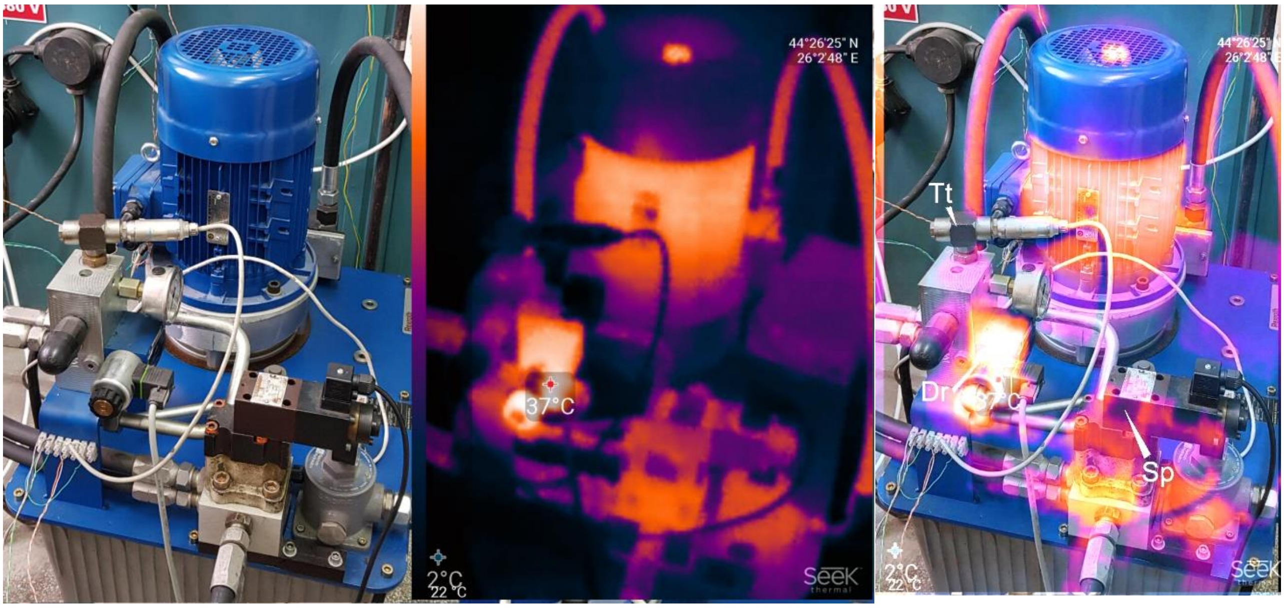


Fig V-36 Imagine termală pompă și vedere suprapusă

At the level of the energy generation group, an increase in temperature at the level of the conventional distributor 4/2 is observed in the area of the actuator electromagnet, which during operation is powered, the consumption at the level of this actuator being 24W.

In Fig V-37 is presented a detail from the area of the mentioned distributor in the desire to better highlight its thermal behavior.

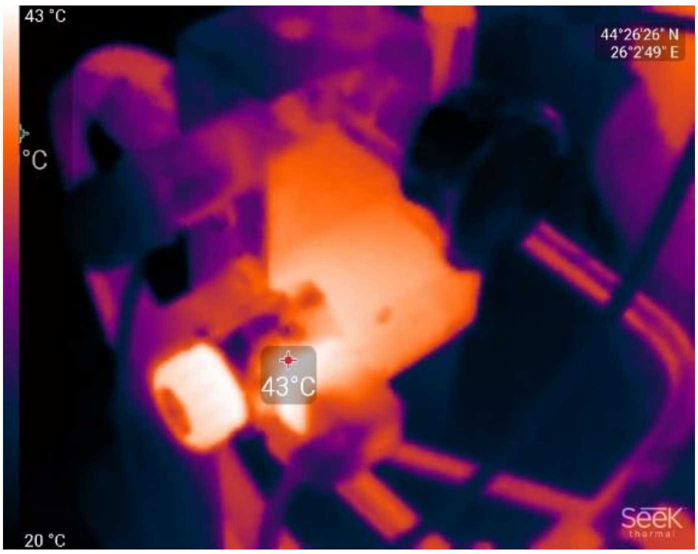


Fig V-37 Distribuitoarele prezente în sistem

The proportional *Sp* valve has a temperature close to the temperature of the ambient environment, which can be explained by the fact that it is activated only if the pressure in the system exceeds the adjusted value, while the fact that the group tank has been correctly sized favours the cooling of the working environment during operation, the regime temperature falling within the range 60-65$°C$. On the other hand, the operating time did not exceed 30 minutes which favoured the classification in the temperature range specified above.

At the level of the *proportional DrP* distributor, the flow sections being small, there is a significant loss of pressure, taken up by the fluid in the form of heat. This explains the image in Fig V-38 that highlights a local increase in fluid temperature.

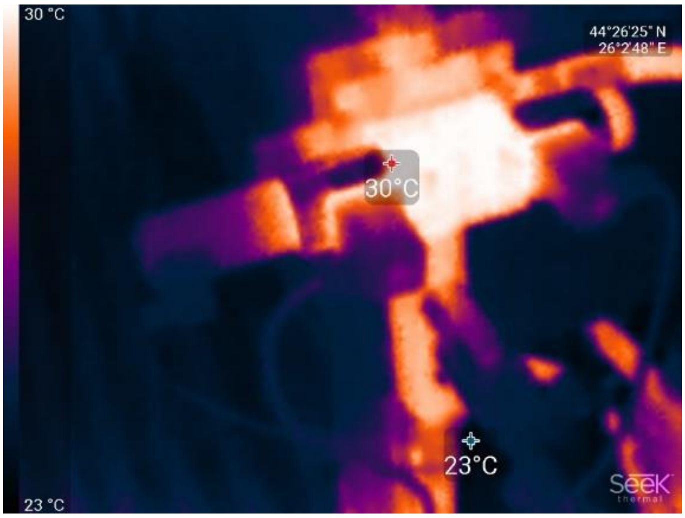


Fig V-38 DrP Thermal Camera View

V.6 Optimizing the designed systems

The design of intelligent systems is complex and can be done with numerous architectures, each with its advantages.

In the case of the model made for the 1.5kW pumping group, optimizations can be made in the following directions:

- making a single board containing the power board, inverter control board and acquisition board; therefore, the cost of the experimentally validated independent board system will decrease;
- the acquisition board can also be converted into a control board by connecting a communication line with the inverter processor; a direct link is thus made between the information system (made up of transducers) and the actuator system; another advantage is to reduce the number of external connections required and improve response time;
- Reducing the number of physical connections by adding a WiFi/BlueTooth module in the acquisition card area to replace the USB wired connection into a wireless one.

The stand designed and constructed to measure the density of the working environment in the system can be redesigned and made modular so that it can be easily integrated into any hydraulic actuator system. With his help the system user can determine at certain intervals the density of the working environment existing in the system. On the basis of these measurements, it may decide whether it corresponds qualitatively. In addition, in precision hydraulic actuators where reliability is critical, devices that measure the parameters of the working environment are used. Measurements taken to determine the density of the hydraulic environment at different pressure values and flow sections could thus be used as a reference for a system which indirectly determines the existence of contaminants in the hydraulic environment.

Measurements can be stored in the process computer memory as a two-dimensional table (Fig V-39) or even an equation with two unknowns that provide a close result. Comparing the pressure drop or the resulting flow with the memory reference, you can detect and prevent damage situations (excess air or water in the hydraulic environment) or even provide a forecast of the next necessary change of working fluid.

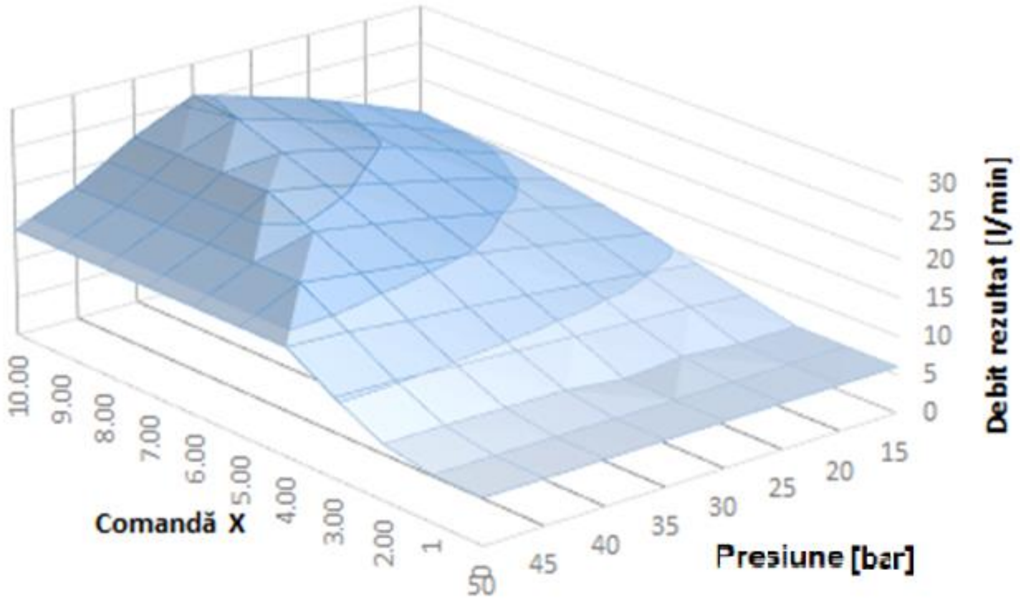


Fig V-39 Determinarea condiției mediului hidraulic

This test could be done at fixed intervals and the result saved as a list to track the trend of deterioration of the working environment. A trend line can be added to Matlab and the intersection point with the limit value considered to be the crash can predict the time until the next revision.

VI.SYSTEMS MADE THAT ADHERE TO THE IOT CONCEPT

This chapter describes how the internet connection of groups made in order to be able to communicate with other systems has been achieved. The simplest and most accessible IoT platform is Mathworks' ThingSpeak. This company also owns Matlab software, so it has very good integration with this programming language. The 4kW hydraulic power generation group has been redesigned so that it can be used independently of a computer or laptop; in this way the group can be easily accessed and monitored remotely.

A Raspberry Pi single-board computer was used for this. The Windows IoT operating system was chosen because it offers the ability to design the app on a normal computer with Visual Studio software and is a very well known programming environment by the author.

The information received by the server is uploaded to the web page corresponding to the application, which was generated by the web application produced by ThingSpeak in the desired format, with instant numeric display elements, analog clock displays or time graphics (Fig VI-2).

To connect students to the platform there are three options: providing them with the channel number in the form of an address, a QR code scannable with the phone's camera with the website encoded in it and last but not least the most convenient solution, an NFC card.

NFC cards are purchased blank and are programmed using a module provided by NXP, namely PN7150 (Fig VI-3) .

The interface performed is shown in Fig VI-1. The control board is the only non-standard component present in the designed IoT system, the rest of the components are easy to find at suppliers of electronic and electrical components.

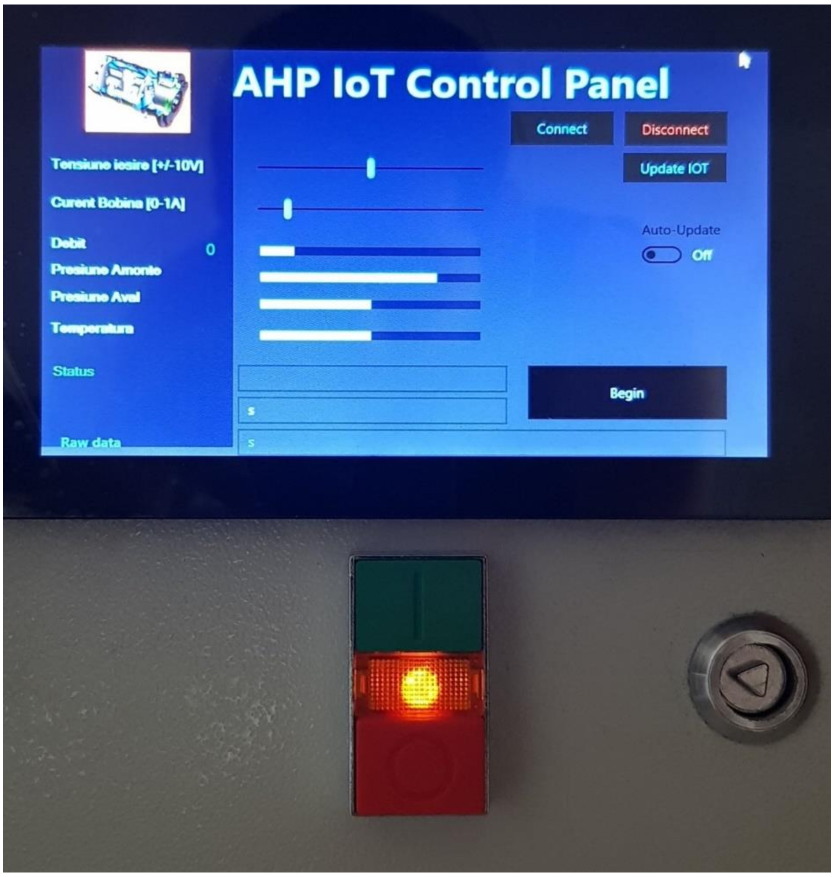


Fig VI-2 User interface

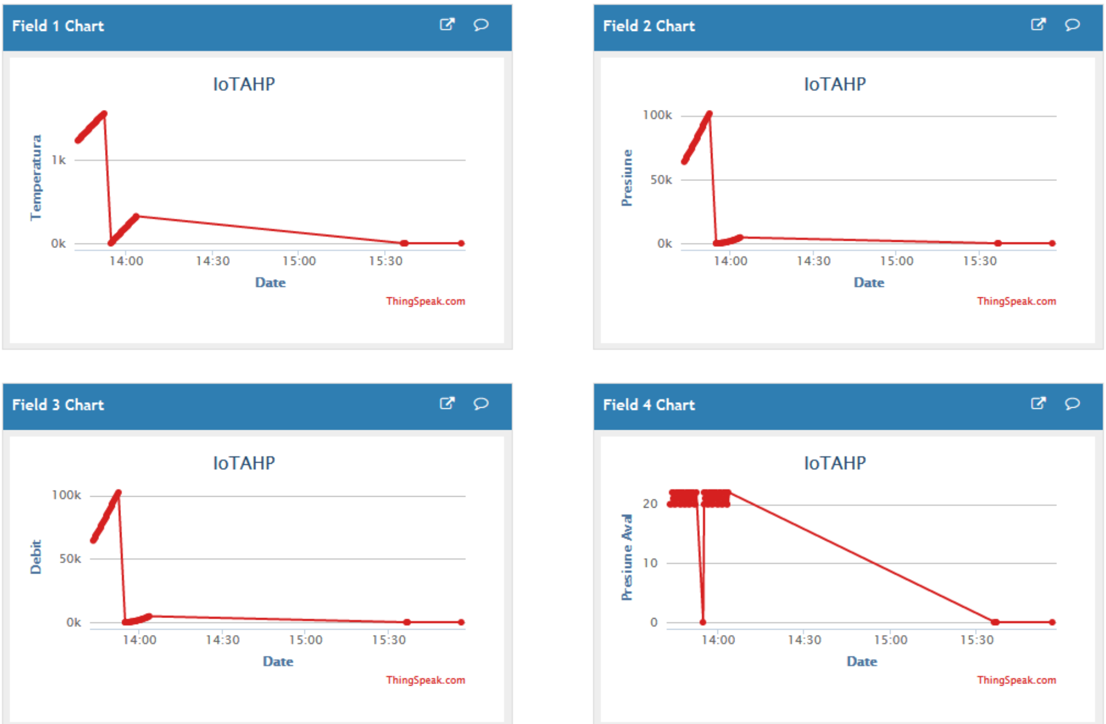


Fig VI-1 Variabile proces disponibile online

Fig VI-3 NFC Card Programmer/Reader OM5578 / PN7150 **[31]**

VII. FINAL CONSIDERATIONS

The theme addressed in this doctoral thesis is part of a highly topical field, that of intelligent systems for the generation of hydraulic energy, integrated into applications specific to the leading industry, characterized by a high degree of technicality and complexity.

The novelty of the approach is given primarily by the combination of the existing experience in the field of classical hydraulics with the facilities offered by modern testing and experimentation systems made in mechatronic design, including sensors and transducers, circuits for signal processing, Converters A/D and D/A, microcontrollers or PCs and not least appropriate software, systems heavily promoted in recent years.

The complex nature and wide range of approachable subjects required structuring of the work on the objectives proposed in paragraph II.1 namely:

- analysis of the current state in the field of hydraulic power generation groups,
- identification of trends and perspectives in the development of hydraulic power generation groups,
- establishing an original structure for a hydraulic power unit in mechatronic design; identifying methods of transforming classical structures into intelligent groups,
- the design and development of intelligent actuator systems in which the proposed groups are integrated followed by their testing and experimentation to determine performance,
- the design and construction of electronic blocks for controls specific to conventional and proportional hydraulic automation equipment, as well as data acquired from transducers integrated into the proposed systems,
- theoretical analysis of the proposed models of hydraulic power generation groups,
- the development of related software packages for the control, acquisition, processing and storage of data obtained in the experimental measurement and research processes,
- the design and presentation of testing methodologies,
- experimental testing to determine the dynamic behavior of the proposed systems,
- constructive-functional optimization of the proposed systems.

In the case of both theoretical and experimental studies, the results obtained were analyzed and interpreted.

Considering the proposed objectives, the author's contributions in this paper can be summarized as follows:

- Contributions to the analysis of the current state of development of energy generation groups
  - carrying out a comprehensive study on energy generation groups, identifying mechatronic structures of such groups, highlighting their peculiarities,
  - comparative analysis of hydraulic power generation groups,
  - establishing the basic structure of a conventional hydraulic power generation group,
  - presentation of the main trends and perspectives in the development of hydraulic power generation groups,
  - establishing the structure of a hydraulic energy generation group in mechatronic design, identifying its characteristics as well as performance criteria and main sources of disturbance,
  - identification of conventional energy generation groups to be transformed into intelligent groups with a mechatronic structure,
  - analysis of the current state of play in the field of experimental research of hydraulic power generation groups and establishment of principles for the development of intelligent experimental testing systems.

- Contributions to the identification of constructive models of hydraulic power generation groups in mechatronic design
  - establishing the structure of the models of energy generation groups, in mechatronic design, to be carried out and tested,
  - the design of the inverter, the acquisition and control board and the presentation of the operating principle,
  - integrating a typed inverter into the structure of a classical hydraulic power generation group, designing the electronic acquisition and command block and identifying a process calculator to control such a structure,
  - the design of the electronic block for power supply but also for protective functions for the 15kW group,
  - implementation of the models of hydraulic power generation groups proposed in the structure of intelligent actuators (precision hydraulic positioning system, speed adjustment system of a rotary hydraulic motor, system for experimental determination of working fluid density).

- Contributions to the theoretical analysis of a hydraulic power generation group
  - identification of the basic equations used for mathematical modelling of hydraulic systems,
  - establishing the influence of the working environment on the performance of the system,
  - elaboration of the mathematical model for the hydraulic energy generation group (establishment of the scheme of principle, pump sizing, theoretical calculation of displacement on the basis of several methods identified in the literature, plus an original method, establishment of equations forming the mathematical model),
  - numerical simulation of system operation based on the facilities of Matlab Simulink, Amesim simulation media and the Simscape extension of the Matlab-Simulink programming environment,
  - interpretation of the results obtained from the simulation and drawing conclusions on the static and dynamic behavior of the theoretically analyzed group.

- Contributions to the implementation of models developed in intelligent hydraulic actuators
- For the speed adjustment system of a rotary hydraulic motor in which the 1.5kW power generation group variant has been integrated:
    - carrying out a simulation program in the Amesim environment in order to carry out the theoretical analysis of the system,
    - making the user interface in the LabView environment for experimental analysis of the real system; the algorithms allow controlling the inverter, distributor and also data to be acquired from the transducers present in the system,
    - comparative analysis of the theoretical and experimental results obtained,
    - the construction of a system for simultaneous monitoring of temperature at multiple points, its own design,
    - the construction of a system for determining the displacement of a pump with known geometric parameters, by image processing, its own algorithm.
- For the pressure control system integrated into the hydraulic power generation group variant with 4kW power:
    - studying the documentation of the original regulator written in c++,
    - simulating the operation of the regulator in different scenarios,
    - the implementation of a regulator performing a similar function,
    - testing and validation.
- For the position adjustment system:
    - research on how to interface with the group-powered positioning unit,
    - designing and achieving the elements necessary to interface the HNC100 controller with the control PC,
    - calibration of transducers and implementation of a work program in machine code,
    - simulation of compatibility with the pressure regulator,
    - carrying out tests and experiments,
    - validation of the results.
- For the environmental density measuring stand:
    - implementation of test algorithms in LabView,
    - management and processing of experimental results,
    - initial processing in Excel of the results for verification,
    - implementation of a program in Matlab that automates the steps of management, processing, generating results,
    - interpretation results.

- Contributions to connecting systems to the Internet of Things (IoT)
    - research on the possibility of using Microsoft Azure services for IoT,
    - identifying alternative solutions: Amazon AWS, ThingSpeak, SparkFun.io,
    - IoT application development with ThingSpeak, initially on a computer and then directly on Raspberry Pi,
    - change the 1.5kW group program to be connected to its own ThingSpeak monitoring platform.

On account of the results obtained with the equipment available as well as those designed, it can be said that the hydraulic power generation groups achieved have been brought up to the high performance standards, existing on the market at the time of their design, with much lower costs compared to those already present on the market and also in a compact form.

VII.1 Directions for further research opened by doctoral thesis

We live in a world where every human has at least one internet-connected device that constantly generates and transmits data. These data are processed for many purposes ranging from sleep study, heart rate monitoring to storing personal interests, shopping habits, internet browsing history, etc.

And among the "things" came this concept called "Internet of Things" (IoT) but with a different purpose, that of optimizing production, increasing efficiency, reducing physical effort by people, better managing machine tools and even whole factories. The information taken from these "things" depends on the types of sensors integrated into the systems and for an entire factory the volume of data generated is exorbitant. BigData is the concept that deals with its storage and Machine Learning algorithms must study data, manage, and process it to optimize processes automatically.

Three groups of hydraulic power generation have been studied in this thesis. The first two were connected to an *IoT* monitoring service and the data taken from them can then be processed to extract more information.

The mechanism by which remote control can be achieved is missing, this being a limitation of the ThingSpeak platform that does not support *two-way communication*. Without this mechanism, the data obtained cannot be used to control a particular action and direct communication between two "things" is impossible. These limitations, however, are an opportunity for future developments of these groups, the changes already made being a solid foundation to which only adequate software is lacking.

Security is an important issue in IoT applications and even imperatively necessary when implementing two-way communication. Factories upgraded to be connected are constantly attacked both from outside the network (on the internet) and from the inside (even by employees); protection algorithms for improper use must be very well thought out. The solution for attacks coming from outside the factory is to use an internet network of industrial things (IOT); this type of network improves security compared to IoT standards by using authentication certificates and dynamic [25]passwords. This topic needs to be further studied and developed to implement two-way communication in intelligent, secure systems.

The stand for determining the density of the working environment is original and could be patented. For this to be possible it must be experimentally validated, optimized, and miniaturized; in short, it needs to be rethought to be an easily integrated accessory in any structure. The information obtained from it must be presented in the form of a report which is automatically sent to the operator at fixed intervals and the processed results must ultimately represent the characteristics of the hydraulic environment.

The hydraulic power generation group with a power of 15kW should be carried out practically in the form designed in paragraph III.3, i.e. Start/Stop system with a few safety systems implemented. Subsequently, the structure must be supplemented with transducers, actuators, and controllers to join the two already computerized groups in the Internet of Things (IoT). The control board made for the 4kW hydraulic power generation group (described in III.2.1 second variant) is also an excellent candidate for this group, with 6 relays that can operate contactors and sufficient digital inputs (with small modifications) to achieve the logic necessary for safe start-up and operation.

In the case of the stand designed to determine the displacement of a real pump or created on a 3D printer (IV.1.1 Method 5) there are numerous development opportunities at this point. An interactive course can be performed with this stand to explain the operation of pumps more easily with toothed gears; pumps with different geometries, atypical tooth shapes or even different number of teeth can be studied on each tooth wheel. The image processing algorithm can be improved to be less sensitive to lighting conditions.

I believe that the thesis has brought significant innovations in the field of hydraulics, dominated largely by big companies like Bosch-Rexroth, Eaton, Festo, etc. It is demonstrated that this area does not necessarily have to be restricted due to it being costly, as it is considered, on the contrary it should be promoted as an open area for research, development and innovation for anyone who has the drive, motivation and time to do so.

VII.2 Publications

1. Avram, Mihai, **Valerian-Emanuel Sârbu**, Alina-Rodica Spânu, and Constantin Bucșan. "Intelligent hydraulic power generating group" International Journal of Mechatronics and Applied Mechanics, 2018(3), pp. 157-162 și Lecture Notes in Networks and Systems, 48, pp. 104-114, 2019, indexat SCOPUS;

2. Avram, Mihai, Spânu, Alina-Rodica., **Sârbu Valerian-Emanuel,** "Method for controlling the hydraulic pump flow following an imposed frequency law for AC motors", IOP Conference Series: Materials Science and Engineering, 444(4),042009, 2018, indexat SCOPUS și ISI, WOS:000467443600045;
   Citări:
   Fu, S., Wang, L., Lin, T., Control of electric drive powertrain based on variable speed control in construction machinery, Automation in Construction 119,103281, 2020, indexat ISI, WOS:000579045500010, FI=6,121;

3. Avram, Mihai, Constantin Niţu, Lucian Bogatu, and **Valerian Sârbu.** " Theoretical analysis of an external gear pump-methods for determining the pumping capacity" International Journal of Mechatronics and Applied Mechanics 2(6), pp. 182-190, 2019, indexat SCOPUS;
   Citări:
   Saleem, A.M., Alyas, B.H., Shaalan, Z.A., Numerical analysis of standard-unstandard gears for an external gear pumps, International Journal of Fluid Machinery and Systems, 14(1), pp. 25-33, indexat SCOPUS.

4. Avram, Mihai, Mariana-Florentina Ştefănescu, **Valerian-Emanuel Sârbu**, and Gabriel Năstase. " Theoretical analysis of a hydraulic drive system. The influence of the work environment on the performance of the system", International Journal of Mechatronics and Applied Mechanics 1(7), pp. 152-157, 2020, indexat SCOPUS;

5. Avram, Mihai, **Valerian Sârbu**, Emil Ionuț Niță, and Lucian Bogatu. "Theoretical analysis of a hydraulic energy generation system equipped with a gear pump", Lecture Notes in Networks and Systems 143, pp. 231-241, 2020, indexat SCOPUS;

6. Avram, Mihai, and **Valerian-Emanuel Sârbu**. "Upgrading Obsolete Hydraulic Power Units to Become Remotely Monitored, Energy Efficient and Intelligent", Lecture Notes in Networks and Systems 143, pp. 221-230, 2020, indexat SCOPUS;

7. **Sârbu, Valerian**, and Mihai Avram. "A novel approach for assessing the instantaneous flow rate of an external gear pump using 3d printing and computer vision", IOP Conference Series: Materials Science and Engineering 997(1),012060, 2020, indexat SCOPUS;

VII.3 Accepted papers that are not yet published

1. Mihai AVRAM, **Valerian-Emanuel SÂRBU**, Mariana-Florentina ŞTEFĂNESCU " STUDY OF A TEST STAND FOR DETERMINING THE OIL DENSITY IN HYDRAULIC SYSTEMS" ICECCME 2021 The International Conference on Electrical, Computer, Communications and Mechatronics Engineering.

VIII.BIBLIOGRAPHY

[1] „Free Dictionary Intelligent Machine," Farlex Inc, [Interactiv]. Available: https://encyclopedia2.thefreedictionary.com/intelligent+machine.

[2] D. Octavian și D. I. Grigore, TEHNOLOGII SI SISTEME INTEGRATE DE FABRICATIE PENTRU MECATRONICA, PRINTECH, 2009.

[3] Rexroth, „Ready for Industry 4.0: Connected hydraulics," Rexroth, Iulie 2017. [Interactiv]. Available: https://m.boschrexroth.com/en/web/xc/trends-and-topics/directions/ready-for-industry-4-0-connected-hydraulics. [Accesat Ianuarie 2018].

[4] Electromechanical Team , „Is Industry 4.0 Driving the Need for Smarter Motion Control Products?," Parker, Aug 2017. [Interactiv]. Available: http://blog.parker.com/is-industry-40-driving-the-need-for-smarter-motion-control-products.

[5] http://empoweringpumps.com/ac-induction-motors-versus-permanent-magnet-synchronous-motors-fuji/, „ac-induction-motors-versus-permanent-magnet-synchronous-motors-fuji/," empoweringpumps, [Interactiv]. Available: http://empoweringpumps.com/ac-induction-motors-versus-permanent-magnet-synchronous-motors-fuji/.

[6] Martin Endres, „Pump control: Which is the right one?," Rexroth, 29 Nov 2017. [Interactiv]. Available: http://blogs.boschrexroth.com/en/topics/decision-making-hydraulic-pump-control/. [Accesat 03 Ianuarie 2018].

[7] M. G. R. S. Arthur Akers, Hydraulic Power System Analysis, CRC Press, 2006.

[8] „Mathematical Modeling and Experimental Research of Characteristic Parameters Hydrodynamic Processes of a Piston Axial Pump," *Journal of Mechanical Engineering* , nr. Strojniški vestnik, p. 6, 2008.

[9] D. S. Haack, „Hydraulic valves will benefit from connectivity," BoschRexroth, 30 Aug 2017. [Interactiv]. Available: http://blogs.boschrexroth.com/en/topics/hydraulic-valves-technology-will-benefit-from-networkability-interview-dr-steffen-haack/.

[10] C. Gonzalez, „IoT Empowers Control in Fluid Applications," hydraulicspneumatics, 14 11 2017. [Interactiv]. Available: http://www.hydraulicspneumatics.com/hydraulic-fluids/iot-empowers-control-fluid-applications.

[11] J. Joyce, „The Powerful Impact of Preventive Maintenance," HydraulicsPneumatics, 6 Dec 2017. [Interactiv]. Available: http://www.hydraulicspneumatics.com/hydraulic-fluids/powerful-impact-preventive-maintenance.

[12] [Interactiv]. Available: https://conspecte.com/marketing/ciclul-de-viata-al-produsului.html.

[13] Martin Endres, „Pump control – simple or intelligent?," Rexroth, 6 Dec 2017. [Interactiv]. Available: http://blogs.boschrexroth.com/en/topics/hydraulic-pump-control-systems-simple-or-intelligent/. [Accesat 01 Ianuarie 2018].

[14] „AWS IoT Core," Amazon, [Interactiv]. Available: https://aws.amazon.com/iot-core/.

[15] R. A. Mammano, Fundamentals of POWER SUPPLY DESIGN, Texas Instruments, 2017.

[16] B. Rexroth, „Datasheet PGF2x," [Interactiv]. Available: https://md.boschrexroth.com/modules/BRMV2PDFDownload-internet.dll/re10213_2015-05.pdf?db=brmv2&lvid=1188621&mvid=13760&clid=20&sid=FA0A4812C9BBE797FCD1096A16DAFABA.borex-tc&sch=M&id=13760,20,1188621. [Accesat 02 1 2019].

[17] „IE2 Electric Motor | 4,00 kW - 4P - Frame 112 - B5," Hoyer Motors, [Interactiv]. Available: https://hoyermotors.com/products/motors/ie2-industrial-motors/3141120200. [Accesat 10 12 2018].

[18] M. AVRAM, C. BUCŞAN, S. MIU, A. SPÂNU și M. TĂNASE, „incdmtm," 2011. [Interactiv]. Available: http://www.incdmtm.ro/editura/documente/pag.%20311-314.Modular%20Intelligent.pdf. [Accesat 11 2019].

[19] G. Viorel, M. Avram, D. P. Duminică și C. Udrea, Hidronica si pneutronica, Bucuresti: Editura Universitară, 2008.

[20] C. N. L. B. V. S. Mihai Avram, „THEORETICAL ANALYSIS OF AN EXTERNAL GEAR PUMP-METHODS FOR DETERMINING THE PUMPING CAPACITY–,” *International Journal of Mechatronics and Applied Mechanics,* vol. 1, nr. 6, pp. 250-258, 2019.

[21] V. a. M. A. Sarbu, „A novel approach for assessing the instantaneous flow rate of an external gear pump using 3d printing and computer vision,” în *OP Conference Series: Materials Science and Engineering, vol. 997, no. 1, p. 012060.,* Bucharest, 2020.

[22] M. Avram, Actionari hidraulice si pneumatice, Bucharest: Editura Universitara, 2005.

[23] Wikipedia. [Interactiv]. Available: https://en.wikipedia.org/wiki/Simcenter_Amesim.

[24] A. Hughes și B. Drury, Electric Motors and Drives: Fundamentals, Types and Applications, 4th Edition, UK: Newnes, 2013.

[25] W. C. W. M. Sadeghi AR, „ Security and privacy challenges in industrial internet of things,” *InDesign Automation Conference (DAC),* nr. 52nd ACM/EDAC/IEEE 2015, 2015 .

[26] M. Avram, D. Duminica, C. Udrea și V. Gheorghe, HIDRONICA SI PNEUTRONICA - Aplicatii -, Bucuresti: Editura Universitara, 2008.

[27] Rexroth, „4WRE,” 11 2012. [Interactiv]. Available: https://dc-kr.resource.bosch.com/media/kr/products_9/data_sheet_8/4wree/re29061_2012-11_wree.pdf.

[28] M. Avram, V.-E. Sârbu, A.-R. Spânu și C. Bucșan, „ijomam :INTELLIGENT HYDRAULIC POWER GENERATING GROUP,” 02 2017. [Interactiv]. Available: http://ijomam.com/wp-content/uploads/2017/02/pag.-157-162_INTELLIGENT-HYDRAULIC-POWER-GENERATING-GROUP.pdf. [Accesat 11 2019].

[29] Microchip, „ATSAM3S2A,” [Interactiv]. Available: https://www.microchip.com/wwwproducts/en/ATSAM3S2A.

[30] Panasonic, „AMG8834,” [Interactiv]. Available: https://industrial.panasonic.com/ww/products/sensors/built-in-sensors/grid-eye/models/AMG8834.

[31] Element14, „NFC Development kit for Raspberry PI,” NXP, [Interactiv]. Available: https://www.element14.com/community/docs/DOC-86578/l/nfc-development-kit-for-raspberry-pi.

[32] Moog, „RKP with Digital Control for High Performance Machines,” Moog, 2017. [Interactiv]. Available: http://www.moog.com/products/radial-piston-pumps/rkp-with-digital-control-for-high-performance-machines.html.

[33] M. Avram, A. .. și a. V. Sârbu, „Method for controlling the hydraulic pump flow following an imposed frequency law for AC motors,” *IOP Conference Series Materials Science and Engineering,* nr. DOI: 10.1088/1757-899X/444/4/042009, p. 444(4):042009, 2018.