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# ELECTROHYDRAULIC SERVO SYSTEM FOR REAL TIME MAPPING SOIL PROPERTIES

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*The paper contains a short report on the design, laboratory test and practical implementation of an original electrohydraulic servomechanism in a platform for real time mapping soil. The great interest for this subject was generated by the wide change occurring in the agriculture practice, oriented to the proper exploitation of all the available soils. The new wave of "intelligent agriculture" starts by the deep knowledge of the soil's capabilities with modern hardware and software tools. The servomechanism created by the authors was successfully implemented and tested in a mapping platform designed together with The National Institute of Research – Development for Machines and Installations Designed for Agriculture and Food Industry – INMA Bucharest, and the Optoelectronics Department of the P.U.B.*

**Keywords**: modeling, simulation, implementation, electrohydraulic servo system, real time mapping soil properties.

## 1. The need of the mapping soil properties

The traditional agriculture is undergoing a considerable reform whose core force is "information technology". This integrates mobile terminals, IT platforms, cloud calculation, big data, internet of things and internet technology. The first step in this process is the replacing of the traditional soil sampling and laboratory analysis by On-The-Go sensing with mobile platforms. The mobile sensors could have a lower accuracy than laboratory techniques, but they offer an intense spatial coverage. Based on the remarkable book of White R.E. [1], ASTM generated in 2000 the "Standard Practices for Infrared Multivariate Quantitative Analysis" [2]. The main contribution to the wide application of this technology was offered by the studies of Christy C.D. [3]. The practical spectrophotometer presented by him performs near infrared (NIR) diffuse reflectance spectroscopy (fig. 1). Using one-

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field-out validation, which matches the prediction problem posed by real-time measurements, the system can replace well the laboratory measurements.

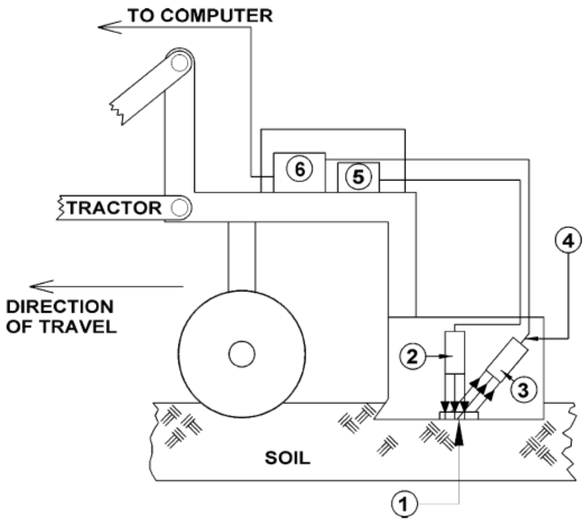


Fig. 1. Spectrophotometer used to obtain NIR reflectance spectra:
1-spahire window; 2-halogen lamp; 3-collection optic; 4-fiber optic; 5-spectrometer;
6-power supply. [3]

Another important step in the on-the-go soil scanning process was studied by Schirrmann M. [4] in 2011 by testing the “continuous pH mapping”. The team of the Department of Engineering for Crop Production from Leibniz-Institute for Agricultural Engineering (Germany) tested the accuracy of a sensor for mapping of soil pH type Veris pH ManagerTM [5], on real fields. While testing on the field, soil pH is measured on-the-go directly within the soil by ion selective antimony electrodes, with good accuracy. The same important research activity regarding the use of pH sensors are carried on in different countries with important agricultural resources as India [6].

This paper describes the activities carried out by the Fluid Power Laboratory of P.U.B. in order to promote the same concept of on-the-go positioning of a pH sensor by the aid of a high response speed electrohydraulic servomechanism; this was set up on a mobile sensing platform designed together with the ITC Department of I.N.M.A. [7], [8]. The controller of the sensors system of the platform was designed by the Optoelectronics Department of the P.U.B. [9].

## 2. Main design data for the servomechanism

The peculiarities of the servomechanism task necessary to operate the pH sensor of the platform for mapping the properties of different soil types in our country imposed the design and testing of a complete model of servomechanism, in order to establish optimal operating conditions and meet the performance required by the national research project leaded by I.N.M.A. The supply of the platform servomechanism by the tractor pump that ensures its movement in the investigated terrain limited the supply pressure of the servomechanism to 14 MPa and the flow - to 45 l/min.

The mapping of some compact soils imposed the dimensioning of the hydraulic cylinder for the maximum sampling depth at 20 cm with a maximum speed of 10 cm/s. In order to ensure the speed of sampling the soil samples, it was decided to equip the servomechanism with a PARKER industrial servovalve compatible with the pressure and flow of the tractor's hydraulic power pack [10]. Starting from a relatively small amount of information regarding the soil sampling process, a BOSCH hydraulic cylinder [11] equipped with a position transducer was chosen, capable of achieving a stroke of 200 mm and a maximum force of 4000 N. The load of the servomechanism model is performed by a spring that develops the same resistance force in both directions, considering the need to reach the same speed of movement of the pH transducer in both directions. The equivalent mass of the moving part of the moving assembly is 24 kg. This indicative information was sufficient for the elaboration of the nonlinear mathematical model of the servomechanism, as well as for the design of the electronic and hydraulic equipment necessary to control the servovalve and to identify the real performances of the system, according to the international procedures.

## 3. Modeling and simulation of the system dynamics

The Simcenter Amesim R13 software package produced by SIEMENS [12-15] was used for the numerical simulation of the dynamic behavior of the servomechanism. The numerical simulation network used is shown in figure 2. The controller used in the simulations has a real correspondent in the one used for experiments. All parameters assigned to the system components have the real values from the simulated system, predetermined in the laboratory according to the international methodology. Preliminary simulations were performed using the static and dynamic parameters of a PARKER servovalve supplied at a relatively low pressure (14 MPa), corresponding to the conditions imposed by the mandatory running in of the powertrain. It has been aligned by design and execution regulations specific to fast electrohydraulic systems.

The preliminary series of numerical simulations confirmed the validity of the mathematical model built on the available data. This created the possibility of a systematic study of the dynamics corresponding to the entire piston stroke for three characteristic pressures (7, 10.5 and 14 MPa) and two frequencies relevant to the sampling process: 0.05 Hz and 0.1 Hz, the amplitude of the sinusoidal signal being maximum (10V), corresponding to the maximum piston stroke (200 mm). Increasing the pressure of the power supply to 14 MPa in the conditions of maintaining the frequency of the control signal at 0.05 Hz considerably reduces the hysteresis of the servomechanism.

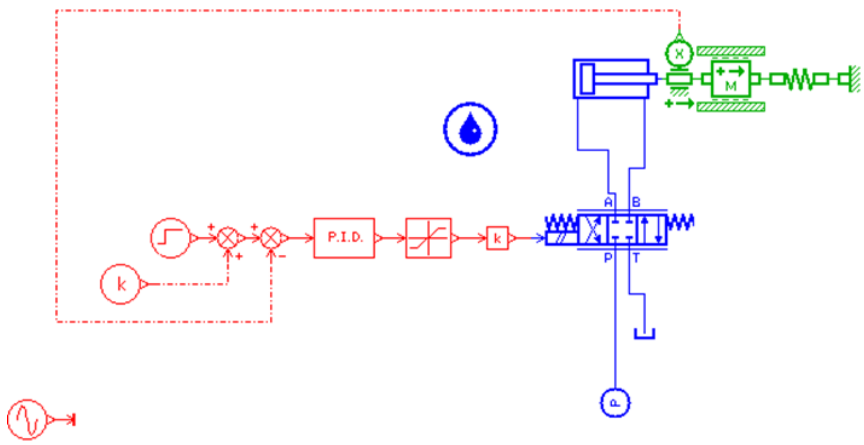

Fig. 2. Simcenter Amesim simulation network for the servomechanism dynamics

The main test was performed with a sine input of 0.1 Hz and a supply pressure of 14 MPa. The main results are presented in figures 3...7.

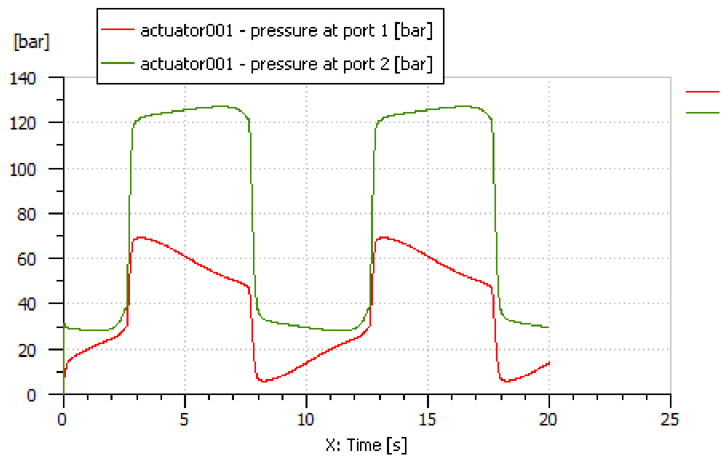

Fig. 3 Pressure variations in the chambers of the hydraulic cylinder for a sine input of 0.1 Hz and a supply pressure of 14 MPa.

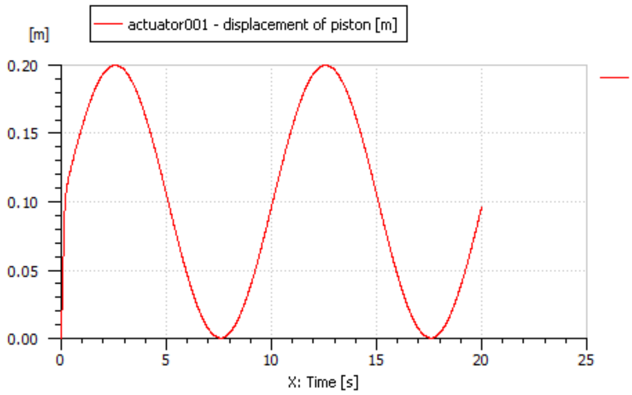


Fig. 4. Piston displacement for a sine input of 0.1 Hz at 14 MPa pressure supply.

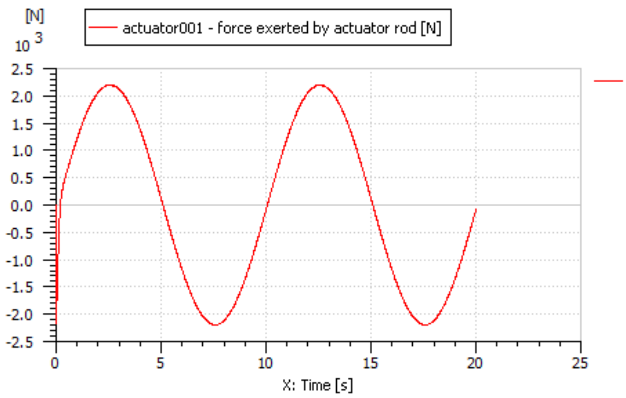


Fig. 5. Force on the piston of the hydraulic cylinder (f=0.05 Hz; p=14 MPa).

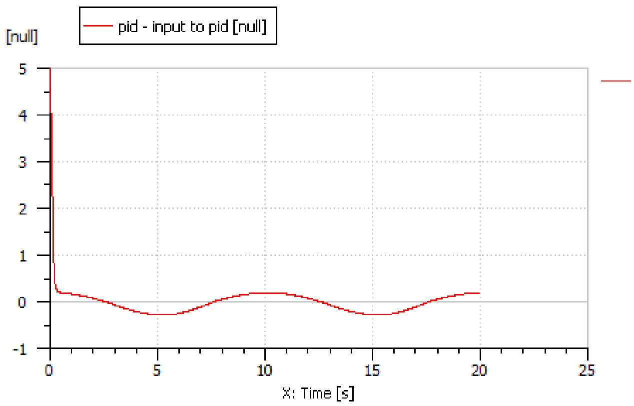


Fig. 6. Input signal of the PID controller for f=0.1 Hz and p=14 MPa.

The hysteresis of the steady state characteristic has a normal value: less than ±5 mm as shown on figure 7.

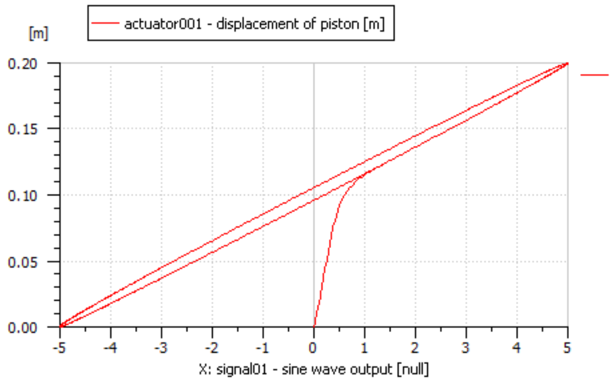


Fig. 7. The steady state characteristics for f=0.1 Hz and p=14 MPa.

The tests performed with low frequency sinusoidal signals, necessary to establish the static accuracy of the servomechanism were completed with dynamic virtual tests with rectangular signals. The response of the servomechanism to 10V amplitude signals is shown in figure 8. The force developed by the piston is presented in figure 9.

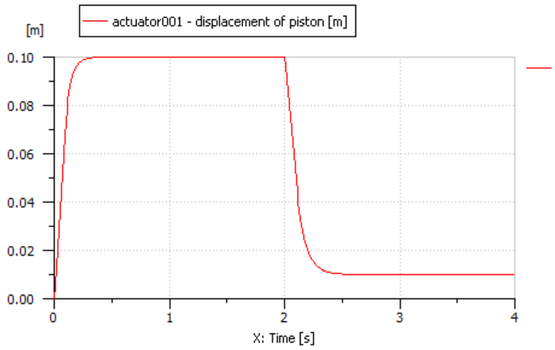


Fig. 8. Piston stroke for an input of 10V.

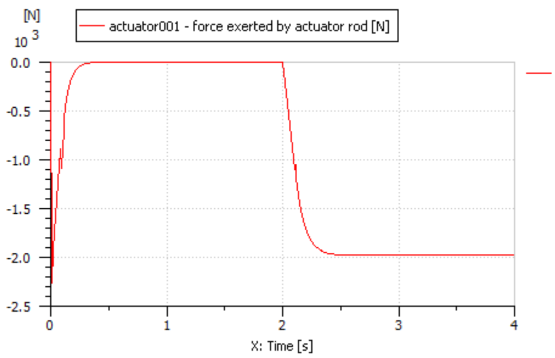


Fig. 9. Force delivered by the servomechanism for an input of 10 V.

There is a slight oscillation of the force in its growth phase, specific to all automatic hydraulic systems of 3rd order. The displacement of the piston indicates a rapid response (0.5 s) for the maximum amplitude step input signal.

Figure 10 shows the evolution of the signal at the input of the PID controller, which corresponds quite well to an automatic system of order 3 well damped.

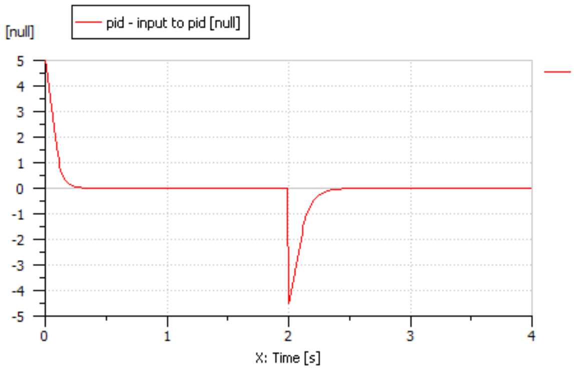


Fig. 10 Input voltage of PID for $K_P = 5$

## 4. Experimental determination of the servomechanism performances in the Fluid Power Laboratory of P.U.B.

### 4.1 Test bench structure

The stand used for identifying the performances of the servomechanism was designed modularly. Its subassembly, shown in fig. 11 is located on a rigid table capable of supporting high frequency longitudinal oscillations (fig. 12), an electrical panel for managing the motion regimes, a high-performance pumping unit and a system of digital control for the entire stand. The stroke of the piston can be controlled from the local panel of the servomechanism, or from the platform controller. In both cases, the complete motion of the piston is confirmed to the main controller, in order to start the data acquisition from all platform sensors.

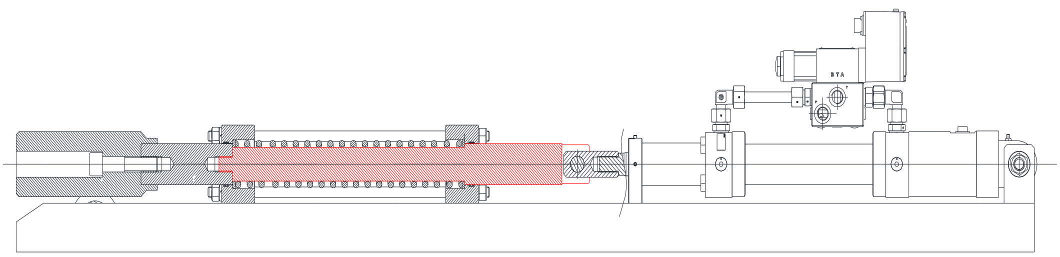

Fig. 11. Lateral hybrid view of the servomechanism

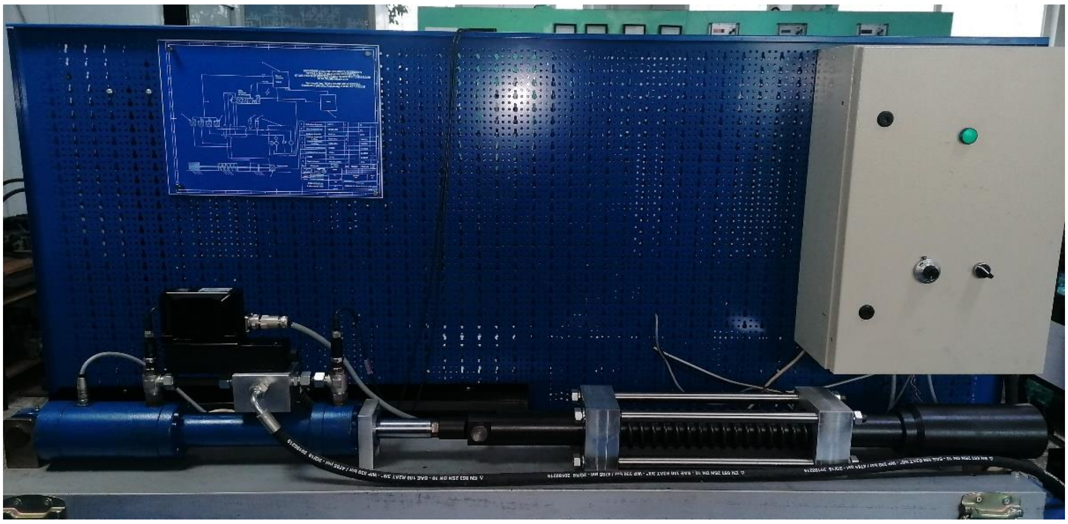

Fig. 12. Front view of the servomechanism set up on the test table.

The hydraulic diagram of the test bench is presented in figure 13. The main components of the electrohydraulic servomechanism with elastic load are:

-Differential hydraulic cylinder, type CDH1 / CGH1 / CSH1, equipped with magnetostrictive position transducer (BALLUFF), produced by BOSCH REXROTH AG for a nominal pressure of 25 MPa and a stroke of 200 mm;

-Industrial servo valves for fast processes: a) PARKER HANNIFIN D1FPE50MA9NB0039; b) REXROTH 4WRSEH 6C–A1–30; c) MOOG D633/634;

-Analog controller for fast servomechanisms type AVPC, produced by the BOSCH REXROTH AG;

-Piezo ceramic high-speed pressure transducers produced by WIKA Group.

The servomechanism tests were performed successively with all three types of servovalves. All of them have the same hydraulic and electrical connections. The constant pressure oil supply system of the test bench includes an axial pistons pump sized for the maximum flow of 60 l/min and the nominal pressure of 35 MPa, equipped with a hydro pneumatic accumulator of adequate capacity for reducing the hydraulic noise of the pump, a “cascade” of filters, a normally-closed pilot valve with an optimal damping factor, pressure transducers, quick hydraulic couplings, and control panels of different kind for electrohydraulic servomechanisms. The stand was executed by SC ICPEST SRL– a high level aerospace manufacturing company. The control and retrieval schemes of the measured data, executed with the help of the LabVIEW program, are partially presented in figure 14.

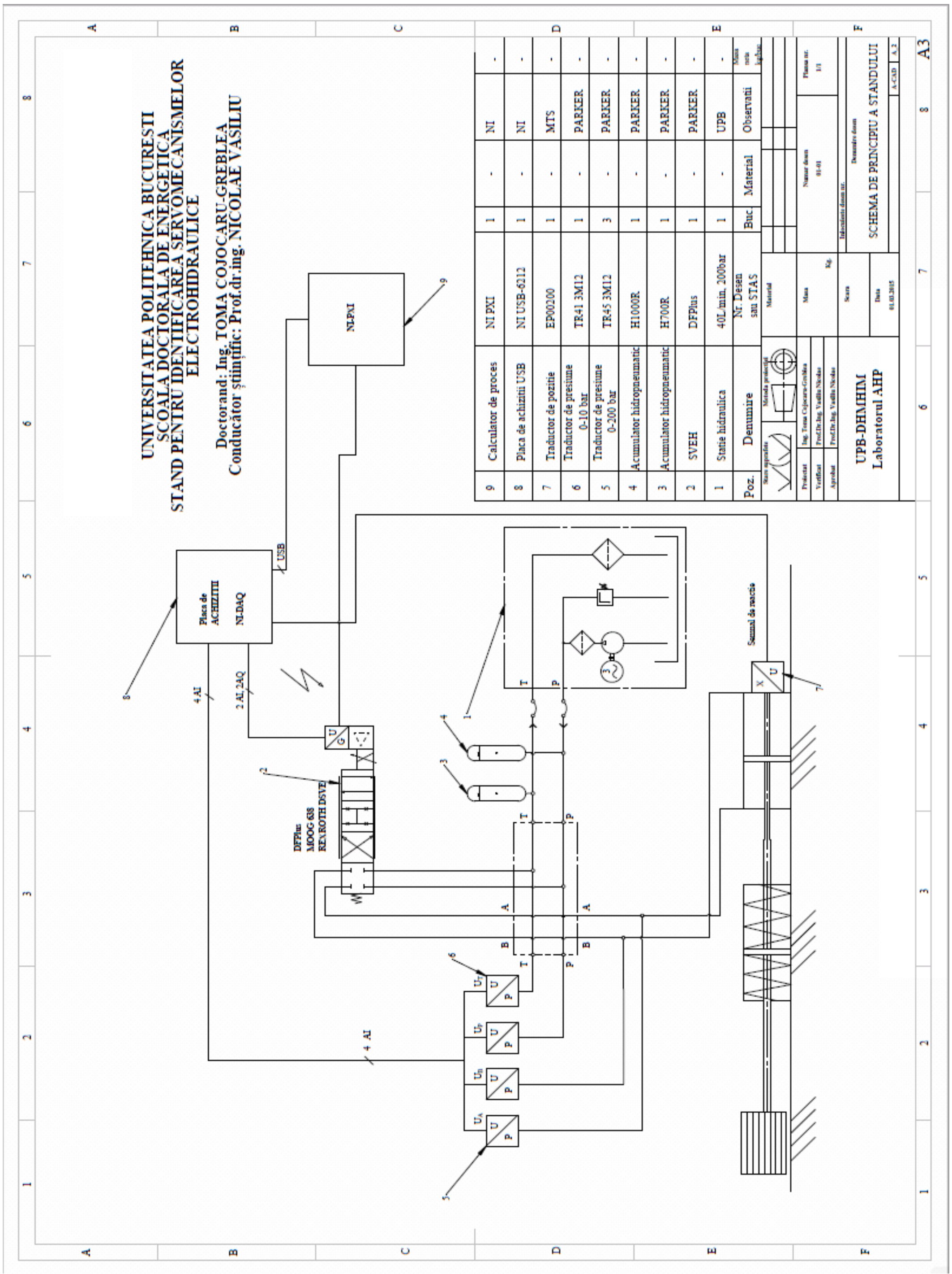

Fig. 13. Hydraulic diagram of the test bench

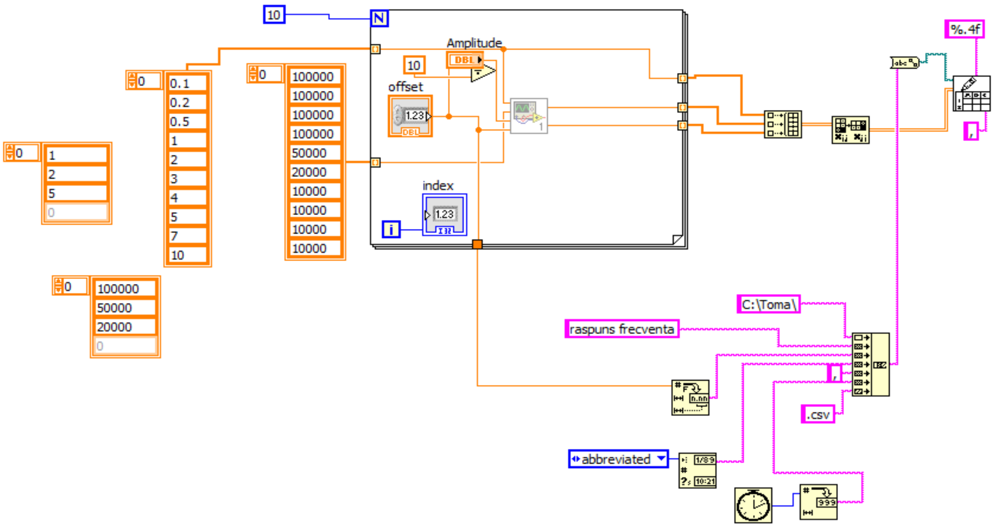


Fig. 14. Control and acquisition scheme of measured quantities executed using the LabVIEW program (partial view). [17-18]

### 4.2 Steady state performances of the servomechanism

According to international standards, the real static performances of electrohydraulic servomechanisms are obtained for sinusoidal signals of low frequency (0.05 Hz) and low amplitude (0.1 V), aiming to determine two major parameters: linearity of response and maximum amplitude of hysteresis, measured around the null input signal. These tests were performed for three usual supply pressures. The typical results are shown in figs. 15 and 16.

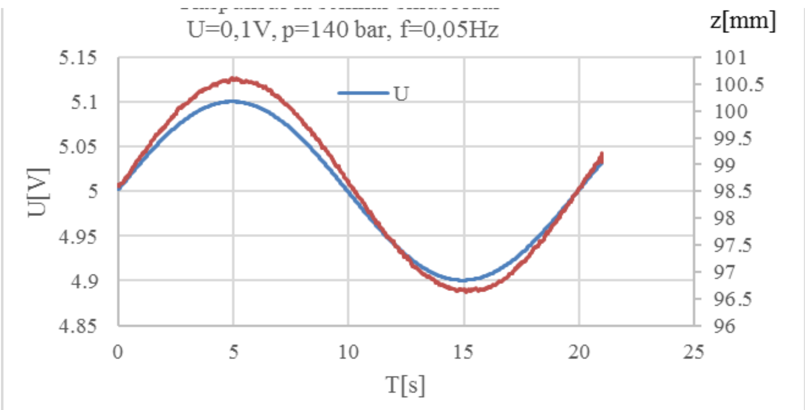


Fig. 15. Input sine response for p=14 MPa

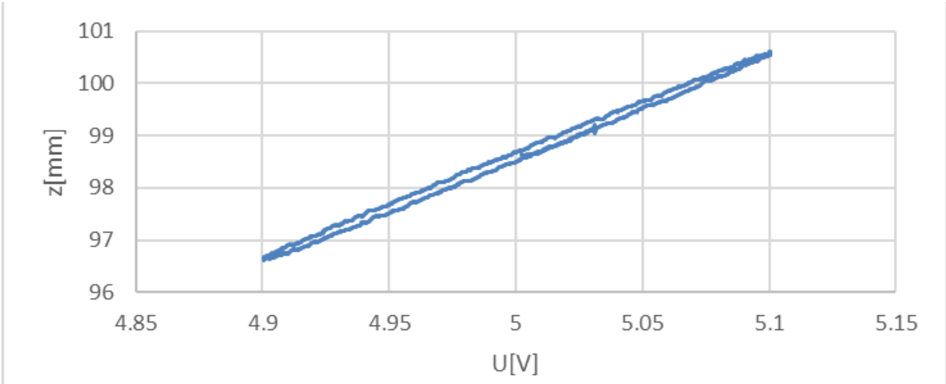


Fig. 16. Steady state characteristics of the servomechanism for p=14 MPa

### 4.3 Dynamic performances of the servomecanism

The best evaluation of the dynamic performances is obtained by exciting the servomechanism with rectangular signals of maximum amplitude. Finally, the tracking capacity is evaluated by determining the attenuation-frequency and phase-frequency curves [16], [17]. The response to rectangular signals with the maximum amplitude (10 V) and the supply pressure of 140 bar is shown in figure 17, indicating an overall time constant of less than 0.6 s for 66% of the entire stroke (200 mm). Tests performed at higher pressures exceed the piston stroke calculated for the static stiffness of the spring specified in the design theme of the platform on which the servomechanism is to be installed. Reducing the amplitude of the rectangular signals to 5V allows the determination of the time constant for the pressure of 280 bar, resulting a typical value of about 50 ms indicated in the literature for purely elastic loads and negligible masses. Details of the dynamics of the servomechanism for step signals of increasing and decreasing amplitude indicate the same very good dynamic behavior (figs. 17 and 18).

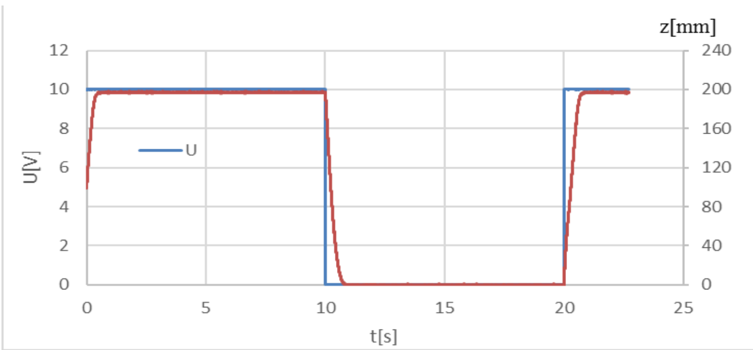


Fig. 17. Typical response of the servomechanism to rectangular inputs.

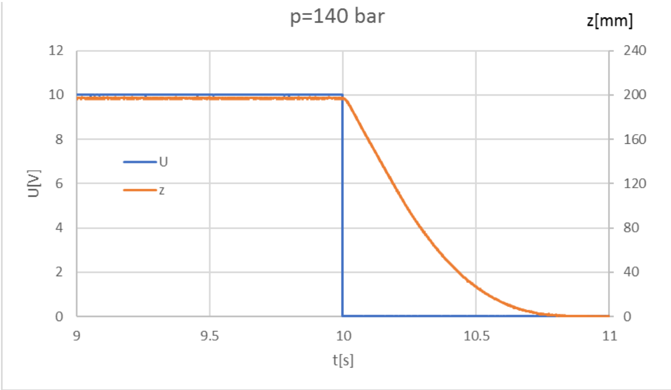


Fig. 18. Response for the nominal input voltage step

The tracking capacity of the servomechanism was determined by the frequency response for the same three supply pressures and for three amplitudes of the applied sinusoidal signals. The final result is shown in figure 19. All the experiments undertaken in the laboratory indicated a very good static and dynamic behavior of the servomechanism, at the level of the achievements of the companies specialized in the conception, manufacture and implementation of the high-performance electrohydraulic servosystems.

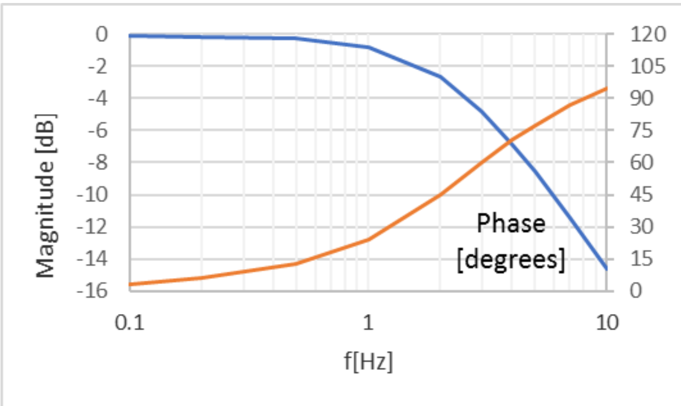


Fig. 19. Frequency response for 0.5 V and 14 MPa

## 5. Implementation of the servomechanism components in the platform

The experimental servomechanism was implemented in a distributed form on the platform designed and manufactured in collaboration with I.N.M.A. The picture shown in figure 20 indicates the placement of the main components in appropriate spaces on the platform, so that the soil sampling mechanisms can operate optimally.

Fig. 20. Overall view of the platform set up at I.N.M.A.

## 6. Conclusions and future researches

The servomechanism was tested together with the optoelectronic soil composition analysis system, located on the platform, by the specialists of I.N.M.A., Fluid Power Laboratory and Optoelectronics Laboratory of the P.U.B. The two systems communicate digitally in order to synchronize the specific actions. Overall, the platform fully responds to the national research project that funded the entire research. The servomechanism realized within the project can be used in many industrial applications, as well as for testing with Hardware in The Loop the components of different complex aerospace, naval, military equipment etc. The future research, devoted to the same objective, will be oriented to an autonomous platform using both hydrostatic transmission, and hybrid compact servomechanisms with brushless motors digitally controlled. [19], [20]

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