Universitatea „Dunărea de Jos" din Galaţi
Şcoala Doctorală de Inginerie

TEZĂ DE DOCTORAT

CONTROLUL PROCESULUI DE SĂPARE LA EXCAVATOARELE CU O CUPĂ

CONTROL OF DIGGING PROCESS ON SINGLE BUCKET EXCAVAOR

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This thesis starts from a reality of the current excavator park in Romania, namely that their moral wear and tear is advanced. More specifically, the mechanical condition is good, but the lack of hydraulic system automation leads to a low performance.

The current park of hydraulic excavators in Romania is made up of the machines manufactured by PROMEX S.A. Braila, whose nominal capacity is in the following categories: 0,4 m3; 0.6 m3; 0.8 m3; 1.0 m3; 1.2 m3; 1.8 m3. These machines are based on constructive and actuator solutions designed at the technical level of knowledge in the field 30-35 years ago, which indicates the need to bring them to a certain level of improvement of the technological performances;

This work proposes an inexpensive technical solution and accessible to many excavator owners by using programmable electronic boards together with a series of sensors as well as the replacement of hydraulic equipment (distributors, hydraulic cylinders) with new ones that can be electrically controlled (mainly 12V).

As regards the electronic part, there is a **RaspberryPi** programmable plaque that is a single-board computer with an open-source hardware and was made and developed in the UK by Raspberry Pi Foundation to promote computer-based education for the countries in progress development . Later it became very popular for amateur or professional robots.

To convert analog signals (as they come from sensors) into digital (for their numerical processing by the board), a MCP3008 DIPADC type converter interface is used. This plate will be assigned the role of process controller.

Such a board is shown as in the figure below.

1

This type of microcomputer has the advantage that each pin can be ordered through the user's written program. The programming language is Pyton a high-level, easy-to-write programming language (uses white spaces for block delineation) that allows for clear instructions.

This board has 40 pins and provides a General Purpose Imput Output (GPIO) based on a programmed function. The functions of these pins are given in the figure below.
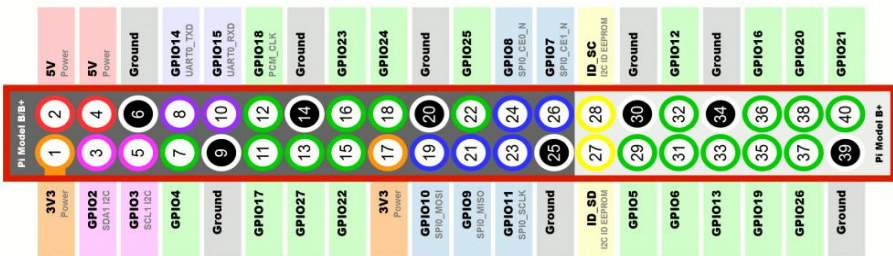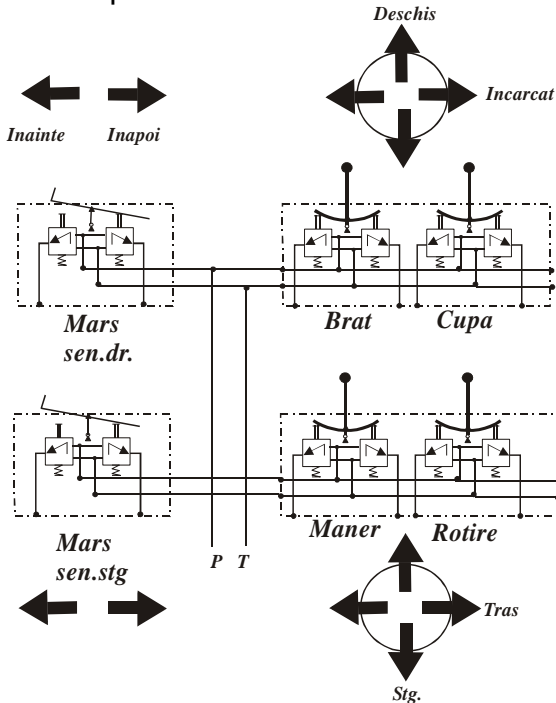

So we have a new technical concept for assisting commands (called assist) by introducing board microcomputers.

Starting from the above, the work is structured as follows: Chapter 2 refers to the current state of research in the field of work process control.

This study was carried out on types of excavators manufactured in Romania (Promex), including the range of sizes of the cup capacity between 0,4 ... 3,3 m^3 and the Volvo EC 460. The presentation referred to the capacity of the bucket and the excavator's work chart.

In this chapter we presented the schematic diagram of the hydraulic drive on a tracked excavator.

Within this scheme we have three groups of hydraulic elements:
- pumping
- distribution
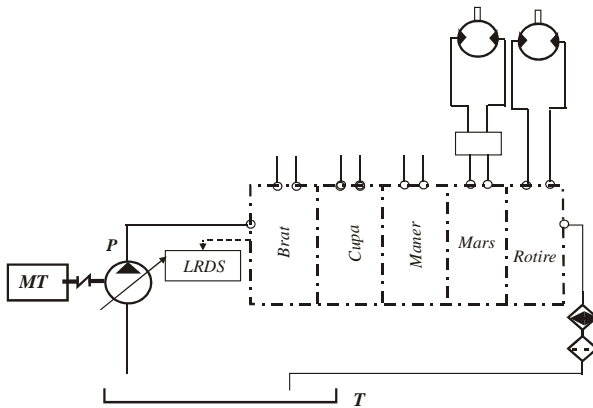- hydraulic drive (hydraulic motors and hydraulic cylinders)

The pumping group consists of a thermal motor (MT) and two variable cylinder pumps (P1, P2), combined in the same housing that contains both the distribution box and the single regulator of the two pumps
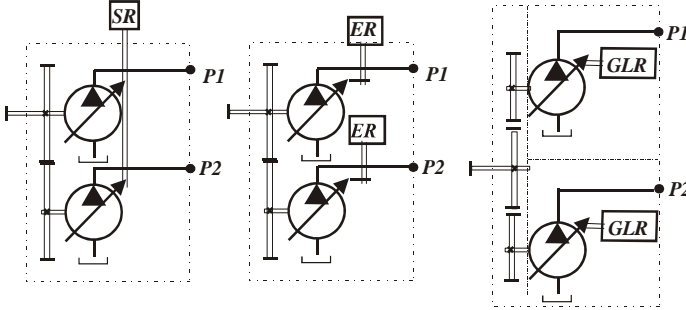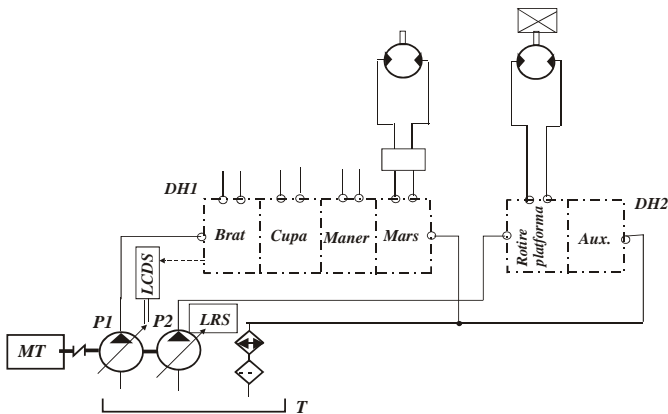

The distribution group may be monobloc or battery with inlet section containing primary protection and secondary and anticattacous protection on consumer circuits.

In the case of a tire excavator we have a single hydraulic pump

P   *Brat*   *Cupa*   *Maner*   *Mars*   *Rotire*

MT   *LRDS*

T

or two hydraulic pump.

DH1   *Brat*   *Cupa*   *Maner*   *Mars*   *Rotire platforma*   *Aux.*   *DH2*

LCDS

P1   *P2*   *LRS*

MT

T

The LOAD SENSING (LS) operation of the wheel excavators consists of adjusting the LS of the pump cylinder and using the hydraulic distributors.
The excavator **drive group** is in the open circuit with variable speed cylinders, coupled to a two-speed gearbox. The first gear stage is specific to the technological movement of the excavator or the movement in the working front, and the second stage for traveling on public roads between the work points.

Punte fata   **Punte spate**
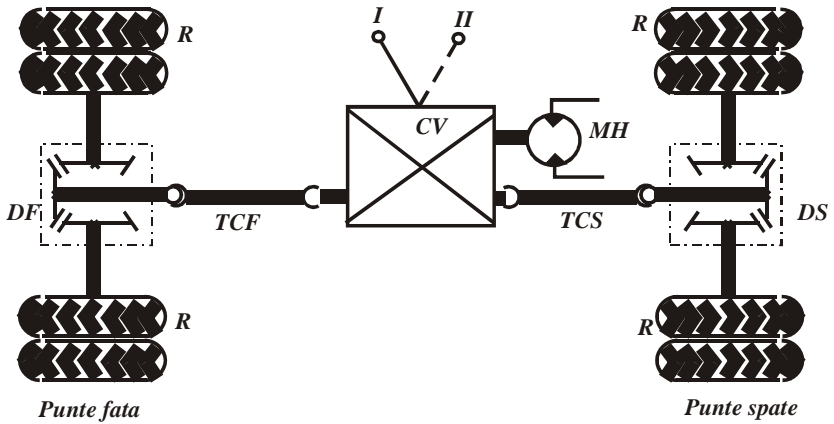
Regarding the current stage of research in the field of open and closed circuit operation monitoring, with electronic control of the working process is used the microprocessor adaptive system which is used in medium and large excavators and has as main role the optimal control of the energy consumption of the machine
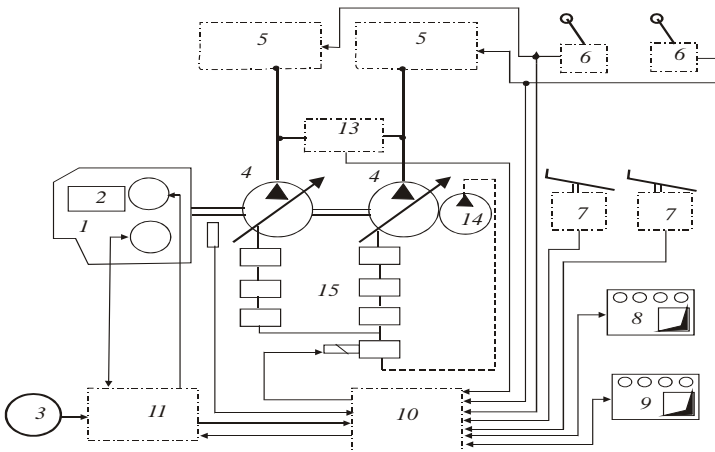
By monitoring the working process for open and closed circuit operation with electronic control of the working process,aim the electronic control of the machine movements is monitored by both the assist function and the learning function as follows:

a) for the assist function:

- monitoring the hydraulic oil parameters that are:

  o a pressure whose values can be monitored at any point in the hydraulic system;

  o a flow whose values can be monitored at any point in the hydraulic system;

  o a temperature with the automatic start of the cooling fans on the hiral oil tank when it exceeds a certain value;

  o a minimum amount of hydraulic oil by acting on the thermal engine (injector lock) when the tank quantity is minimal.

- the control of the two basic parameters in the hydraulic drives, namely the pressure and flow from the pump outlet to the entry of hydraulic cylinders or displacement or rotation hydro motors:

  o a reduction in cylinder pressure when the piston approaches the maximum stroke;

  o a proportional increase in pressure in the case of hydromotors;

  o a proportional increase in pressure when the cylinders enters the load;

  o maintaining a minimum pressure in the stand by position.

The use of electronic control makes it possible to optimize the 2D movements of the bucket making it precisely influencing the quality of the boom, and on the other hand we have a precise drive of the dispensers, resulting in minimizing the amount of pressurized oil reaching the tank.

In Chapter 3 is analyze the performance of the drive components for single-bucket excavators.The direct adjustment of the pump is accomplished by operating the hydraulic cylinder control cylinder pump.
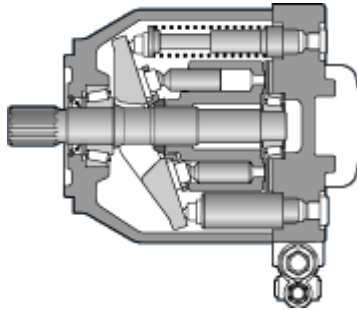
Variable flow pumps having an inclined disk are most suited to using the pressure control with the help of a single microcomputer. For these pumps a hydraulic compensator can also be used on the basis of the pressure differential ΔP given by a variable section orifice, this method being most suitable for mechanical adjustment (manual or mechanical devices)
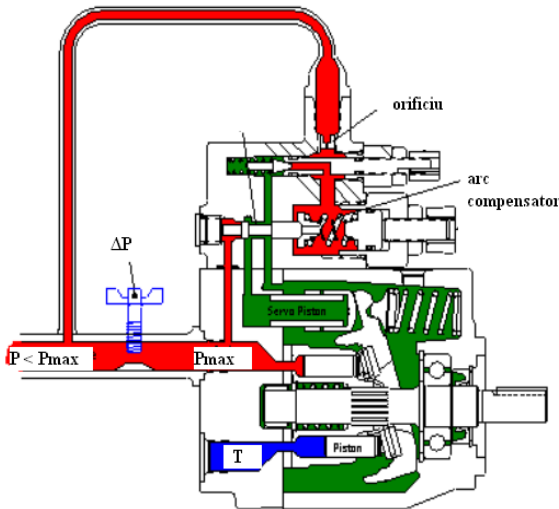
Adjusting the movement of the speed of the cylinders is usually done with a discharge valve which aims to discharge a quantity of fluid into the tank, thus reducing the flow flowing into the cylinder. This method is most used when using microcomputers on the excavator.
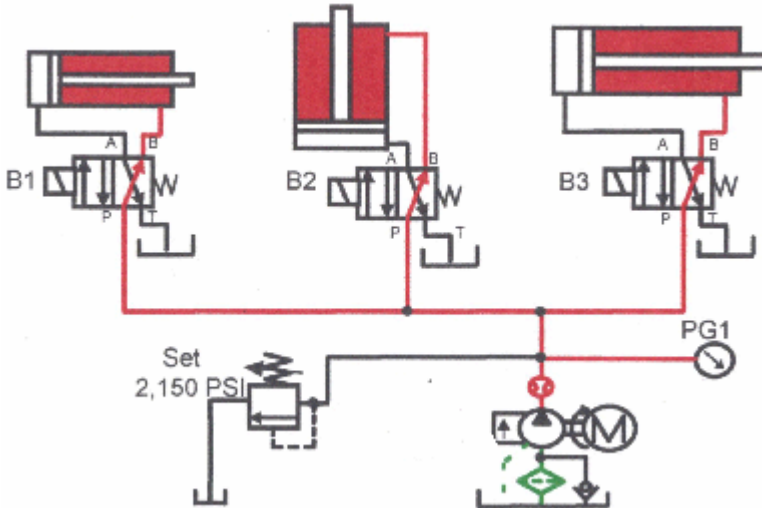
Another method is to connect E.C.U. (Electronic Control Unit) of thermal motors with controller.For mechanically adjusting the movement of the cylinder, an electrically driven discharge valve is required,


and at the end of the stroke a race limiter is used that overrides the inflation of the valve coil with the consequence of the fluid spilling into the tank. The place where the cylinder stops depends on several parameters that can´t be controlled by the most important user being the force of inertia of the actuator.
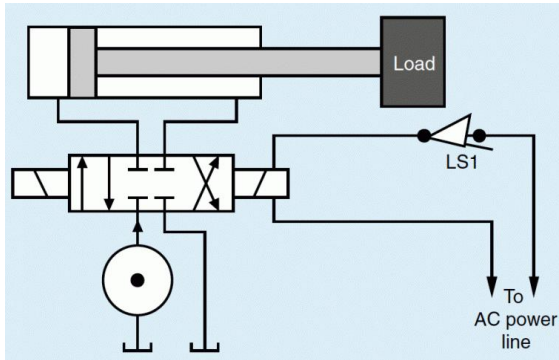
The electronic pressure control uses a pressure sensor mounted at the end of the cylinder.

The analog signal from the sensor is inserted into a chip that converts it into a digital signal taken over by the controller. The latter outputs a pulse signal based on a transistor that transmits 12 V continuous current into a signal identical to the microcomputer.
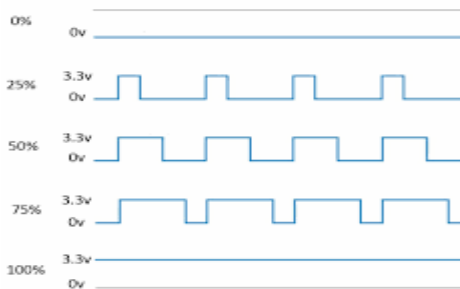
The 12-volt pulse signal goes into the coil that drives the pump cylinder's drive roller distributor, so this system does not heat the coil.
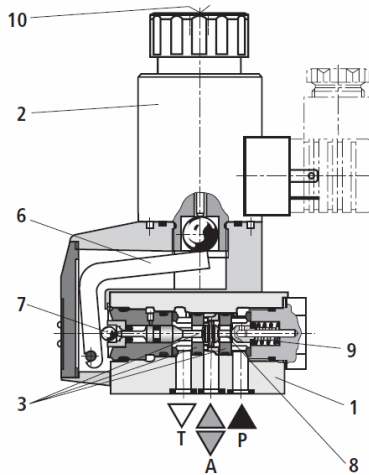

For setting the cylinder movement, use a *Temposonic Magnetostrictive, Absolute, Non-Contact Linear-Position Sensors* which is mounted directly on the cylinder


In this case, the cylinder dispenser is also the one that has the role of regulating its movement, both in terms of its travel speed and its stopping at a certain position. For this operation, the board has the ability to change the frequency of the signal so that the distributor plunger can be placed anywhere in the race

by pulling more and giving less the hole through which the fluid comes from the pump.
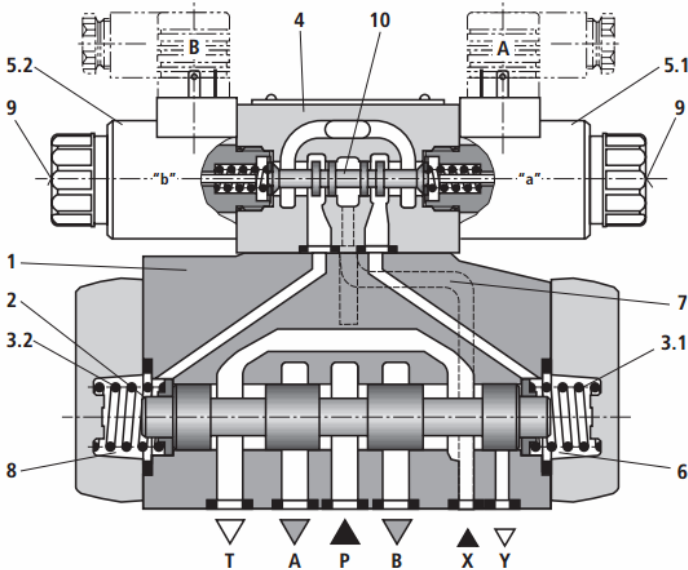
example of modifying the pulse signal 10 μs and 15 μs.
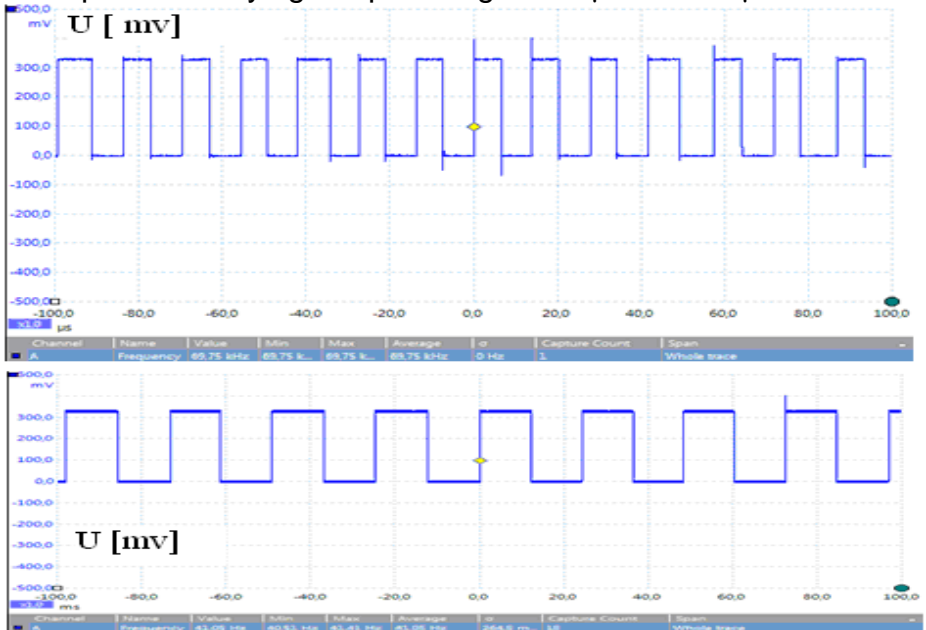
In chapter 4 is analyzed. real-time kinematic behavior of excavators with a cup in the work process using a kinematic study as well as a numerical simulation.For the kinematic study, the simplified computation scheme is presented, as shown in the figure below.
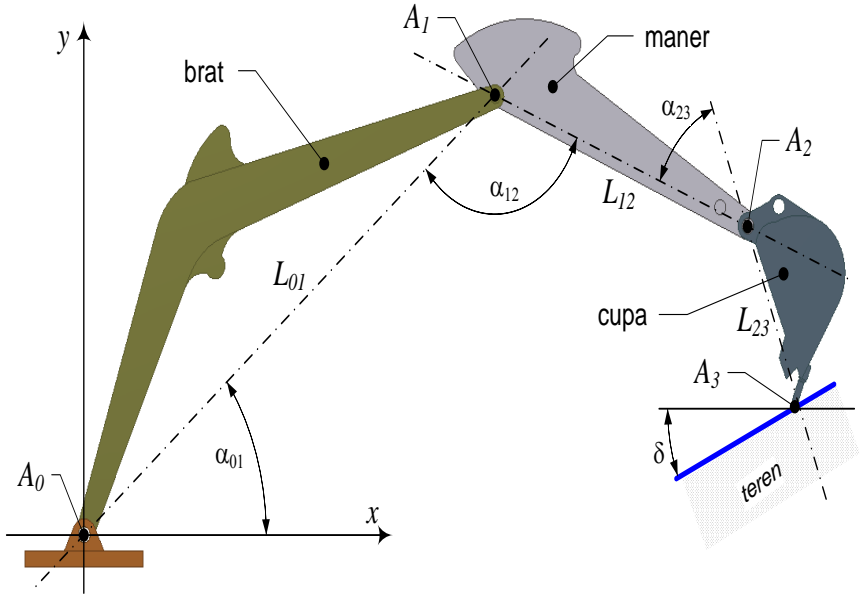
Evaluate the trajectory of the bucket according to its structural parameters (L_{01}, L_{12}, L_{23}) and functional ones (x $_{A3}$ and y $_{A3}$), base in the coordinate system xOy, is done in accordance with the schematic of Fig. 4.3. Under these circumstances, the vertical coordinates of the cutting edge of the workpiece (bucket) are given by the following expressions:

$$\begin{cases} x_{A3} = L_{01}\cos\alpha_{01} + L_{12}\cos(\pi - \alpha_{12} - \alpha_{01}) + L_{23}\cos(\pi - \alpha_{12} - \alpha_{01} + \alpha_{23}) \\ y_{A3} = L_{01}\sin\alpha_{01} - L_{12}\cos(\pi - \alpha_{12} - \alpha_{01}) - L_{23}\cos(\pi - \alpha_{12} - \alpha_{01} + \alpha_{23}) \end{cases}$$

in which the dependence between the three angular displacements is given by the relation:

$$\alpha_{23} = \alpha_{01} + \alpha_{12} - \frac{\pi}{2} - \delta,$$

where *δ* is the angle of inclination of the required excavation profile with respect to the horizontal axis.

Angular displacement α_{12} gets the following expression:

$$\alpha_{12} = \pi - \alpha_{01} + \delta - \arcsin\left(\frac{\xi \cos\delta}{L_{12}}\right),$$

where the parameter ξ has the following form :

$$\xi = L_{01}\sin\alpha_{01} - L_{23}\cos\delta - b - (L_{01}\cos\alpha_{01} + L_{23}\sin\delta - a)\tan\delta,$$

the parameters (a, b) being the coordinates in the vertical plane of a point belonging to the straight support of the imposed trajectory.

Changing the functional parameters according to the initial requirement of a trajectory imposed to the work organ can be achieved by virtually operating each piece of equipment (arm, handle, cup). For this, it is necessary to evaluate the relationship between the functional parameters (α_{01}, α_{12}, α_{23}) and the control parameters (the actual instantaneous lengths of each hydraulic drive cylinder – L_{cyl1}, L_{cyl2}, L_{cyl3}).
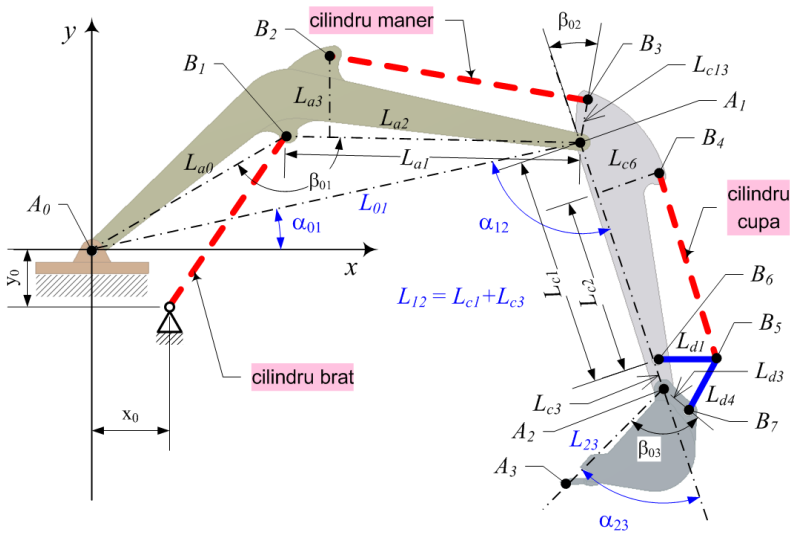
Taking into account the structural and functional geometric parameters, indicate on the model in Figure 4.8 and using the following notations necessary to simplify the final expression formulation

$$a^2 = y_0^2 + x_0^2 ,$$

$$b^2 = L_{a3}^2 + L_{a2}^2 ,$$

$$c^2 = L_{c3}^2 + L_{c4}^2 + L_{d3}^2 - 2L_{d3}\sqrt{L_{c3}^2 + L_{c4}^2} \cos\left[\pi - \beta_{03} + \alpha_{23} - \arctan\left(\frac{L_{c4}}{L_{c3}}\right)\right]$$

results in the instantaneous total length expressions of each hydraulic actuator cylinder according to the parameters considered

$$L_{cyl1}^2 = L_{a0}^2 + a^2 - 2L_{a0}a \cos\left[\arctan\left(\frac{y_0}{x_0}\right) + \arccos\left(\frac{L_{01}^2 + L_{a0}^2 - L_{a1}^2}{2L_{01}L_{a0}}\right) + \alpha_{01}\right]$$

$$L_{cyl2}^2 = L_{c13}^2 + b^2 - 2L_{c13}b \cos\left[\beta_{01} + \beta_{02} - \alpha_{12} + \arccos\left(\frac{L_{01}^2 + L_{a0}^2 - L_{a1}^2}{2L_{01}L_{a0}}\right) - \arctan\left(\frac{L_{a3}}{L_{a2}}\right)\right]$$

$$L_{cyB}^2 = L_{c2}^2 + \left(L_{c6} - L_{c4}\right)^2 + L_{d1}^2 - 2L_{d1}\sqrt{L_{c2}^2 + \left(L_{c6} - L_{c4}\right)^2} \ldots$$

$$\cos\left[\frac{3\pi}{2} - \arctan\left(\frac{L_{c6} - L_{c4}}{L_{c2}}\right) - \arctan\left(\frac{L_{c3}}{L_{c4}}\right) - \arccos\left(\frac{L_{c3}^2 + L_{c4}^2 + c^2 - L_{d3}^2}{2c \sqrt{L_{c3}^2 + L_{c4}^2}}\right) - \arccos\left(\frac{L_{d1}^2 + c^2 - L_{d4}^2}{2L_{d1}c}\right)\right]$$

This set of correlations, which ultimately has to make the functional link between the command signal and the evolution of the parameters at the work organ, requires the implementation of an automatic system that ensures the necessary precision at the working organ. It is obvious that there are two possibilities for obtaining a precision dig:
- realization and implementation of a computer simulator for analyzing the dynamics of a excavating equipment with a bucket during excavation on a trajectory imposed by a computer application
- inserting into the memory of the board the minimum and maximum angles for the arm handle and bucket by commanding

15

the digging
Chapter 5, the physical and numerical modeling of the drive performance was presented starting from the identification, taking over and implementation of an operational scheme for the hydrostatic hydraulic system with linear motor - hydraulic cylinder.
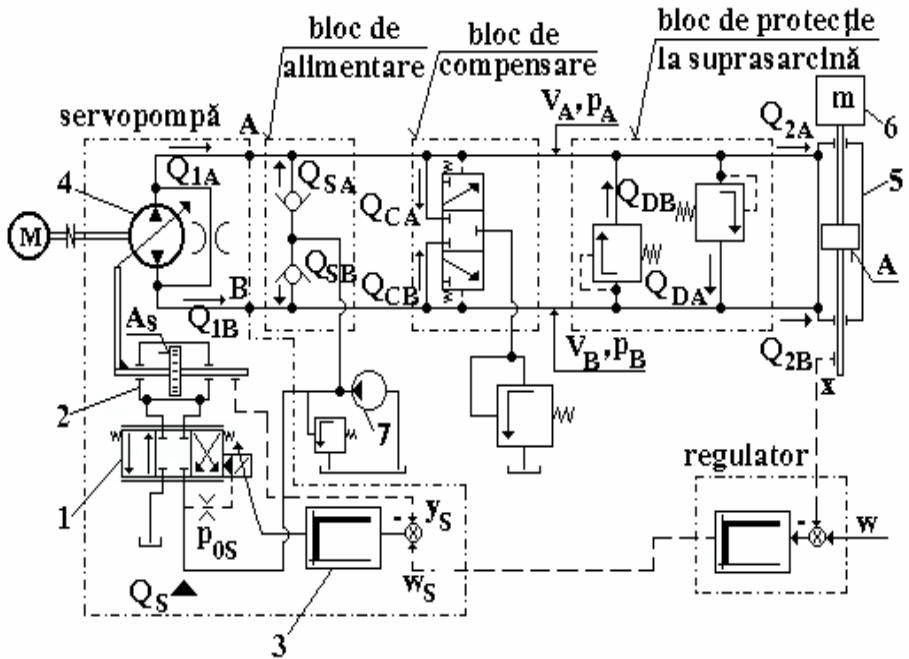
This scheme consists of the following functional groups, namely:

- pump cylinder control system, consisting of proportional distributor with electric proportional command (1), pump block positioning cylinder (2), proportional position (P) - position regulator (3);

- the actuator drive, consisting of the variable-displacement pump (4), the actuator cylinder, the double action (5), the mass load (6);

- *electronic control system,* including electronic circuits for electronic information processing.

The block diagram of the control and control system is the following:
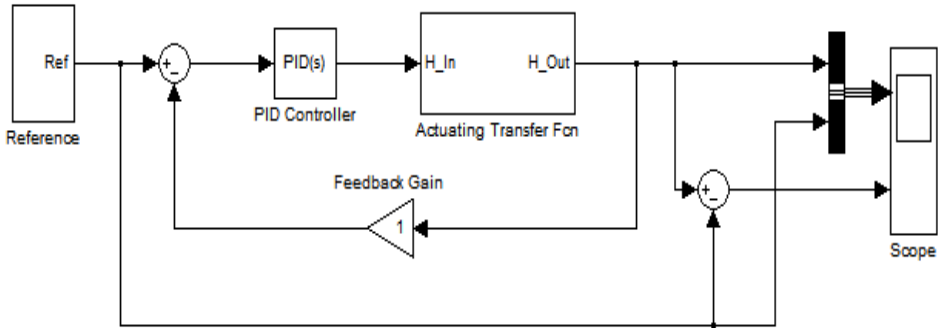
As a result of the numerical simulation, it was observed that the dynamic regime is characterized by a set of high frequencies and reduced amplitudes, which corresponds generally to the experimental observations, the maximum values for the positioning of the actuating cylinders are 0.016 m for the arm cylinder, 0.020 m for the handle cylinder and 0.004 m respectively for the bucket cylinder , which at respective cylinder lengths of about 1.2 m means a race error of approximately 1.7%;

Developments characterized by an intense dynamic regime are specific to the rapid change in the automated system so that this highlights the need to adapt the characteristic parameters of the control and control system to the whole hydraulic and mechanical drive, automatic regulator with permanent auto-adjustment of the parameters to the actual conditions imposed by the working regime.

The dynamic behavior of the bucket, although characterized by minimal amplitudes, has an evolution in the upper frequency range, while the arm and the handle have considerably higher amplitudes, but the oscillation frequencies are lower. It is also noticed that both the arm and the handle have a positive displacement dynamic over the reference signal - on the respective diagrams of the positioning errors one observes a

deviation from the null line, while the cup oscillates around the reference.

In Chapter 6, the sculpture was presented after a certain profile with a helper controller. The facility that this system provides is that all three movable elements can move simultaneously or consecutively to get a certain position.
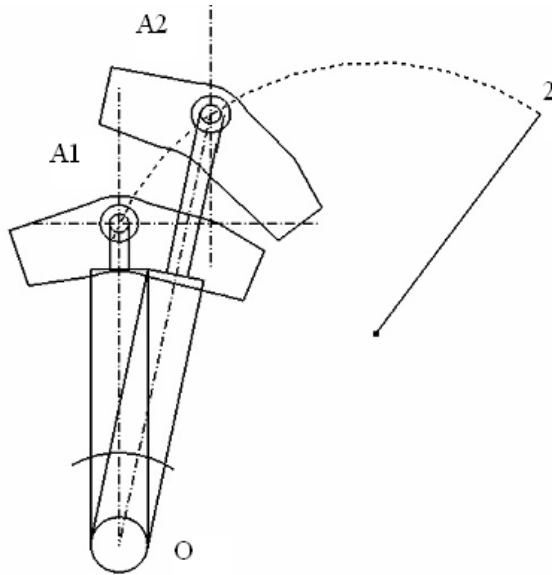
The sensors in the cylinder will transmit the position of the A point 500 times per second and the number of the digital analogue device in the board will reach a number. This number per cylinder is corrected by a particular formula displaying on a display the size with which the piston has moved. In the controller memory there is a maximum and minimum value of this dimension inserted in the controller profile. Here is the assist function so that the size of the cylinder does not change regardless of the machine's will on the machine. The values in memory are those from the numerical simulation in the previous chapter. Similarly in the memory are the minimum dimensions

and the maximum between which the cylinder that moves the handle and the bucket can move.

A1

β

A

O1

α
unghiul de
inclinare a
cilindrului
bratului

α

O

B

O2

C

θ

C

B1

O2

O1
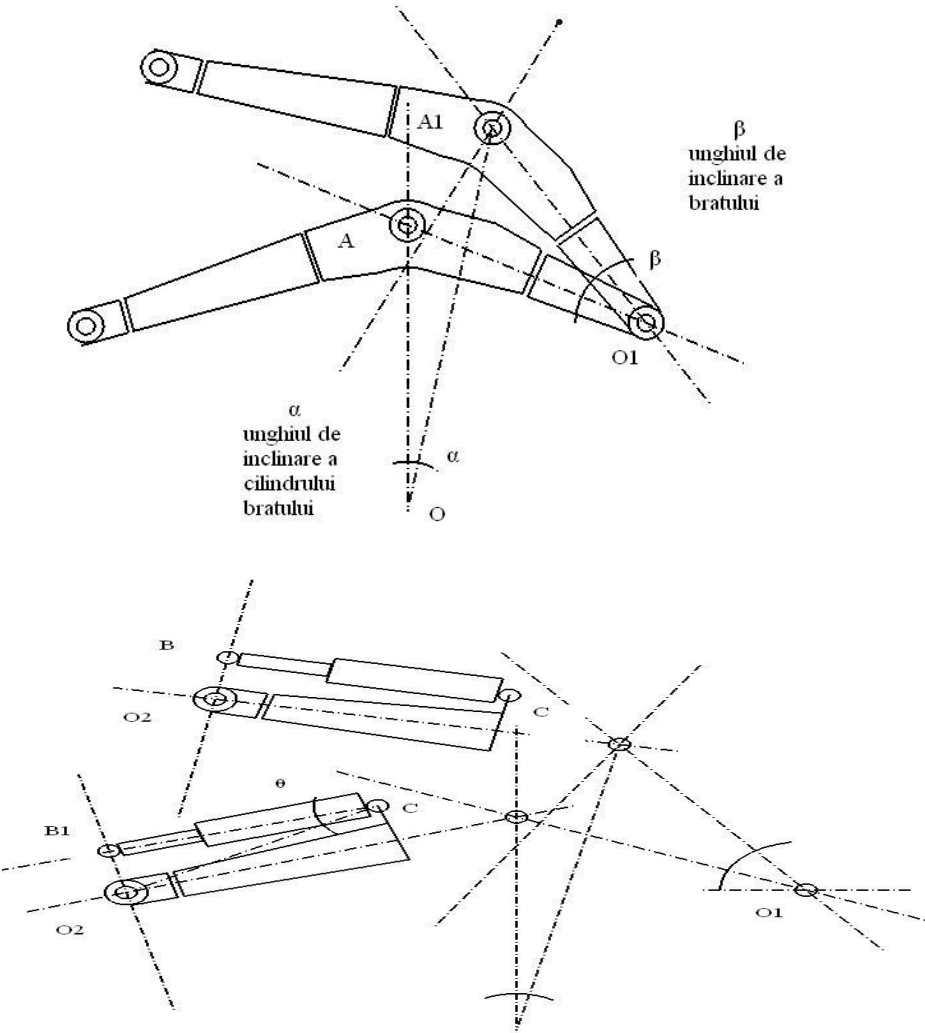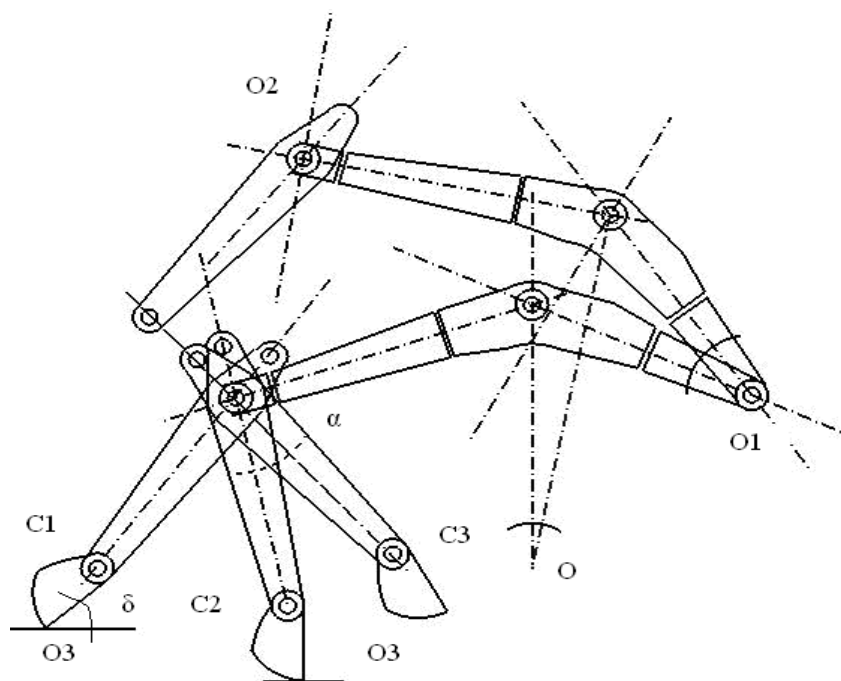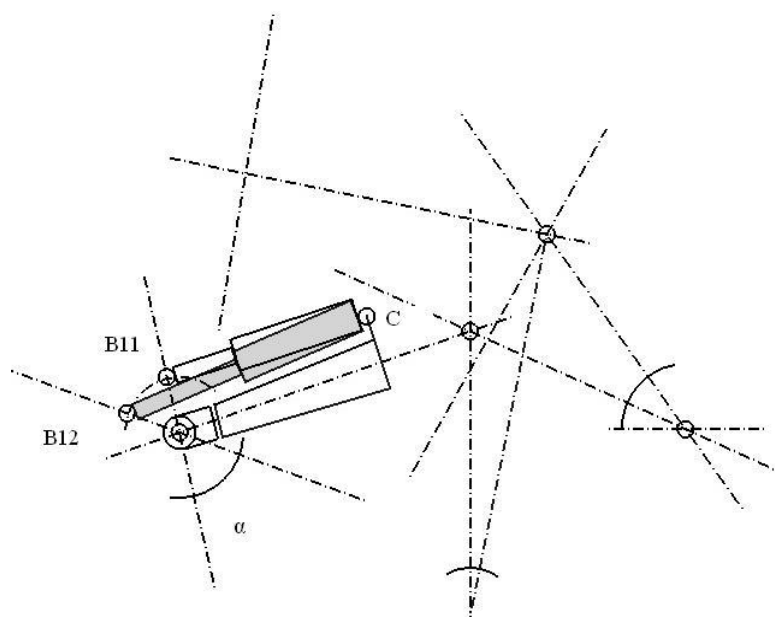
The main conclusions that can be synthesized are as follows:

a) actions affecting the behavior of the machine during operation may be controlled by at least 500 cycles per second;

b) the machine drive system offers the possibility of using energy as much as necessary to perform the work tasks;

c) the use of various dynamic regimes that can be achieved according to the technological stage of work;

d) the use of a universal software to which is added the specific programming for the drawing diagrams;

e) establishing the correlation of monitoring functions for various dynamic regimes and energy parameters of the machine.