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# Applications of the Electrohydraulic Servomechanisms in Management of Water Resources

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## 1. Introduction

Water and energy are key component of almost all human activities. Water supply is vital to feeding the growing world population, to production of natural systems on which life on earth relies. In the context of material goods which cause rising of living standards and to maintaining the integrity of **world water crisis**, more and more governments have begun to develop new policies for future, aiming at rationalization and efficiency of water consumption.

Maximum reduction of waste and undue loss of water is an important objective in the management of water resources. In this sense any valuable technical solution that helps achieve these goals, especially at the large water consumers, deserves to be implemented. To illustrate this, we propose the use of the automated land leveling systems, tracing a laser reference plane, as a method of reducing water losses in two activity areas: crop irrigation and construction of earth dams in hydropower stations. In the last decade, these works are performed with leveling machines equipped with laser modular systems manufactured by companies like TOPCON from Japan or APACHE and SPECTRA PRECISION from USA.

In the first kind of activity, the solution ensures equal conditions, in terms of water consumption, for all plants on agricultural land, watered by natural way - rainfalls, or artificially - by irrigation systems. This solution prevents areas of "pools" of water on agricultural land, and providing deviations from the reference plane of max.  $\pm 2$  cm by only 2 passes of the leveling machine (rough, and smoothing leveling) eliminates soil loosening works, which are necessary after conventional leveling.

In the second case, the method ensures optimal thickness, depending on the type of compression equipment, of the earth layers deposited when constructing dam body, with maximum deviations of  $\pm 2$  cm over the entire surface of the deposited layer. This type of smoothing performed before the compaction of each layer of soil deposited in the dam body, ensures a uniform degree of compaction of the dam, fig.1. Homogeneity of dam compaction is a measure for reducing seepage through the dam and pronounced settlements of the top, causing possible overflowing of water above the top of the dam, fig.2. Laser modulation systems are not included in the standard facilities, not even in the latest modern leveling machines, fig.3. They can be installed on any hydraulically actuated

leveling machine, regardless of its wear or origin. The laser modular system includes a laser emission module, a laser receiver module, an electronic block and an electro hydraulic servo system (distribution block). Starting in 2008, the mounting on leveling equipment and the service of TOPCON laser modular equipment is performed in Europe by the representatives of Geodis Brno, Geodis Slovakia, Geodis Geodis Ro and Geodis Austria. These distributors are companies that get the laser and electronic modules from TOPCON, and the electro-hydraulic components from different suppliers.

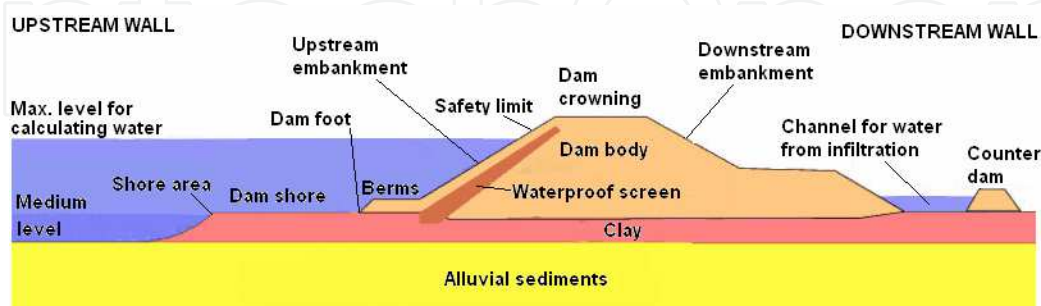


Fig. 1. Main section through an earth dam



Fig. 2. Example of water flood over a dam January the 1<sup>st</sup> 2006 Sherman Island



Fig. 3. Laser controlled electro hydraulic leveling machine (courtesy New Holland)

The wide diversity of the fluid power systems used on leveling machinery, supplied by various manufacturers, and with different degree of wear, represents factors that leads to extension of mounting period of a modular laser system type TOPCON on a leveling machine.

This chapter presents the structure, performance, and the optimal synthesis by numerical simulation of a testing bench designed for TOPCON laser modular systems, which reproduce the operating conditions of the systems set up on the real leveling machines. The device was developed by the aid of a numerical simulation model built in AMESim, is an electro hydraulic servomechanism of position control with feedback by laser. This servomechanism contains two internal control loops for position control: the first loop appears at the level of a servomechanism that simulates the profile of uneven soil, and the

second control loop appears at the level of a tracing servomechanism with laser reference. Dynamic performance obtained by numerical simulation and experimental identification of a TOPCON laser modular system, are in good agreement with those obtained by comparative testing of the same system mounted on a motor grader, in actual operation (Popescu et al., 2008, 2009).

The testing bench developed by INOE 2000-IHP Bucharest, allows the laboratory tuning always needed to be made in order to fit the parameters of laser modular system with the parameters of machine on which are to be mounted. If some malfunction occurs in operation of the machine equipped with a laser modular system, using the testing device one can detect which component of the system no longer provides the functional parameters (laser emitter, laser receiver, electrohydraulic block or electronic block).

## 2. Laser modular systems made for equipping the ground leveling installations

The leveling technology which uses laser, fig.4, implies a leveling performed by a complex installation, equipped with laser controlled modular system, which is able to perform work from 2 passes, a rough leveling and a fine one at finish, with deviations from the reference plane of max. 2,5 cm on the entire leveled surface with a significant reduction of the tracking, transposition and materialization process during the leveling work.

The modular mechatronic system with laser, electronic and electrohydraulic components, which allows reaching this leveling technology may be mounted on any land leveling equipment whose work bodies, scoops or blades are hydraulically powered. It is conceived as an additional option of the land leveling equipment, which offers to it the possibility of leveling land automatically, without any human error occurrence in what regards precision.

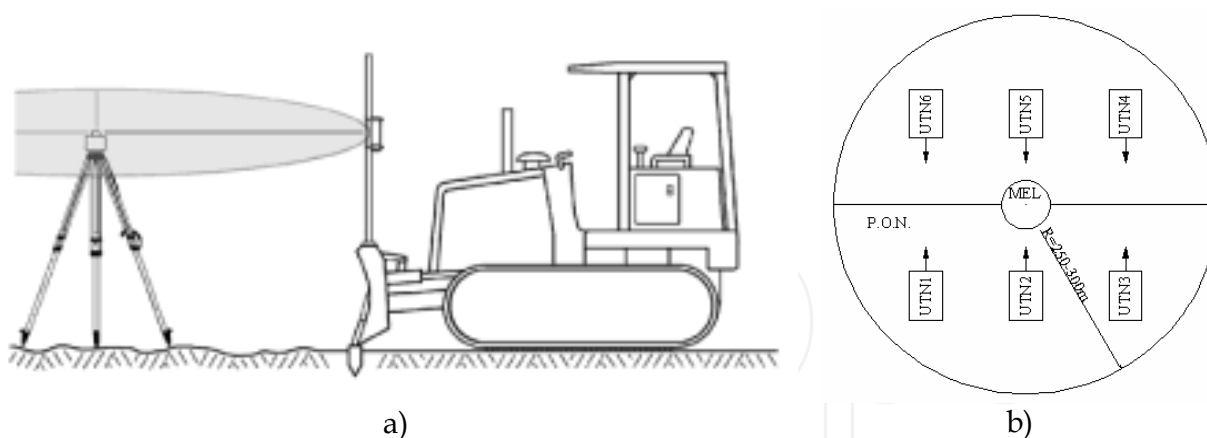


Fig. 4. The laser leveling technology: a) mounting the laser modules transmitter and receiver; b) automatic leveling after an optical leveling plan PON performed simultaneously by 6 land leveling equipments UTN

In the classic acceptance land leveling controlled by laser systems implies a modular system with the following structure.

- The laser transmitter** placed in the center of the surface to be leveled above a point with a known quote mark, on a tripod which may be adjusted vertically, emitting a laser beam in its rotation movement. This generates the laser reference plane or the optical refence plane (with programming options for the longitudinal and transversal slope in

- the forward direction) which the work body of the equipment will follow during leveling. After setting the slope needed at leveling, the laser transmitter positions itself automatically.
- The laser receiver**, whose support is connected to the work body of the land leveling equipment, intercepts the laser fascicle generated by the laser transmitter and sends altimetric information, namely the position of the work body accountable to the laser reference plane, to an electronic control and monitoring module, placed in the cabin of the land leveling equipment.
  - The electronic monitoring and control module** which connects and amplifies the laser information received, compares it with a prescribed dimension specific for the leveling quote value, finds the error and emits a prompt for cancelling error, towards an electrohydraulic drive system.
  - The electrohydraulic system** controlled by the electronic module has the role of driving the hydraulic cylinders of the blade for maintaining the work body in the leveling plane set by the leveling project, plane which is parallel with the laser reference plane. In fig.5. are presented two types of land leveling machines equipped with modular systems.

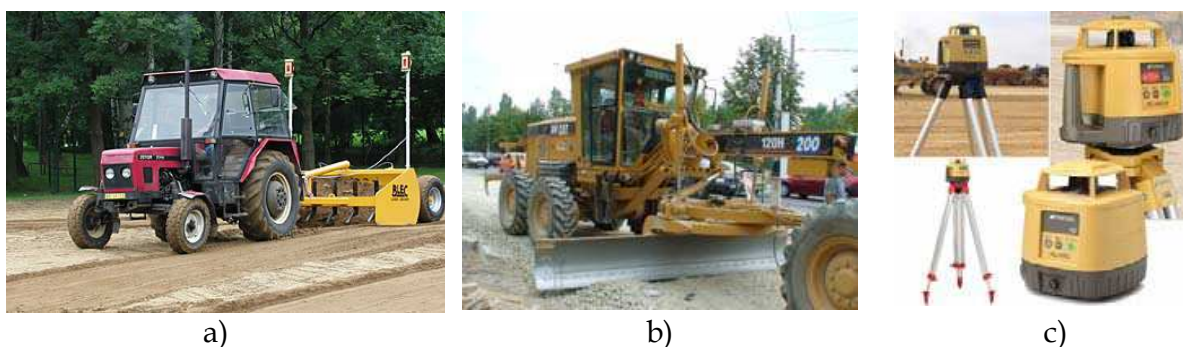


Fig. 5. Leveller (a) and autograder (b) equipped with laser controlled modular systems (c)

### 3. Simulating the real operational conditions of the laser module by an original test bench

In fig.6-a is shown the laboratory test bench which simulates the real behavior of the TOPCON laser controlled modular system purposefully created for equipping the automatic land leveling machines in horizontal plane (Popescu et al., 2008). Fig.6-b shows the mode of equalization of the device with the simulation model from AMESim.

On the rod of the upper hydraulic cylinder is fixed the laser receiver which may move by the action of the upper cylinder or of the bottom cylinder or of both.

The device for testing the laser controlled equipment includes 2 electro hydraulic servomechanisms that simulate the real behavior of the upward downward hydraulic cylinders of the blade of the land leveling machine, and the second - the profile of the land to be levelled.

The first servomechanism contains a hydraulic cylinder similar with that mounted on the machine, supplied from the hydraulic delivery block TOPCON depending on the level of detection of the laser reference plane, generated by a rotary laser transmitter TOPCON.

The second servomechanism consists of a hydraulic servocylinder controlled by a proportional valve with integrated electronics, by means of a data acquisition board, a PC and the data acquisition software TEST POINT produced by Capital Corporation from USA.



The TOPCON electronic block receives electric signal from the laser receiver, placed on the rod of the upper cylinder of the device. The signal size varies depending on the level of detection of the optical reference plane, generated by the rotary laser transmitter; the input sent to the proportional valve of the TOPCON hydraulic kit is proportional with the detection level. According to this prompt the rod of the bottom cylinder pulls or pushes the body of the upper cylinder in reverse direction to that of displacement of the cylinder rod.

The upper cylinder is controlled in close loop by means of a servocontroller; a signal generator simulates various profiles for the uneven land. The two inductive transducers of linear displacement of the cylinders are connected by means of a data acquisition board to a PC using TEST POINT DAS.

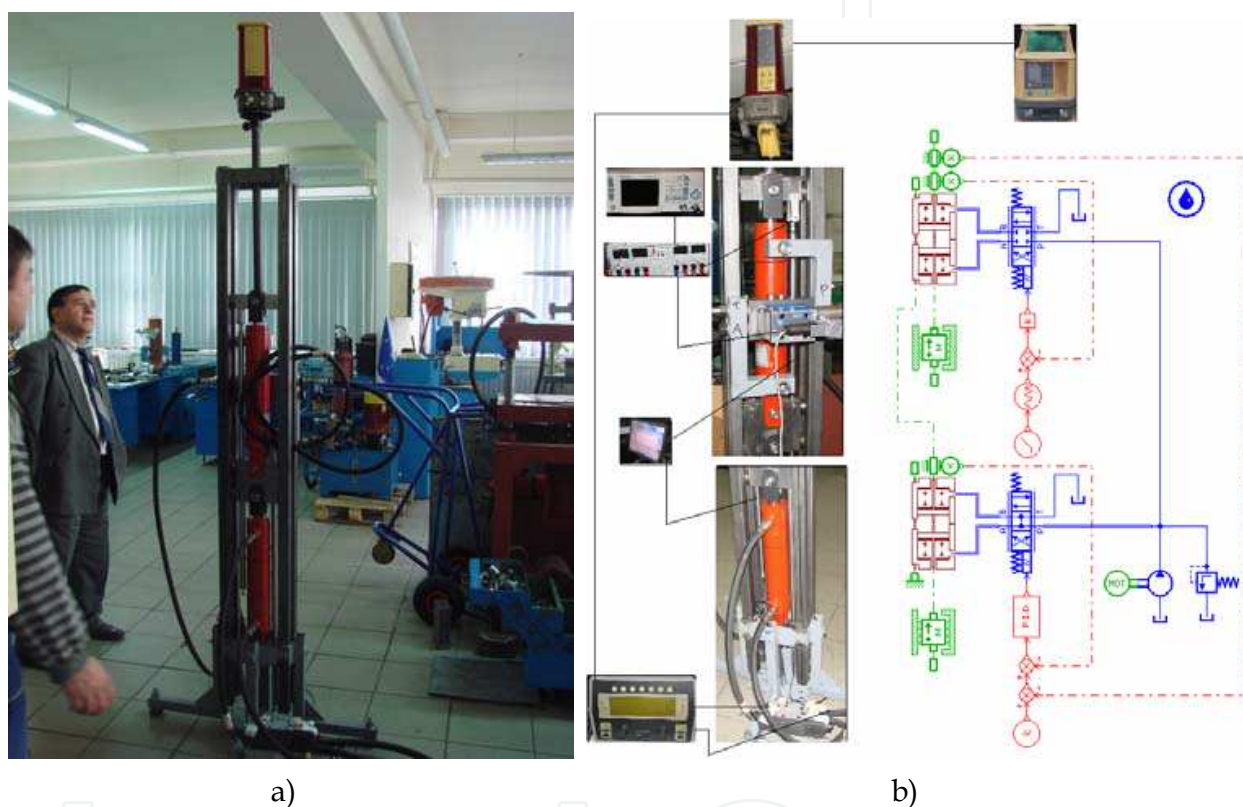


Fig. 6. Test bench for testing the TOPCON laser controlled modular system: a) general overview; b) the test bench versus AMESIM simulation model

#### 4. Basic mathematical model of the test bench components

A deep understanding of the upper physical performance needs at least a mathematical modeling and simulation of an electro hydraulic servomechanism.

The simplest nonlinear realistic mathematical model of such a system contains the following equations (Vasiliu & Vasiliu, 2005):

- a. The steady-state characteristics of the servovalve main stage (four way, critical centre, spool valve):

$$Q_{sv}(x, p) = c_d A(x) \sqrt{\frac{p_s - P}{\rho}} \quad (1)$$

Here  $x$  is the spool displacement from the neutral position;  $P$  - pressure difference between the ports of the hydraulic cylinder;  $A(x)$  - metering ports surface;  $c_d$  - discharge coefficient of the metering ports;  $p_s$  - supply pressure (a constant). The above relation can be written in the form

$$Q_{SV}(x, P) = c_d \pi d_s x \sqrt{p_s / \rho} \sqrt{1 - P / p_s} = K_{Qx} x \sqrt{1 - P / p_s} \quad (2)$$

where

$$K_{Qx} = c_d \pi d_s \sqrt{p_s / \rho} \quad (3)$$

is the "flow valve gain".

- b. The spool motion equation. The servovalves manufacturers specify for each device the transfer functions adequate to slow, normal and high-speed control process. For slow control process, the servovalve can be regarded as a proportional device, having a single constant - the displacement-current (voltage) gain:

$$K_{xi} = \left. \frac{\partial x}{\partial i} \right|_{x=0} \quad (4)$$

Hence the spool motion follows the input current,  $i$  without any lag:

$$x = K_{xi} i \quad (5)$$

For normal control process, a servovalve can be regarded as a first order lag device:

$$\frac{x(s)}{i(s)} = \frac{K_{xi}}{T_{SV}s + 1} \quad (6)$$

The corresponding differential equation is:

$$T_{SV} \frac{dx}{dt} + x = K_{xi} i(t) \quad (7)$$

Here  $T_{SV}$  is the servovalve time constant. For high speed control process, we have to consider the servovalve as a second order lag device:

$$\frac{x(s)}{i(s)} = \frac{K_{xi}}{(s / \omega_n)^2 + 2s\zeta / \omega_n + 1} \quad (8)$$

where  $\omega_n$  is the natural frequency and  $\zeta$  - damping coefficient.

- c. The position transducer equation. The modern inductive position transducers together with their amplifiers behave as first order lag devices; they have a very small time constant, which can be neglected for industrial electro hydraulic control process:

$$U_T = K_T y \quad (9)$$

where  $K_T$  is the transducer constant, and  $y$  - piston displacement from the null position.

- d. The error compensator equation. This stage computes the following error,  $\varepsilon$  as a difference between the input signal,  $U_i$  and the position transducer output,  $U_T$ , and applies the PID control algorithm to find the solenoid control voltage,  $U_c$ :

$$U_c(s) = \varepsilon(s)K_P[1 + 1/(sT_i) + sT_d/(\tau s + 1)] \quad (10)$$

- e. The servocontroller current generator equation. The current generator of the servocontroller is so fast than it can be regarded as a proportional device:

$$i = K_i U_c \quad (11)$$

where  $K_i$  [A/V] is the "medium" conversion factor.

- f. The continuity equation. This equation offers the connection between the servovalve flow and the derivative of the pressure drop across the hydraulic cylinder:

$$Q_{SV} = A_p \dot{y} + K_l P + \frac{A_p^2}{R_h} \dot{P} \quad (12)$$

where  $A_p$  is the piston area;  $K_l$  - leakage coefficient between the motor chambers;  $R_h$  - hydraulic stiffness of the motor:

$$R_h = 2 \frac{\varepsilon_e}{V_t} A_p^2 \quad (13)$$

Here  $\varepsilon_e$  is the equivalent bulk modulus of the oil and  $V_t$  - the total volume of the oil from the hydraulic motor and the connections.

- g. The piston motion equation. The pressure force  $F_p$  has to cover the load force, usually modelled by a spring force  $F_e$ , the inertia of all the moving parts,  $m_e$  and the friction force,  $F_f$  with different components:

$$m_e \ddot{y} = F_p - F_e - F_f \quad (14)$$

where

$$F_p = A_p P \quad (15)$$

$$F_e = 2(K_{e1} + K_{e2})(y + y_{0e1}) = 2K_e(y + y_{0e}) \quad (16)$$

The friction force has mainly a static component,  $F_{fs}$  and a viscous one,  $F_{fv}$ :

$$F_{fs} = F_{fs0} \text{sign } \dot{y} \quad (17)$$

$$F_{fv} = K_{fv} \dot{y} \quad (18)$$

The main non-linearity in the above mathematical modeling is included in the servovalve main stage. A linear solution can be obtained using a linear form of the steady-state characteristics of the servovalve main stage,

$$Q_{SV} = K_{Qx} x - K_{QP} P \quad (19)$$



The results supplied by the linear model are useful for estimating the stability only. For high amplitude input signals the designer has to use the numerical simulation. Some simulation languages are widely used for practical purposes. Two of them are available for any engineering activity: SIMULINK (The Math Works Inc., 2007) and AMESIM (LMS Imagine, 2009). The „building“ of a simulation network in SIMULINK needs a lot of work for using general purpose „icons“, but the toolboxes devoted to systems synthesis are very effective. The fig. 7 contains the simulation network of the above electro hydraulic servomechanism.

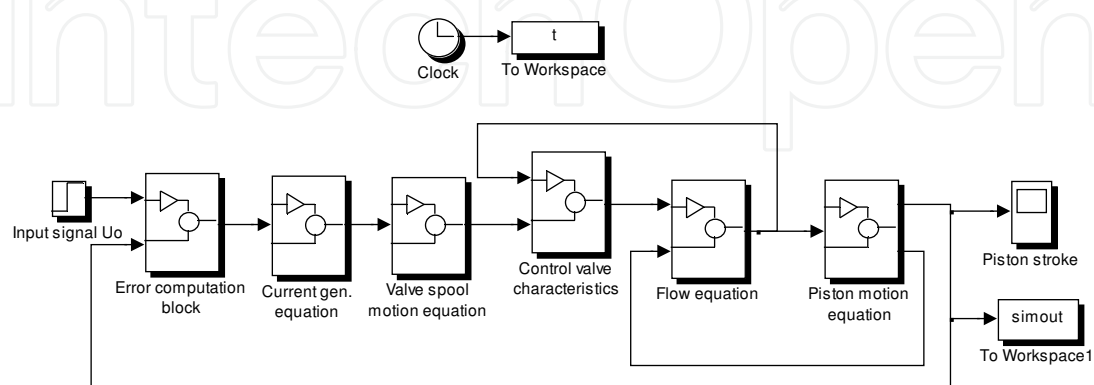


Fig. 7. Simulation network of an electro hydraulic servomechanism in SIMULINK

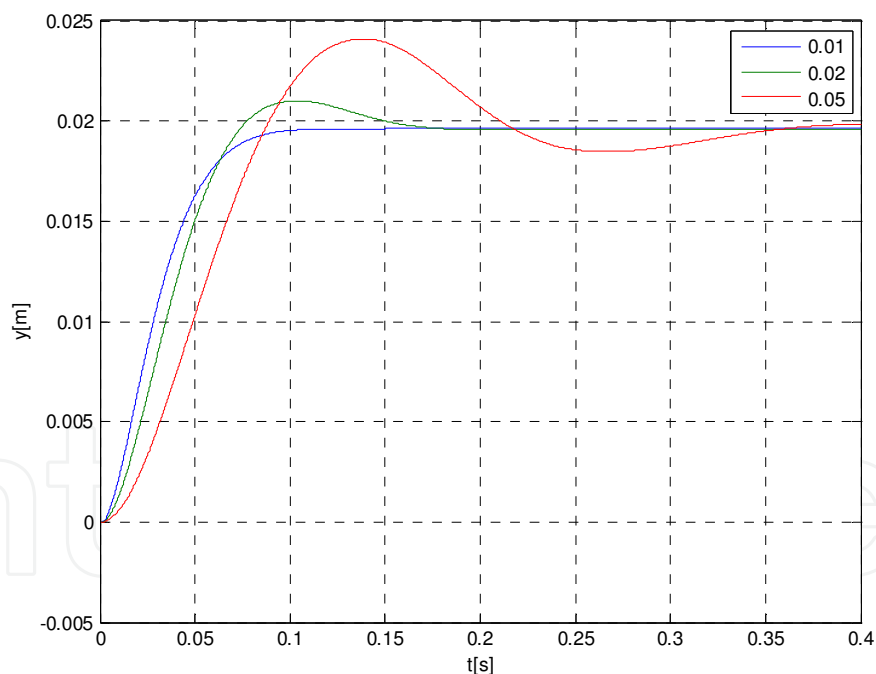


Fig. 8. Small input step response of an electro hydraulic servomechanism simulated by SIMULINK for three values of  $T_{SV}$ : 0.01 s, 0.02 s, and 0.05 s

Figure 8 presents the response of the servomechanism for small step inputs, and three values of the servovalve time constant,  $T_{SV}$ . Using a high speed servovalve one can obtain an overall small time constant of about 0.045 s. The increase of the servovalve time constant spoils the system dynamic performance and can generate steady state oscillations. A long series of experiments were performed by (Calinoiu, Vasiliu & Vasiliu, 1998) in order to find

the difference between the theoretical dynamic behaviour and the real one for a servomechanism using a Bosch NG10 direct drive servovalve (DDV). There is a good agreement between the simulated and measured results, the time constant having practically the same value for both cases. The Bode diagram (fig. 9) shows a good dynamics even for a high spring load. On the same diagram the transfer function identified by IDENTIFICATION TOOLBOX from MATLAB is specified. The computed transfer function and the measured one are nearly the same.

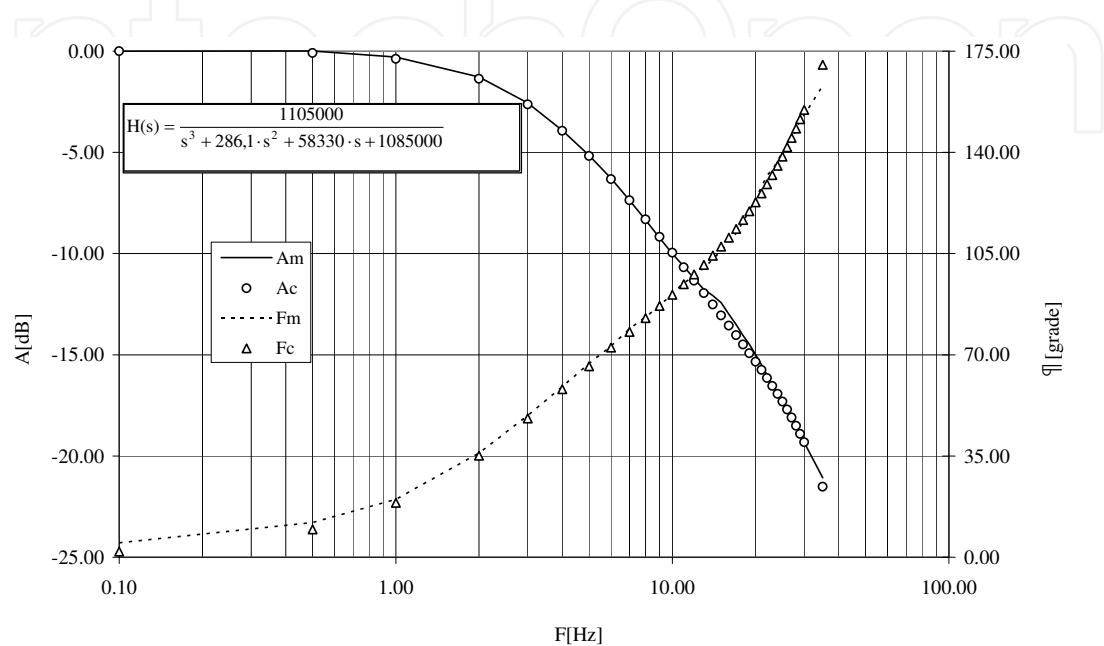


Fig. 9. Bode diagram of an electro hydraulic servomechanism (identification by MATLAB)

The simulation model of the test bench can be assembled by two SIMULINK models as in fig. 7, but the capabilities of AMESIM are very useful for the quick design and optimization.

5. AMESIM design facilities

5.1 Overview

Many different modeling and simulation software packages were created to perform studies in the fields of automobile, aerospace, robotics, offshore and general hydraulics engineering but none offered the full range of capabilities needed. There were deficiencies in the numerical capabilities, in the graphical interface and in the general modeling concept. The AMESim package was developed to overcome these limitations by Michel Lebrun and Claude Richards from Societe Imagine (FRANCE), starting from 1988. This section gives a description of the technical features, which were central objectives in the design of the software, and some examples of typical applications.

The main aim of the AMESim is “To create Good Models without Writing a Single Line of Code” (Lebrun & Richards, 1997). An important prerequisite of the basic element library is the creation of extremely well tested, reliable and reusable submodels that a user can employ with complete confidence (LMS IMAGINE SA, 2009). The writer of the basic element library must be competent in all the modeling skills. However, the user of the basic element library is relieved of the need to write code and formulate the mathematics. Understanding of the details of the physics is not needed but decision on assumption is

necessary which imply some knowledge of physics. Understanding of the engineering system and an ability to interpret results is still important. Experience in training design office staff to use of the basic element library suggests that it is learnt very rapidly.

AMESim is using the multiport approach. In the signal port approach of a numerical simulation environment, a single value or an array of values are transferred from one component block to another in a single direction. This is fine when the physical engineering system behaves in the same way such as with a control system. However, problems arise when power is transmitted. This is because modeling of components that transmit power leads to a requirement to exchange information between components in both directions. In order to use a signal port approach in this situation, two connections must be made between the components where physically there is only one. This leads to a great complexity of connections and means that even very simple models involving power transmission appear complex and unnatural. In contrast to the signal port approach, with the multiport approach, a connection between two components allows information to flow in both directions. This makes the system diagram much closer to the physical system.

## 5.2 Numerical performance

The analysis of the steady state and dynamic behavior of an engineering system leads to a mathematical model of the system. This is in the form of algebraic, ordinary differential and partial differential equations. More recently, differentialalgebraic equations are also used to model the system. The role of simulation software is to provide an environment in which this model can be solved efficiently. For models with large numbers of partial differential equations, there are specialist packages such as those for computation fluid dynamics. Such software is used for detailed analysis of individual components of a system. However, it is often necessary to simulate a completely engineering system or a subsystem of it. The concept of the virtual prototype, in which physical prototypes are replaced by mathematical computer models, makes simulation of this type vital. In this case, it is normal to reduce any partial differential equations to ordinary differential equations. This leads to models with either ordinary differential equations (odes) or differential algebraic equations (daes). Many general and specialized simulation software packages are available for solving such systems of equations. Models arising from engineering systems vary greatly in their character. Thus the equations of the model can be: linear, non-linear, numerically stiff i.e. with very small time constants compared with the overall simulation period, oscillatory, continuous, discontinuous. A large variety of numerical integration methods can be employed to solve such problems. Traditionally the user of simulation software is presented with a menu of typically seven methods from which a choice must be made.

## 5.3 Direct access graphical user interface

Many older simulation packages were developed before modern graphical user interfaces were available. The only graphical facilities provided were for producing simple plots of results. The suppliers of these packages have had to introduce new graphical preprocessing facilities to build the system. More modern software has been designed from the start with a full graphical user interface. Whenever possible, icons for components were based on internationally recognized standard symbols. Thus for hydraulic systems icons are based on CETOPS symbols. Where there are no such standardized symbols, icons are constructed which can be instantly recognized by engineers working in the field.

Throughout the simulation, process the system diagram is displayed. Thus for example when parameters are changed for a particular component, the user points at the icon in question and clicks the mouse button. This produces a menu of items that may be changed. Similarly to plot graphs of results, the user points at the component and clicks the mouse button to produce a menu of items associated with the component that may be plotted.

The possibility of quick high level technical developments as ABS, EBS, common rail multipoint injection systems, electro hydraulic automatic transmissions, self tuning hydraulic and pneumatic suspensions, hydraulic power steering, fly-by-wire systems and many others (Mare & Cregut, 2001). Companies like AEROSPATIALE, MATRA, BOSCH, FERRARI, DAIMLER-CRIYSLER, GENERAL MOTORS, etc. are currently using this modeling and simulation software for future developments. Academic training programs are now developed in different countries, for teaching the software in the terminal years (Vasiliu & Vasiliu, 2005), and for applied researches (Vasiliu, et al., 2003).

6. Numerical simulation and experimental identification of the laser controlled modular system by AMESim

6.1 Modelling the test bench

For the numerical simulation of the laser controlled modular system it was used the simulation in AMESim, namely the model shown in fig.10. All the components of the simulation model are based on mathematical models of differential equations, validated by practice and the method of numeric integration of the differential equations is chosen automatically. If the model is not correct or the inner and outer parameters are not properly determined, the program does not work, cause the system of differential equations is incompatible or undetermined.

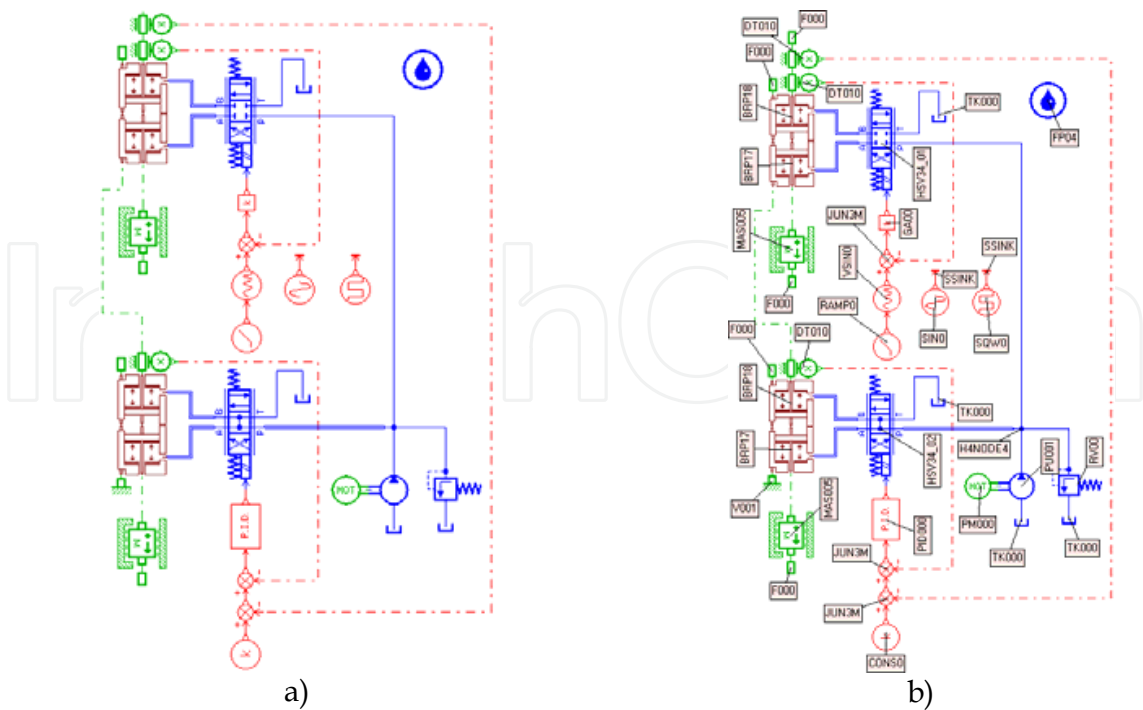


Fig. 10. Model of simulation in AMESim for a TOPCON laser controlled modular system mounted on a testing device: a) simulation model; b) model components

The simulation model represents an electrohydraulic servomechanism for adjusting the position with laser reaction. It includes 2 inner adjustment loops and an outer loop. The first inner loop is set at the level of the hydraulic servomechanism of simulation for uneven land which is excited at entry with rectangular, sinusoidal signals, constant and variable. The second inner loop is set at the level of the servomechanism of monitoring with laser control which is similar to the TOPCON laser controlled modular system. The outer loop of regulation is done between the exit of the first servomechanism and the entry of the second.

## 6.2 Numerical simulation experiments

In fig.11...17 are shown some of the significant numeric simulations. In fig.11 the servomechanism generating profiles of the uneven land receives a rectangular input with an amplitude of 0,14 m and a frequency of 0,05 Hz in a range of 50 s. The red curve 1 represents the displacement of the rod of the generator servocylinder [m], and the green curve 2 represents the rod displacement of the monitoring servocylinder rod and the body of the generator servocylinder [m].

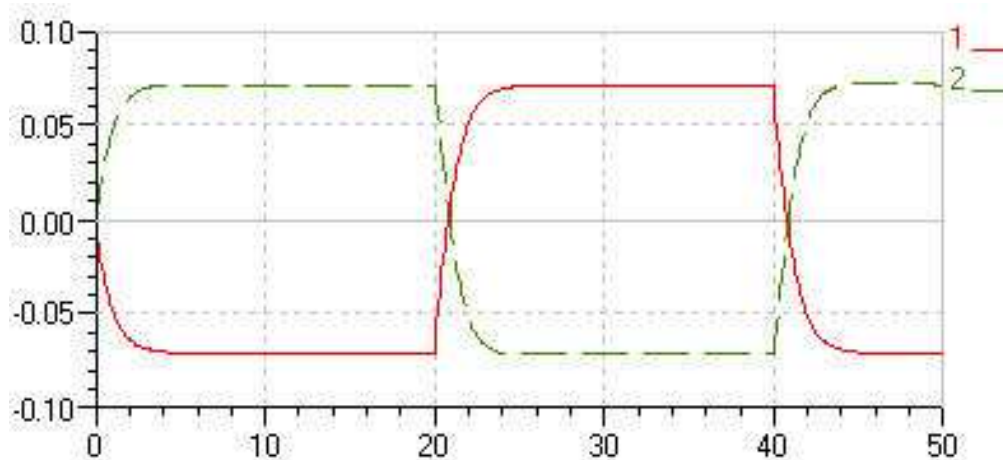


Fig. 11. The answer of the laser monitoring servomechanism at exciting the servomechanism which generates profile with rectangular signal

By the algebraic sum of the graphics from fig.11 results the curve 3 from fig.12. In the terminology related to the operation of automatic land leveling after an horizontal plane curve 3 represents the deviations of the profile of the levelled land from the optical horizontal reference plane. These are present only in the zone of stage jumping last 2 s and have a max.value of 0,01 m.

In fig.13 the servomechanism generating the profile of uneven land is excited with a constant sinusoidal signal with an amplitude of 0,14 m and a frequency of 0,05 Hz lasting 50 s. The meaning of the curves 1 and 2 is the same with that from fig.11.

By the algebraic sum of the graphics from fig.13 it results the curve 3 from fig.14 with the same meaning as that from fig.12. The errors are negligible with max.values below 0,002 m.

In fig.15. is shown a method for emitting in AMESim a sinusoidal signal with variable amplitude and frequency: over the sinusoidal signal with variable frequency and constant amplitude is superposed a ramp signal after this the 2 signals being composed. For the component signals there is a model in AMESim but for the composed signal not.



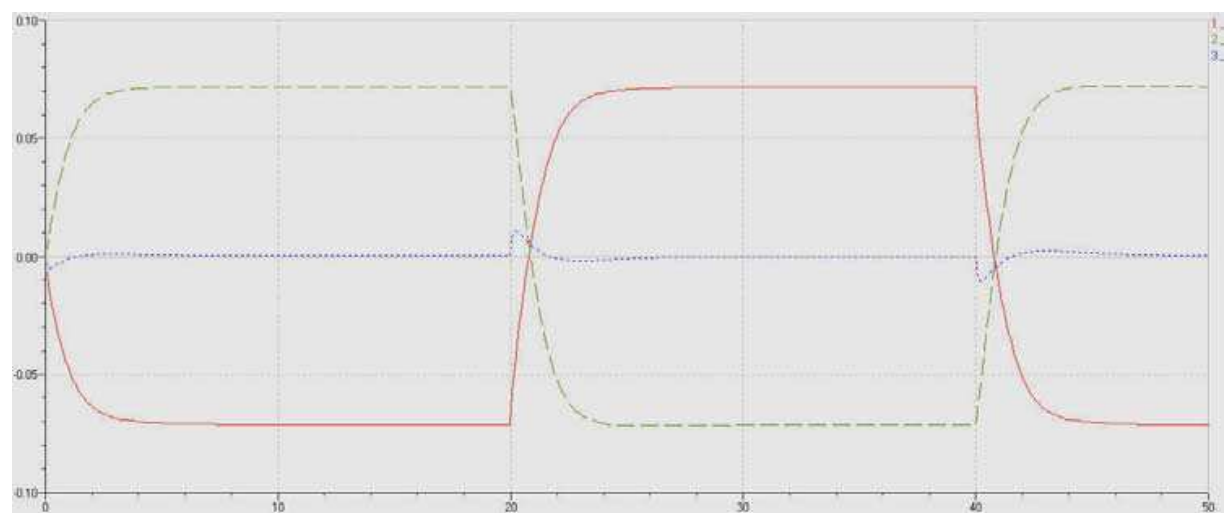


Fig. 12. Deviation profile of the leveled land from the optical reference plane

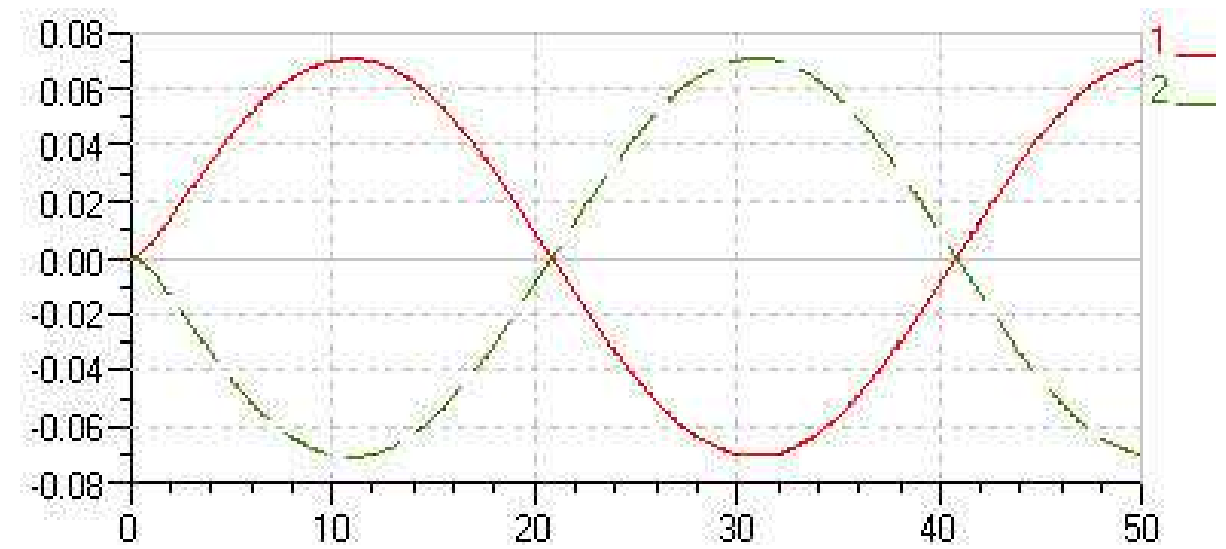


Fig. 13. The answer of the laser monitoring mechanism for a constant sinusoidal input

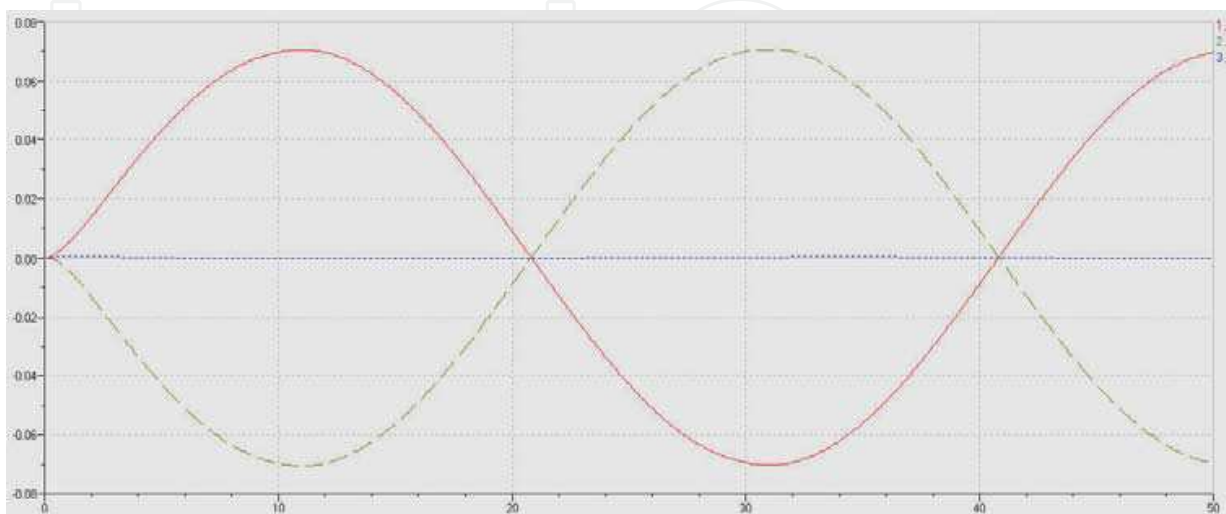


Fig. 14. Deviation profile leveled land from the optical reference plane

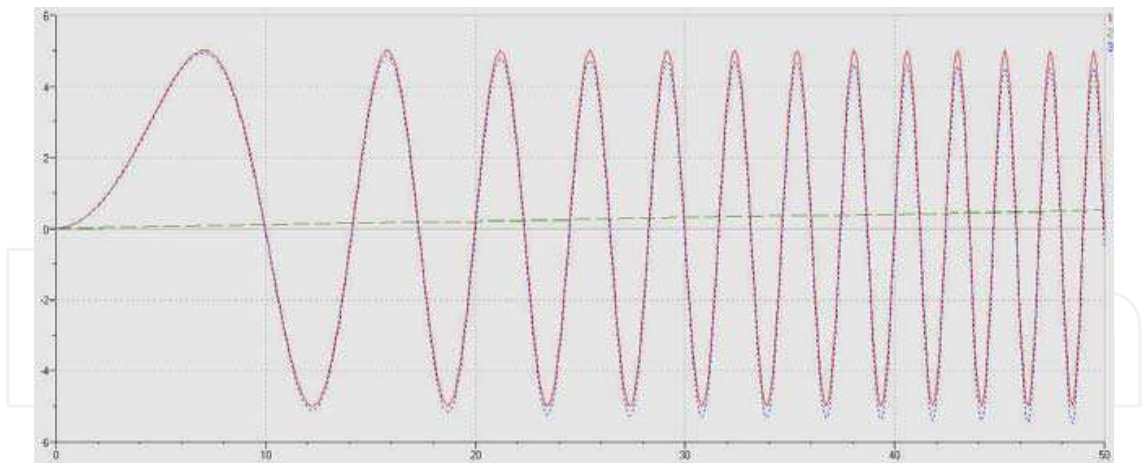


Fig. 15. The formation of a sinusoidal input signal with variable frequency and amplitude

The meaning of the curves from fig.15. is the following: 1- sinusoidal signal with variable frequency, max. frequency 0,5 Hz and amplitude 0,1 m; 2 – ramp signal; 3- sinusoidal signal with variable frequency and amplitude.

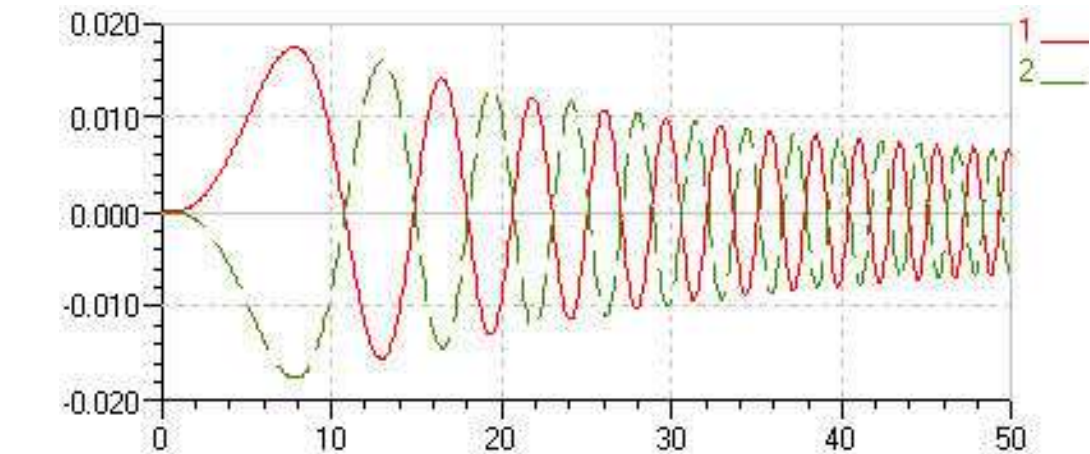


Fig. 16. The answer of the laser monitoring servomechanism at exciting the servomechanism generator of profile with variable sinusoidal signal

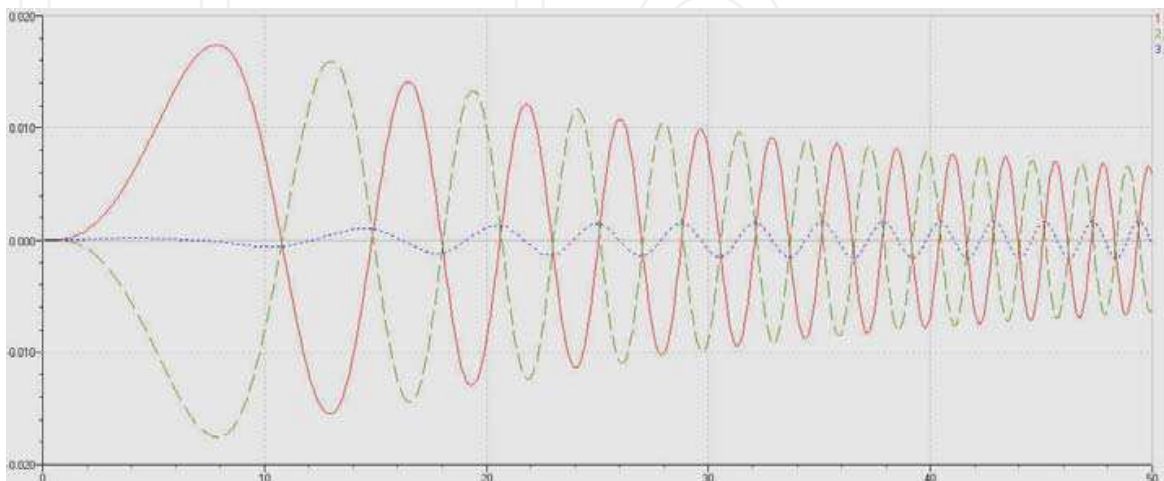


Fig. 17. Deviation leveled land profile from the optical reference plane

In fig.16 the servomechanism generator of uneven land profile is excited with a variable sinusoidal signal of the shape shown in fig.15 with an amplitude of 0,14 m and a frequency of 0,05 Hz lasting 50 s. The meaning of the curves 1 and 2 is the same like that shown in fig.11. By the algebraic sum of the graphics from fig.16 it results the curve 3 from fig.17 with the same meaning like that presented in fig.12. The errors are negligible with frequencies below 0,8 Hz and a max.value of the deviation of 0,004 m.

### 6.3 Fine tuning the parameters of PID controller

The modern fluid control systems are using hybrid tuning algorithms as Fuzzy - PID error compensators (Popescu et al., 2009). The high degree of nonlinearity of these systems leads to the wide use of modeling and simulation techniques for obtaining the tuning parameters by a virtual testing system. This testing manner offers a strong costs cut, and a useful reduction of the real experimental test. After 20 years of intensive development of the symbol libraries in different engineering fields, AMESim became an efficient tool for solving different applications of the fluid control systems. The case presented in this paper intends to offer a model of developing new applications of the electro hydraulic systems by this tool. The authors created both the laboratory model of the electro hydraulic control system, and the real system set up on a modern ground leveling machine. The comparison between the static and dynamic performances of the real system is found in good agreement.

To tune a controller means to find the parameters of an given structure, of a settled degree, so that to achieve from the resulted system a behavior as close as possible to the desired one. In practice the most frequently used regulators are of type P, PI, PD and PID which calculate the  $u(t)$  command according to the following relations: (1), for a **P**: regulator: proportional; (2), for a **PI**: compensator proportional, integral; (3), for a **PD**: regulator proportional, derivative; (4), for a **PID** regulator proportional, integral, derivative, where:  $K_p$  - constant of the proportional part (gain),  $K_i$  - constant of the integral part,  $K_D$  - constant of the derivative part.

$$u(t) = K_p \cdot \varepsilon(t) \quad (20)$$

$$u(t) = K_p \cdot \varepsilon(t) + K_i \cdot \int \varepsilon(t) dt \quad (21)$$

$$u(t) = K_p \cdot \varepsilon(t) + K_D \frac{d\varepsilon(t)}{dt} \quad (22)$$

$$u(t) = K_p \cdot \varepsilon(t) + K_i \cdot \int \varepsilon(t) dt + K_D \frac{d\varepsilon(t)}{dt} \quad (23)$$

**PID** type controllers are used for the error signal in hydraulic rapid servomechanisms. Component **P** amplifies the error, develops a higher-speed system, but it can't cancel the stationary error; component **I** removes the stationary error, but it destabilizes the system, while component **D** stabilizes the system. The last generation of control algorithms are based on the real time simulation of the systems.

The simulation model in AMESim (fig.10a) represents a hydraulic servomechanism for position control with one external feedback by laser and two internal feedbacks, arising at the level of the two included servomechanisms, as follows. The upper servomechanism, that simulates the profile of the uneven land, and the lower servomechanism, a tracing one, that actuates the blade of the levelling machine in a vertical plane.

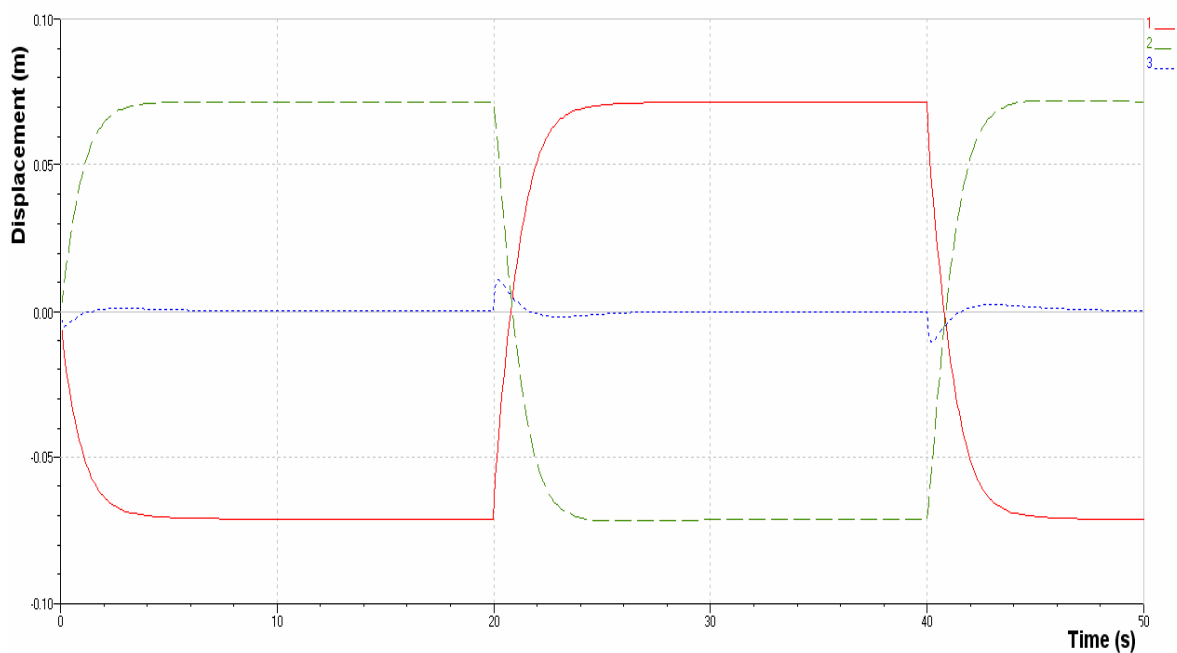


Fig. 18. The response of the tracing servocylinder when the servocylinder that simulates the land profile is excited by a rectangular signal

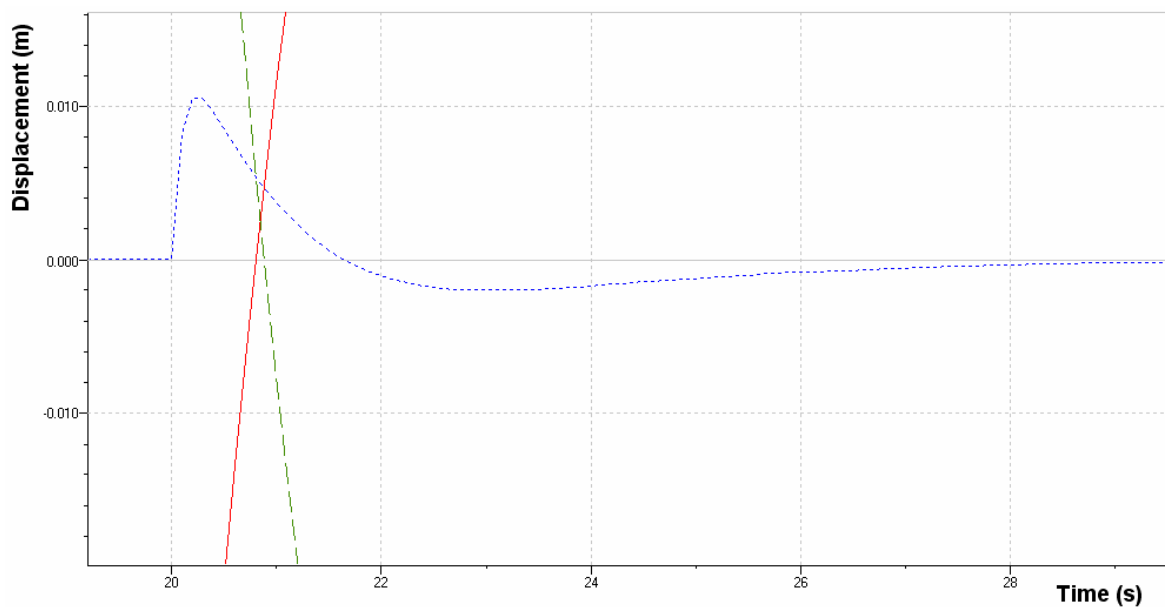


Fig. 19. The maximum value of the deviation of the leveled land from the optical reference plane

The hydraulic servo cylinder of the upper servomechanism has a mobile body, while the one of the lower servomechanism has a fix body. The first internal feedback loop arises between the displacement transducer of the cylinder with mobile body and the upper comparator of the simulation model. The second internal feedback loop arises between the displacement transducer of the cylinder with fix body and the internal comparator of the simulation model. The external feedback loop arises between the displacement transducer placed in the upper side of the model and the comparator placed in its lower side. The

above configuration can be a fair representation of the true system, included in the frame of the levelling machine. The servomechanism that simulates the profile of the uneven land is excited by a rectangular signal with amplitude of 0.140 m and frequency of 0.025 Hz. In fig.18 three curves are set: curve1 – variation of displacement over time of the servocylinder that simulates the profile of the uneven land; curve2 - variation of displacement over time of the tracing servocylinder, that actuates the blade of the navvy machine in vertical plane; curve3 – the amount of the two displacement values, which is the variation over time of the deviation of the uneven land from the optical reference plane.

In these conditions the maximum value of the deviation of the leveled land from the optical reference plane is 0.01m, fig. 19.

6.3.1 Optimizing parameter  $K_P$

Running the application in AMESim is repeated, this time canceling parameters  $K_I$  and  $K_D$  and selecting five values for parameter  $K_P$ , according to the settings in "Batch Control Parameter Setup" box, fig. 20.

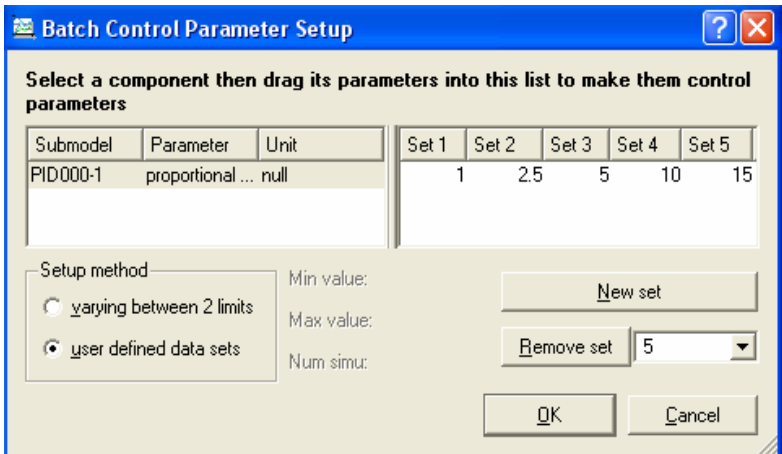


Fig. 20. Setting values for parameter  $K_P$

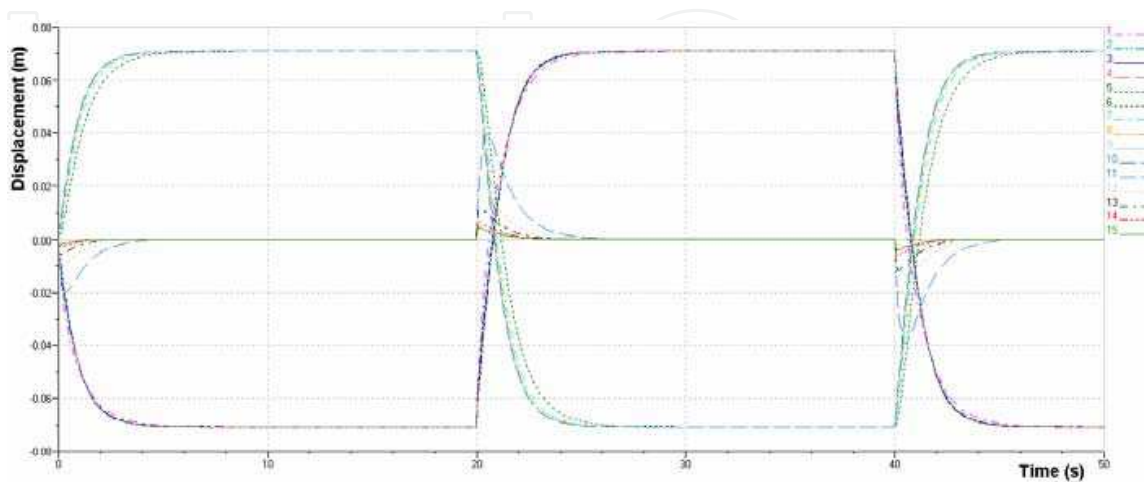


Fig. 21. Influence of the variation of parameter  $K_P$  upon the dynamics of the tracing servomechanism



In "Plot manager" box, there are shown the curves resulted when running the application in *Batch* mode, corresponding to five different values of parameter  $K_P$ . These curves represent: curve1...curve5 – variation over time of the displacement of the servocylinder that simulates the profile of the uneven land; curve 6...curve 10 - variation over time of the displacement of the servocylinder that actuates the blade of the navvy machine; curve11...curve15 - variation over time of the deviation of the leveled land from the optical reference plane. In fig. 21 is shown the influence that the variation of the parameter  $K_P$  has upon the dynamics of the tracing servomechanism when exciting the servomechanism that simulates the profile of the uneven land by a rectangular signal with amplitude of 0.140 m and frequency of 0.025 Hz. In fig. 22 is shown one detail of the variation over time of the amount of the displacement values of the two servocylinders, when applying the settings in fig. 20. One can notice an increasing dynamics of the tracing servocylinder, in accordance with the increase of the value of parameter  $K_P$ .

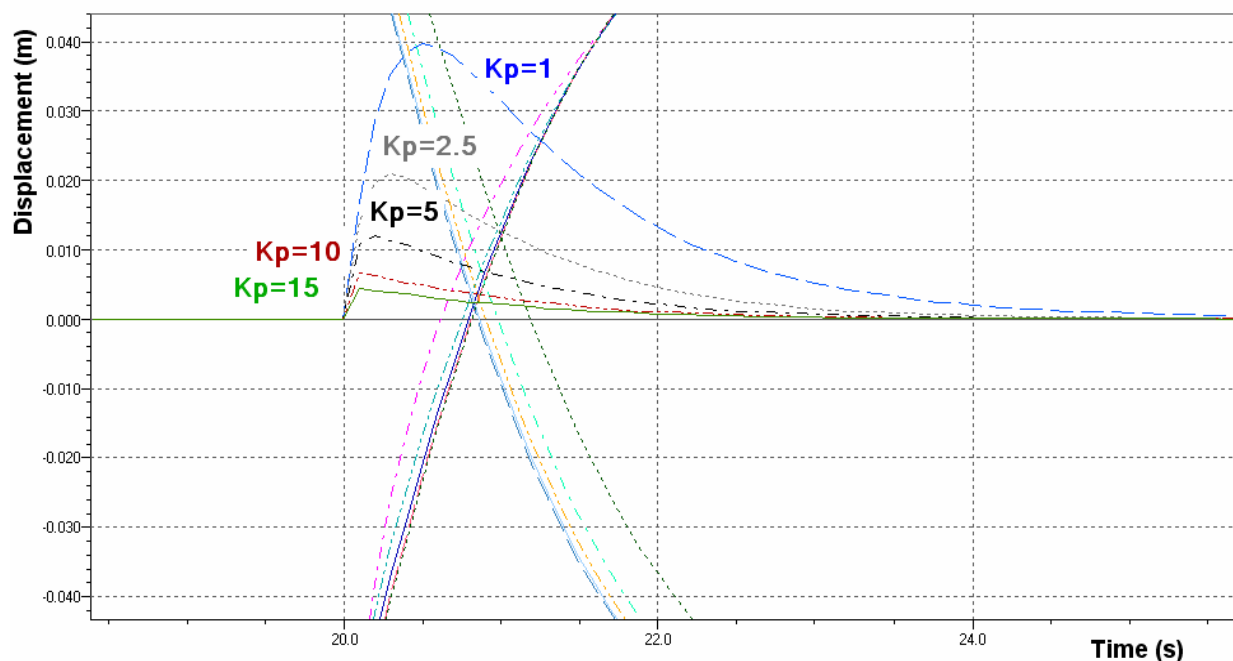


Fig. 22. Variation in the deviation of the profile of leveled land from the reference plane, depending on variation of parameter  $K_P$

### 6.3.2 Optimizing parameter $K_I$

Running the application in AMESim is repeated, this time canceling parameters  $K_P$  and  $K_D$  and selecting five values for parameter  $K_I$ , according to the settings in "Batch Control Parameter Setup" box. In fig. 23 is shown the influence that the variation of parameter  $K_I$  has upon the dynamics of the tracing servomechanism when exciting the servomechanism that simulates the profile of the uneven land by a rectangular signal with amplitude of 0.140 m and frequency of 0.025 Hz. In fig. 24 is shown one detail of the variation over time of the amount of the displacement values of the two servocylinders, when applying the settings  $K_I=0.5$ ;  $K_I=1$ ;  $K_I=2$ ;  $K_I=4$ ;  $K_I=8$ . One can notice that the stationary error in the tracing servomechanism is removed faster at a higher value of parameter  $K_I$ .

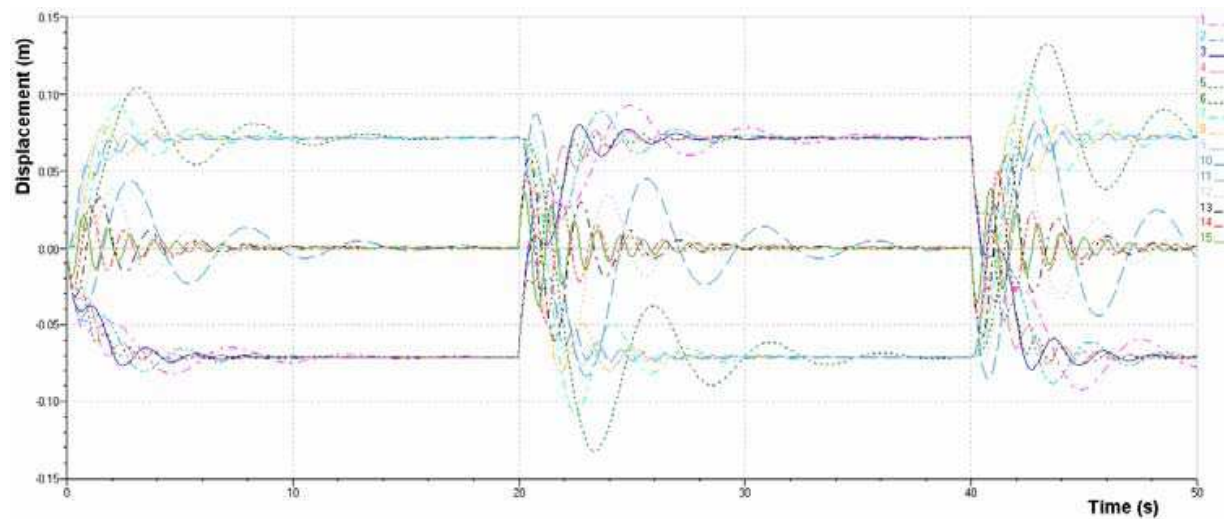


Fig. 23. Influence of the variation of parameter  $K_I$  upon the dynamics of the tracing servomechanism

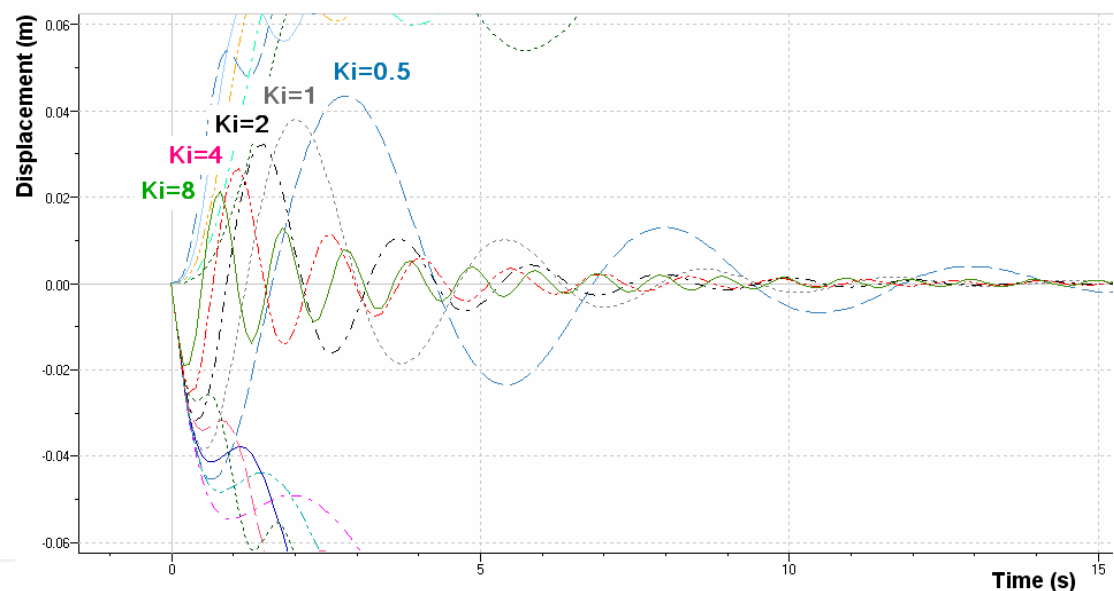


Fig. 24. Variation in the deviation of the profile of leveled land from the reference plane, depending on variation of parameter  $K_I$ .

6.3.3 Optimizing parameter  $K_D$

Running the application in AMESim is repeated, this time setting parameters  $K_P=1$  ;  $K_I=0.5$  and selecting five values for parameter  $K_D$ , according to the settings in "Batch Control Parameter Setup" box. In fig. 25 is shown the influence that the variation of parameter  $K_D$  has upon the dynamics of the tracing servomechanism when exciting the servomechanism that simulates the profile of the uneven land by a rectangular signal with amplitude of 0.140 m and frequency of 0.025 Hz. In fig. 26 is shown one detail of the variation over time of the amount of the displacement values of the two servocylinders, when applying the settings  $K_D=0.1$ ;  $K_D=0.2$ ;  $K_D=0.4$ ;  $K_D=0.8$ ;  $K_D=1.2$ . One can notice that the stabilization in the tracing servomechanism is attained faster at a lower value of parameter  $K_D$ .

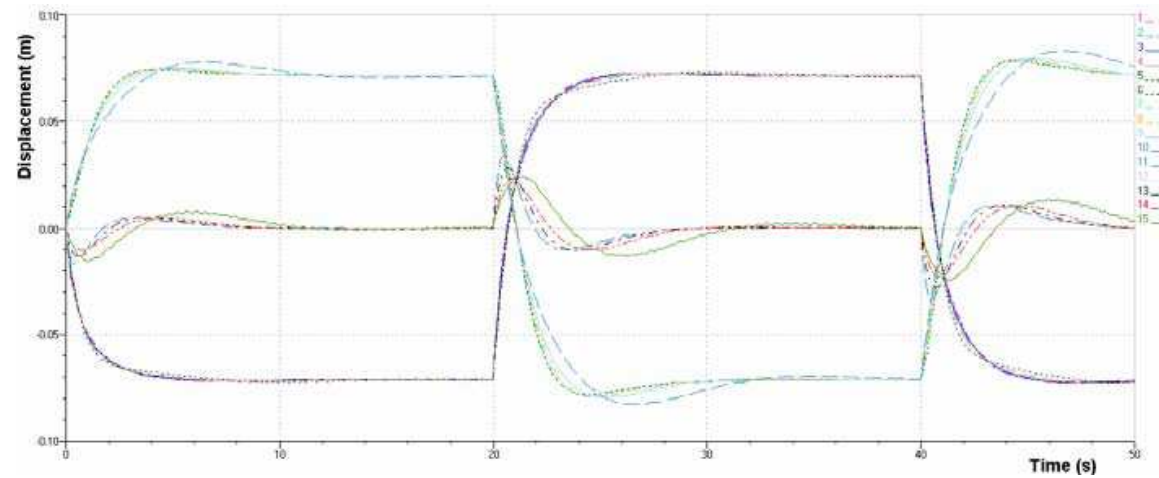


Fig. 25. Influence of the variation of parameter  $K_D$  upon the dynamics of the tracing servomechanism

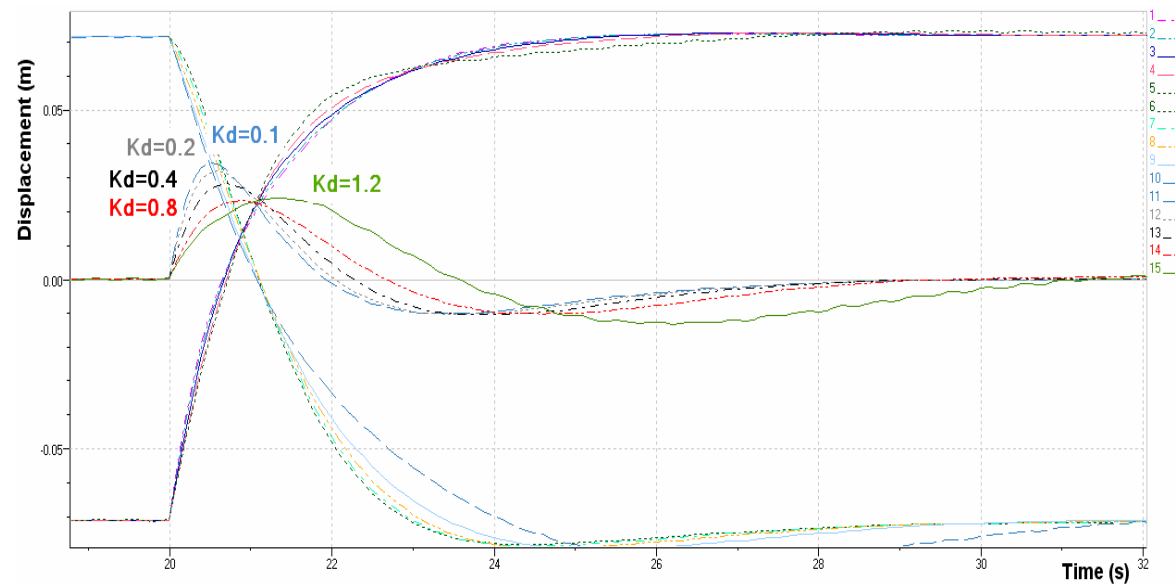


Fig. 26. Variation in the deviation of the profile of leveled land from the reference plane, depending on variation of parameter  $K_D$

6.3.4 Optimizing global parameter  $K(K_P, K_I, K_D)$

Running the application in AMESim is repeated, this time selecting five set of values for parameters  $K_P$ ,  $K_I$  and  $K_D$ , according to the settings in "Batch Control Parameter Setup" box. In fig. 27 is shown the influence that the variation of parameter  $K(K_P, K_I, K_D)$  has upon the dynamics of the tracing servomechanism when exciting the servomechanism that simulates the profile of the uneven land by a rectangular signal with amplitude of 0.140 m and frequency of 0.025 Hz.

In fig. 28 is shown one detail of the variation over time of the amount of the displacement values of the two servocylinders, when applying the settings:  $K_1(15, 8, 0.1)$ ;  $K_2(10, 4, 0.2)$ ;  $K_3(5, 2, 0.4)$ ;  $K_4(2.5, 1, 0.8)$ ;  $K_5(1, 0.5, 1.2)$ . One can notice that the optimal dynamics and stability of the tracing servomechanism is obtained when PID controller has the global parameter  $K_1(15, 8, 0.1)$ , where:  $K_P=15$ ,  $K_I=8$  and  $K_D=0.1$ .

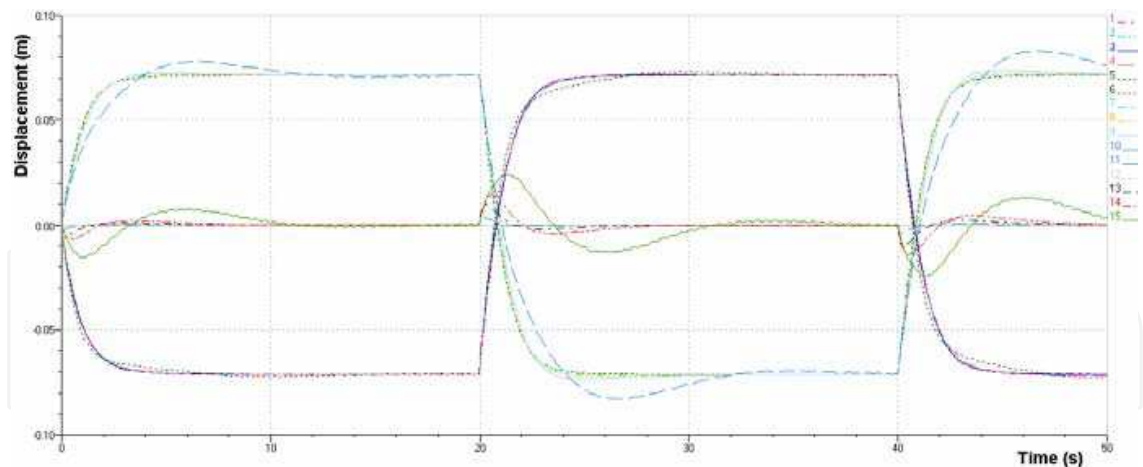


Fig. 27. Influence of the variation of parameter  $K(K_p, K_I, K_D)$  upon the dynamics of the tracing servomechanism

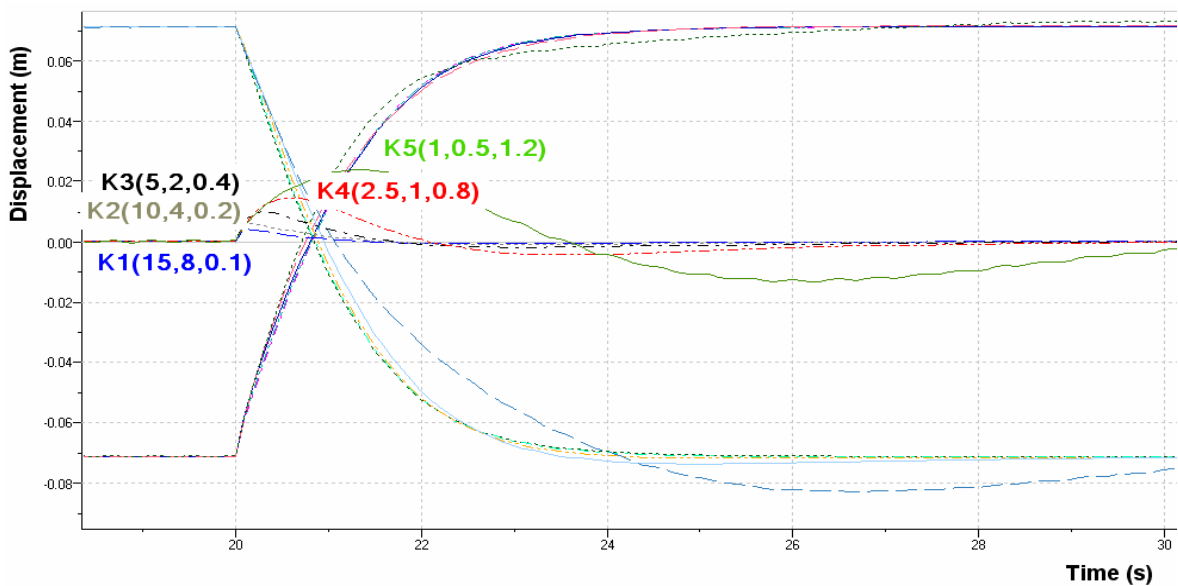


Fig. 28. Variation in the deviation of the profile of leveled land from the reference plane, depending on variation of parameter  $K(K_p, K_I, K_D)$

6.4. Experimental identification

The results of the experimental identification of the TOPCON laser controlled modular system mounted on test devices are shown in fig. 29...32.

In fig. 29-a is shown the dynamics of the laser control hydraulic monitoring system when at the input of the hydraulic mechanism generator of uneven land profiles is applied a constant sinusoidal signal with a frequency of 0,025 Hz and an amplitude of 0,072 m. The test duration was 50 s and it proved a proper dynamic of displacement of the monitoring servosystem (in red) towards the generator of uneven land profile (in black)

The graphics from fig. 29-b was obtained by repeating the test with the same frequency of the sinusoidal signal of excitation 0,025 Hz but with a higher amplitude 0,080 m. The test took 46 s and the results show a proper behavior of the monitoring servomechanism with laser control.

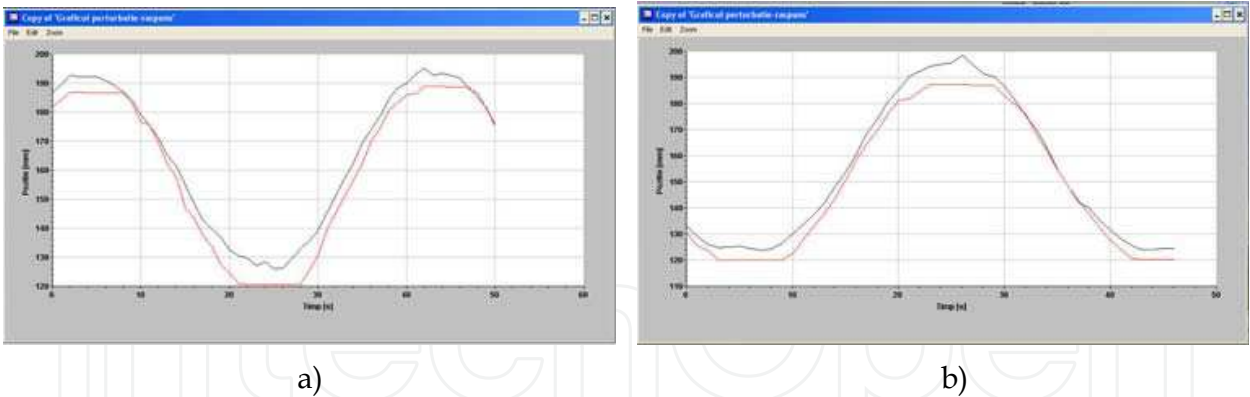


Fig. 29. The answer of the laser monitoring mechanism at the excitation of the servomechanism generator by a constant sine input

In fig.30-a is shown the dynamic of the monitoring hydraulic servosystem with laser control, when at the entry of the hydraulic servosystem generating uneven land profiles it is applied a constant triangle signal with a frequency of 0,025 Hz and an amplitude of 0,060 m which takes 63 s. The test proves the proper work of the laser controlled servomechanism.

In fig. 30-b is shown the dynamic of the hydraulic servosystem with laser control when at the entry of the hydraulic servomechanism generator of uneven land profiles is applied a constant rectangular signal with a frequency of 0,025 Hz and an amplitude of 0,105 m. The test took 51 s.

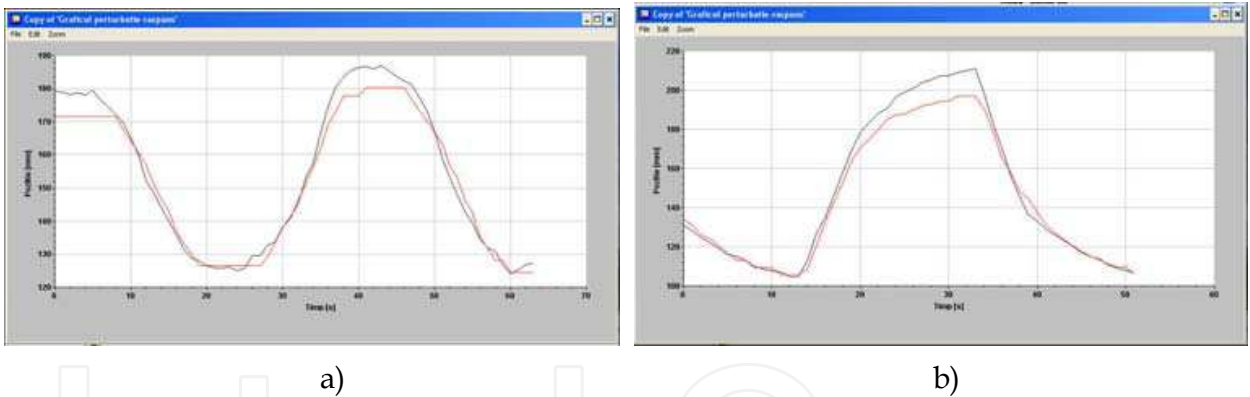


Fig. 30. The answer of the laser control monitoring mechanism at the excitation of the servomechanism generator of profile with: a) triangle input; b) rectangular input

At all tests presented above in fig. 29, and fig. 30 the inductive transducers of lineary displacement of the hydraulic cylinders were set in such a way that the 2 graphics are superposed for noticing easily the dynamic behavior of the hydraulic servomechanism with laser control.

For the test from fig. 31 which uses as excitation signal a constant sine one the inductive transducers of linear displacement of the hydraulic cylinders was set so that they can offer information regarding the real direction of displacement of the cylinders.

In fig. 31 is shown the dynamic of the hydraulic system with laser control when at the entry of the hydraulic mechanism generator of uneven land profiles is applied a constant sinusoidal signal with a frequency of 0,020 Hz and an amplitude of 0,120 m. The test took 115 min.



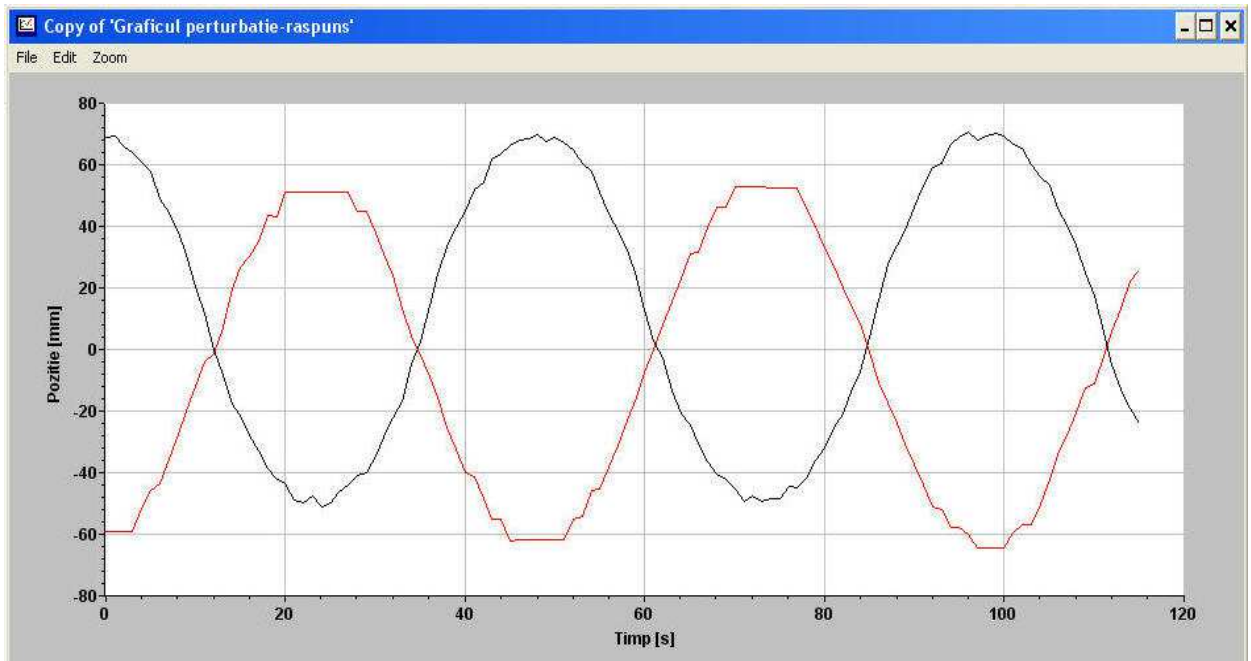


Fig. 31. The answer of the laser monitoring servomechanism at the excitation of the servomechanism generator of profiles with constant sinusoidal signal

In fig. 32 is shown the dynamic of the hydraulic monitoring system with laser control at the excitation of the mechanism generator of variable sine signal with a frequency of 0,010...0,100 Hz and an amplitude of 0,115...0,034 m. The test took 694 s.

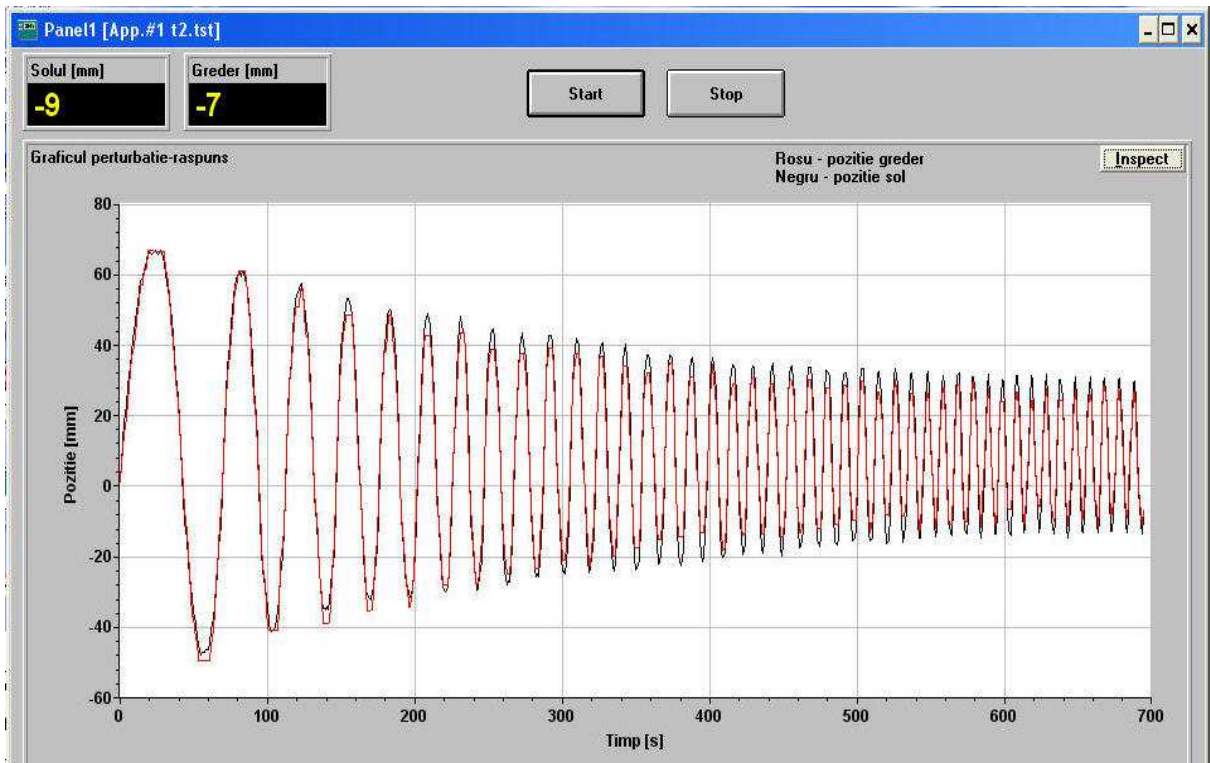


Fig. 32. The answer of the laser monitoring servomechanism at the excitation of the servomechanism generator of profiles with variable sinusoidal signal

Sistematic simulations gave the optimal parameters of the PID controller:  $K_p=15$ ,  $K_I=8\text{ s}$ , and  $K_D=0.1\text{ s}$  (fig.33). The minimum value of the deviation of the leveled land from the optical reference plane is less than 0.004 m (fig. 34). This value is 2.5 times lower than the one resulted from the first running of the simulation model (fig. 17).

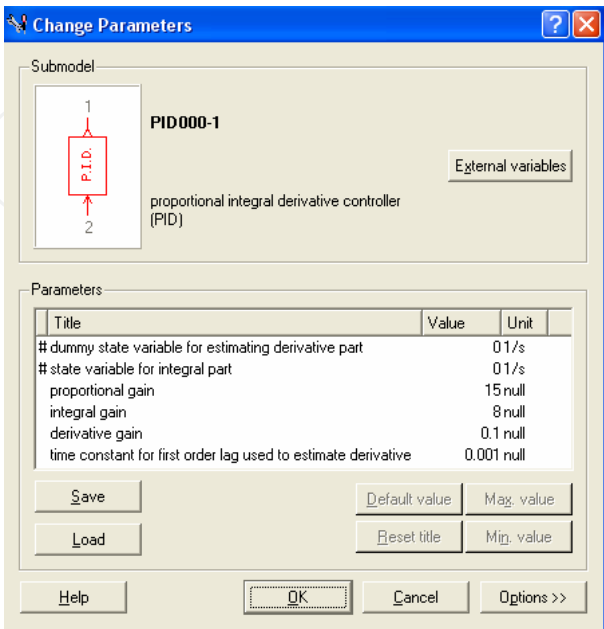


Fig. 33. Setting optimal parameters for a PID controller

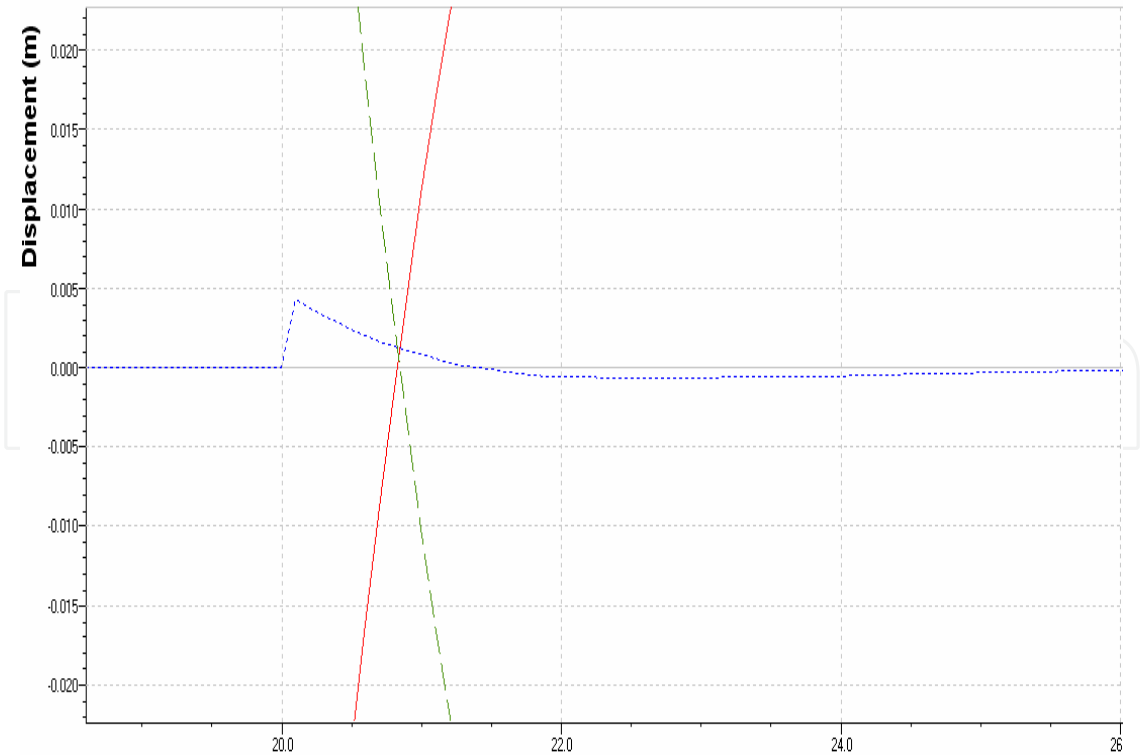


Fig. 34. Maximum optimized value of the deviation of the leveled land from the optical reference plane

## 7. Conclusions

The laser leveling of the land layers laid down when making a dam or a land dikes from the hydropower stations represents a safe and efficient solution for providing optimum breadth with maximum errors of about 2,5 cm on the entire surface of the laid layer. This kind of leveling performed before compaction of each land layer provide a proper and homogenous density of the dam and represents the optimum solution for reducing infiltrations and avoiding the falling of the crowning which may lead to water flood like is shown in fig.2.

The laser controlled modular systems like TOPCON or similar ones are not standard facilities in civil engineering companies not even for the most modern land leveling machines, but they can be mounted on any kind of hydraulic powdered land leveling machine, no matter of the degree of wear or origin.

The set up of these kind of equipments with laser control systems like TOPCON which appeared in the last decade in Romania is performed by specific trained personnel, and not by the manufacturers of the leveling machines.

The steady state characteristics and dynamic performance obtained by a TOPCON laser controlled modular system, set up on an autograder performing an automatic leveling, and the ones supplied by an original test bench are at least comparable.

The original test bench designed and tested at INOE 2000-IHP from Bucharest allows the preliminar tuning of the laser controlled modular system for a given machine which will be turned into an automatic leveling equipment.

The test bench can be also used as a debugger for the leveling machines equipped with laser controlled modular systems as a fault detection tool. The special skilled staff can identify the component which does not provide anymore the required operational parameters: the laser transmitter, the laser receiver, the hydraulic block or the electronic block.

All the design parameters of the test bench were found by the aid of the numerical simulations performed with AMESIM. The facilities offered by this software for the engineering activities are turning this software into a real design tool. A lot of technical fields are developing high performance equipments, like speed governors for modern hydraulic turbines (Vasiliu et al., 2003), thrust vector actuators for aerospace control (Mare and Cregut, 2001), heavy load dynamic testing machines (Vasiliu and Vasiliu, 2004). Special tools as "activity index" for enhancing the synthesis process of the hybrid digital electro hydraulic control systems were developed by SOCIETE IMAGINE SA. The Real Time Simulation facilities of AMESIM widely extended the field of applications for this software (Vasiliu & Vasiliu, 2005).

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