ASSISTED RESEARCH OF THE ELEMENTS AND THE SYSTEMS BY USING THE ELEMENTAR TRANSFER FUNCTIONS AND VIRTUAL INSTRUMENTATION

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Abstract:

In the optimisation stage of the systems one of the more important step is the optimisation of the dynamic behavior of all elements with priority the elements what have the slow frequency, like motors. The paper try to show how will be possible to optimise very easily the dynamic behavior of elements and systems, using LabVIEW propre instrumentation and the application of the transfer functions theory. By appling the virtual LabVIEW instrumentation is possible to choose on-line the optimal values for each constructive and functional parameters of the elements and the systems to obtain one good dynamic answer: maximal acceleration without vibration, minimum answer time and maximal precision. The paper presents some of the more important used transfer functions in the assisted analyse of the elements and systems and some practical results of the assisted optimisation.

1. Introduction

The transfer functions theory applied to the elements and the systems using the LabVIEW non linear components assure one very easily mode of the modeling, simulation and validation of the elements and systems, finally to obtain by sinthesys one integrated and intelligent system. Now, in the world, this theory and virtual LabVIEW instrumentation isn't applied to optimise the systems, perhaps of the dificulties to find the corespondent validated transfer functions for each component of the system, or some complex transfer functions what assures one minimum errors of validation. In the paper will be presented one virtual LabVIEW propre library for the assisted research of the electrical and hydralic elements and systems with many results what will be possible to use in the curently research.

2. Transfer functions theory

The created virtual LabVIEW instrument library contents one specify elementar transfer function for each components of the electrical, mechanical, hydraulic or complex systems. With these elementar transfer functions will be possible to exted the library with many others more complex, like for exemple PT_6 –proportional- inertial system with six inertial order by serial link of three elementar transfer functions PT_2, or PD_2T_2- proportional- derivative and inertial of the second order by serial link of two PDT_1, and s.o. In the table 1 you can see more of these complex transfer functions using the elementar functions and in the table 2 some of the more important transfer functions used in many modeling and simulations of the elements and systems [1], [2], [3], [4], [5]. With the elementar transfer functions theory and by using the non linear functions from LabVIEW library is possible to simulate any complex servo driving systems. The propposed method contents in two ways of optimization: the first is to choose all constructive and functional parameters of the components by on-line work of the propre virtual complex LabVIEW system to obtain the desired dynamic results- perhaps one minimum acceleration time without oscilations, or one output characteristics without vibrations indifferent of the acceleration time, or one Fourier spectrum to the higher field, etc[6], [7], [8], [9]. All these situation is possible to show by on-line work of the *VI*; the second will be to introduce in to the initial schema of many corrections, choose the regulator and controllers parameters, or to introduce complex control laws. These will be possible very easy by using the transfer functions, becouse it is know the action to the dynamic behavior of each of them.

For example to atenuate the intertial action of the second order it is indicated to introduce in to the initial schema of one control law of the type PD_2- proportional derivative of the second order, what control the inertial term, the damper term and the stifness term of the system. By using this control law was possible to minimase the acceleration time and to obtain one answer without any vibrations, like you can see forward in the paper.

Table 1. Some expressions and virtual LabVIEW instruments of transfer functions

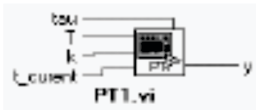
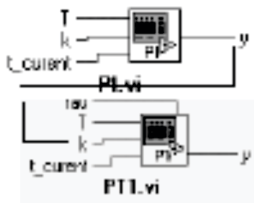
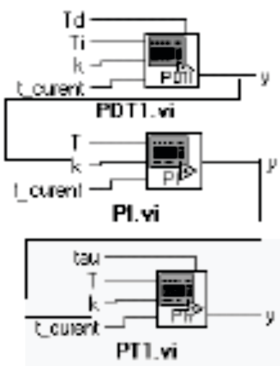
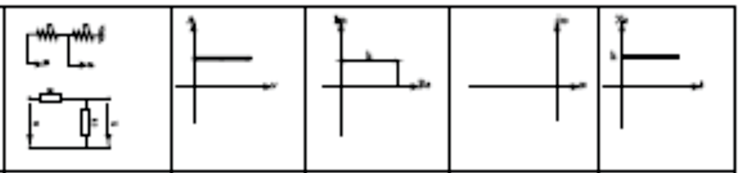
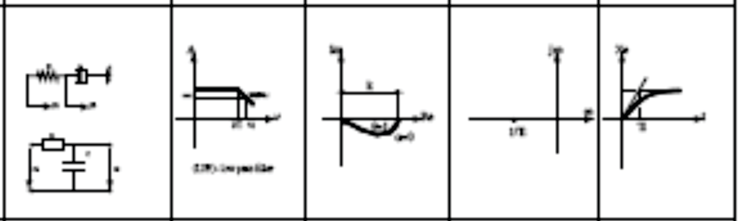
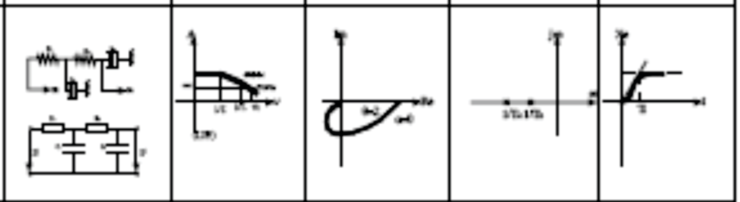
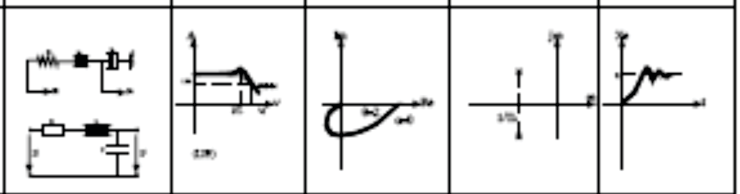
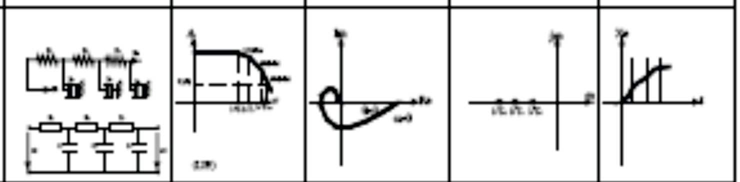
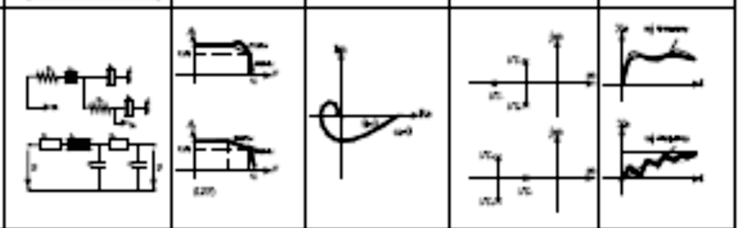
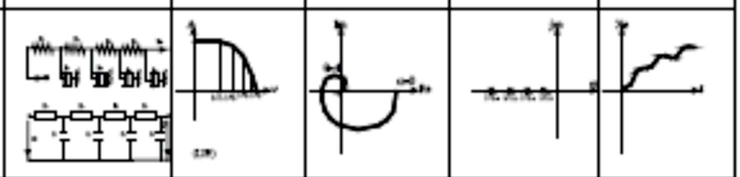
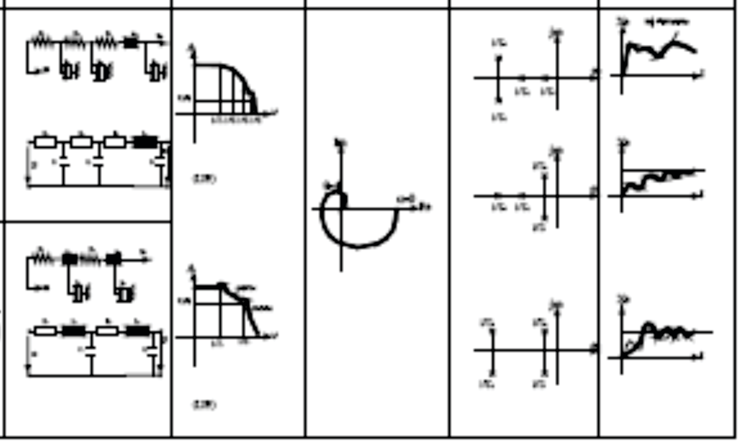
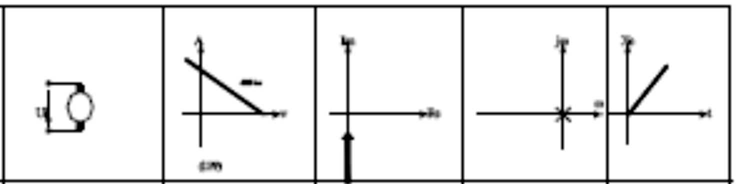
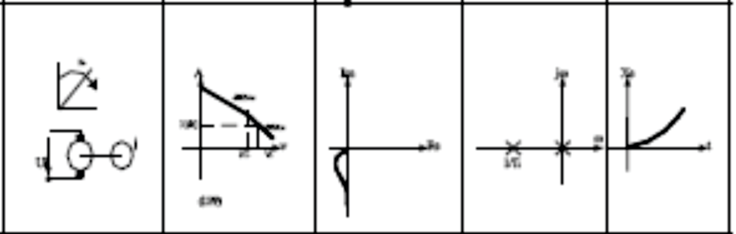
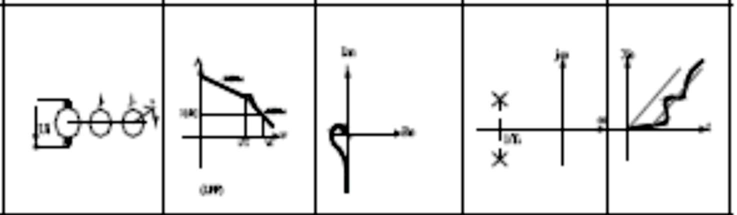
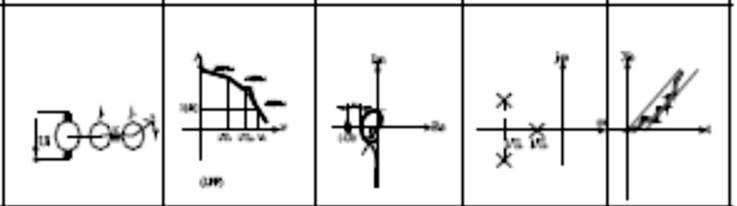
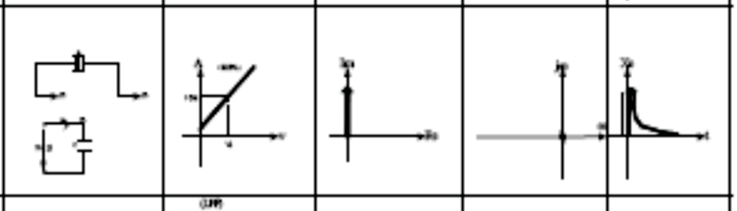
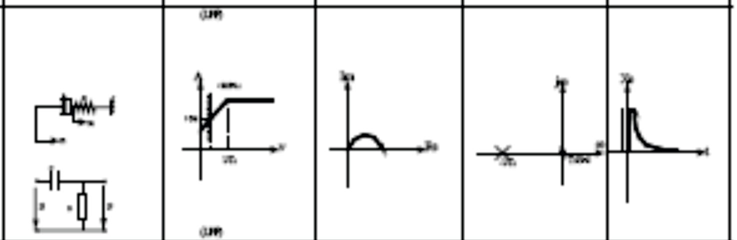
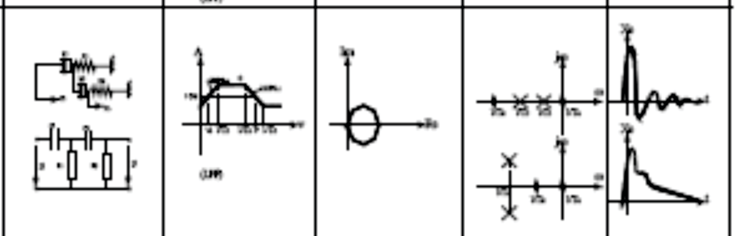
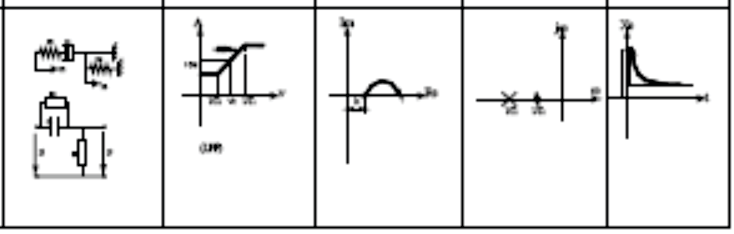
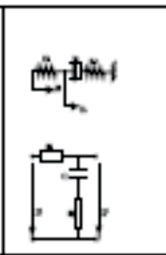
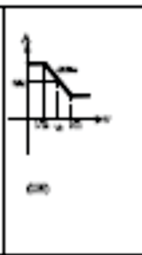
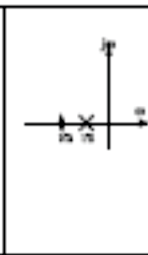
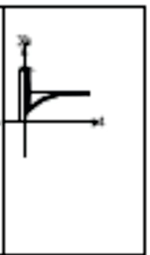
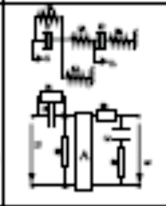
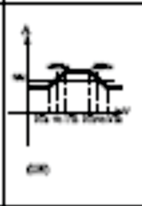
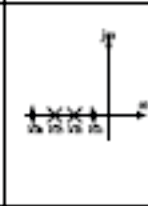
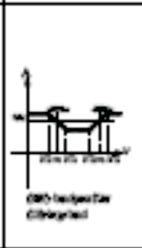
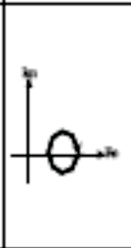
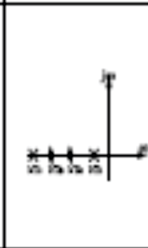
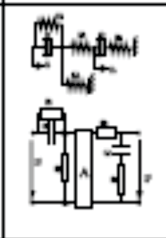
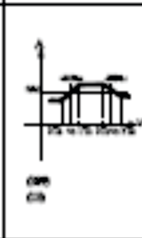
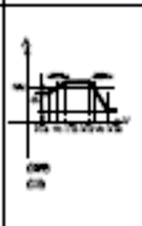
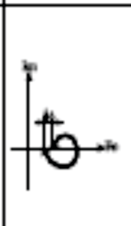
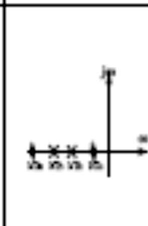
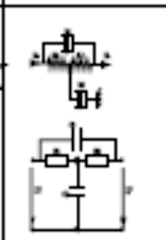
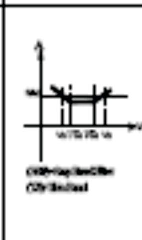
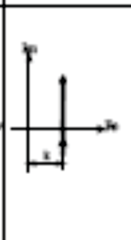
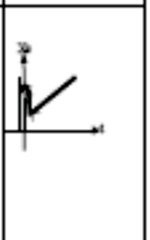
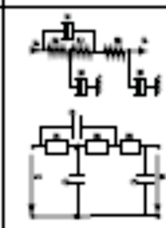
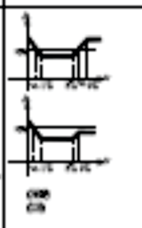
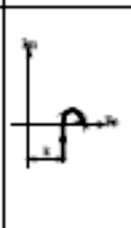
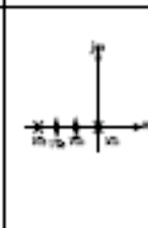
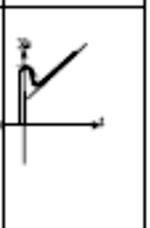
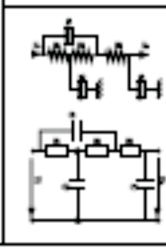
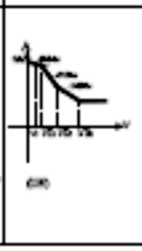
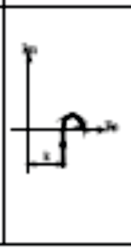
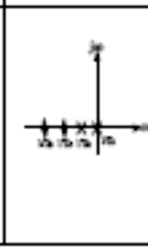
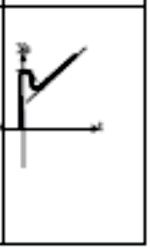
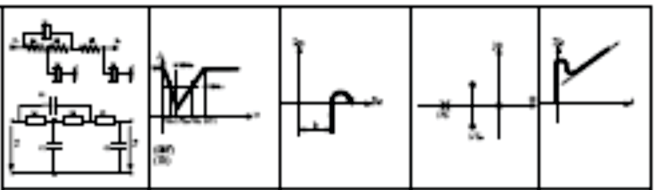
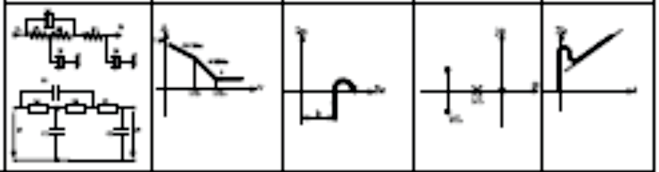
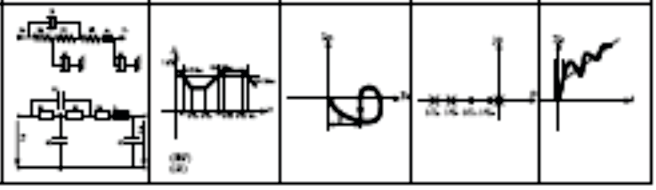
Type	Expresion of transfer function	Virtual LabVIEW instrument
PT_1	$H(s)=\frac{k}{T_i s+1}$	
PT_2	$H(s)=\frac{k}{(s+a)(s+b)}$ $\xi>1$	
	$H(s)=\frac{k}{s^2+a^2}$ $\xi=0$	
	$H(s)=\frac{k}{(s+a)^2}$ $\xi=1$	
	$H(s)=\frac{k\omega_n^2}{s^2+2\xi\omega_n s+\omega_n^2}$ $0<\xi<1$	
PT_3	$H(s)=\frac{k}{(s+a)(s+b)(s+c)}$	
PT_4	$H(s)=\frac{k}{(s+a)(s+b)(s+c)(s+d)}$	
I	$H(s)=\frac{k}{s}$	
IT_1	$H(s)=\frac{k}{s}\cdot\frac{1}{T_i s+1}$	
PDT_1	$H(s)=\frac{k(T_d s+1)}{T_i s+1}$	
DT_1	$H(s)=\frac{T_d s}{Ts+1_i}$	
PID	$H(s)=k(1+T_d s+\frac{1}{Ts_i})$	
PID T1	$H(s)=k(1+T_d s+\frac{1}{Ts_i})\cdot\frac{1}{T_i s+1}$	

Table 2
Some models of transfer functions and his characteristics, mathematical and physical models

P	$H(s)=K$	
PT1	$H(s)=\dfrac{K}{T_i s+1}$	
PT2	$H(s)=\dfrac{K}{(T_{i_1}s+1)(T_{i_2}s+1)}$	
	$H(s)=\dfrac{K}{(T_{i_1}s+1)(T_{i_2}s+1)}$	
PT3	$H(s)=\dfrac{K}{(T_{i_1}s+1)(T_{i_2}s+1)(T_{i_3}s+1)}$	
	$H(s)=\dfrac{K}{(T_{i_1}s+1)(T_{i_2}s^2+T_{i_3}s+1)}$	
PT4	$H(s)=\dfrac{K}{(T_{i_1}s+1)(T_{i_2}s+1)(T_{i_3}s+1)(T_{i_4}s+1)}$	
	$H(s)=\dfrac{K}{(T_{i_1}s+1)(T_{i_2}s+1)(T_{i_3}s^2+T_{i_4}s+1)}$	
	$H(s)=\dfrac{K}{(T_{i_1}s^2+T_{i_2}s+1)(T_{i_3}s^2+T_{i_4}s+1)}$	

I	$H(s)=\frac{K}{s}$	
IT1	$H(s)=\frac{K}{s}\frac{1}{T_i s+1}$	
IT2	$H(s)=\frac{K}{s}\frac{1}{T_{i_2}s^2+T_{i_1}s+1}$	
IT3	$H(s)=\frac{K}{s}\frac{1}{(T_i s+1)(T_{i_2}s^2+T_{i_1}s+1)}$	
D	$H(s)=T_D s$	
DT1	$H(s)=\frac{T_D s}{T_i s+1}$	
D2T2	$H(s)=\frac{T_{D_2}s^2+T_{D_1}s}{T_{i_2}s^2+T_{i_1}s+1}$	
PDT	$H(s)=\frac{K(T_D s+1)}{T_i s+1}$ $T_D > T_i$	

PDT1	$H(s)=\frac{K(T_D s+1)}{T_i s+1}$ $T_D < T_i$					
PD2T2	$H(s)=\frac{s^2+(a_1+b_2)s+a_1b_2}{s^2+(a_2+b_1)s+a_2b1}$ $a_1b_2=a_2b_1;\ (a_1+b_2)>(a_2+b_1)$					
PD2T2	$H(s)=\frac{s^2+(a_1+b_2)s+a_1b_2}{s^2+(a_2+b_1)s+a_2b1}$ $a_1b_2=a_2b_1;\ (a_1+b_2)<(a_2+b_1)$					
PD2T2	$H(s)=\frac{s^2+(a_1+b_2)s+a_1b_2}{s^2+(a_2+b_1)s+a_2b1}$ $a_1b_2=a_2b_1;\ (a_1+b_2)>(a_2+b_1)$ $a>b$					
PD2T2	$H(s)=\frac{s^2+(a_1+b_2)s+a_1b_2}{s^2+(a_2+b_1)s+a_2b1}$ $a_1b_2=a_2b_1;\ (a_1+b_2)>(a_2+b_1)$ $a<b$					
PID	$H(s)=\left(1+T_D s+\frac{1}{T_i s}\right)K$ $4Td > T$					
PIDT1	$H(s)=K\left(1+T_d s+\frac{1}{T_i s}\right)\frac{1}{T_1 s+1}$					
						

						
						
PIDT2	$H(s)=K\left(1+T_d s+\frac{1}{T_i s}\right)\frac{1}{T_2 s^2+T_1 s+1}$					

In the modeling of the elements and systems one more important thing is to aproximate better the real function of the systems. For that will be necessary the folling steps: write the mathematical model and to aplly the Laplace transformation; determine the transfer elementar function of each component; simulation of the elements and compare the results with the real characteristics of the researched elements, in this case LHM (linear hydraulic motor); the validation of the model or changing them to obtain one minimum errors between the model and the real one. After these assisted research will be possible to optimise the results only by numerical simulation becouse the mathematical model was validated and completed with some new coefficients what results from the validation step.

3. The LHM mathematical model and the experimental validation [10], [11], [12], [13], [14]

The applied mathematical model, in this case for the LHM, was developed in one complex matrix form to take in to the research all input and output data.

The general matrix form of one mathematical model with two output and two input data is:

$$[H(s)] = \frac{\begin{bmatrix} x_{e1}(s) \\ x_{e2}(s) \end{bmatrix}}{\begin{bmatrix} x_{i1}(s) \\ x_{i2}(s) \end{bmatrix}} = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix} \quad (1)$$

The LHM is one inertial of the second order type of the transfer function like this:

$$T_1 T_2 \frac{dx_e^2}{dt^2} + h(T_1 + T_2)\frac{dx_e}{dt} + x_e = kU \quad (2)$$

Finally, the matrix form in the state space will be:

$$\begin{pmatrix} x_1' \\ x_2' \end{pmatrix} = \begin{bmatrix} 0 & 1 \\ -\frac{1}{T_1 T_2} & -\frac{h(T_1+T_2)}{T_1 T_2} \end{bmatrix}\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} 0 \\ \frac{k}{T_1 T_2} \end{pmatrix} U(t) \quad (3)$$

$$Y = (1 \quad 0)\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \quad (4)$$

General for of the state space relation will be:

$$\begin{aligned} (x'(t)) &= [A](x(t)) + [B](u(t)) \\ (y(t)) &= [C](x(t)) + [D](u(t)) \end{aligned} \quad (5)$$

After application of the Laplace transformation, the output will be:

$$Y(s) = C^T[sI - A]^{-1}x_0 + C^T[sI - A]^{-1}BU(s) + DU(s) \quad (6)$$

where:

$$T_1 T_2 = \frac{m\frac{A_1 c}{2E}}{A_1^2(1-c_{fu}) + a_m b_m}; h(T_1+T_2) = \frac{m a_m + \frac{A_1 c}{2E} b_m}{A_1^2(1-c_{fu}) + a_m b_m};$$

$$kU = \frac{A_1(1-c_{fu})Q}{A_1^2(1-c_{fu}) + a_m b_m}. \quad (7)$$

and where: Q is the flow 20-100 [cm^3/s]; A– active motor area 50-80 [cm^2]; c- active movement 30-40 [cm] ; a_m- proportional gradient of loss flow with pressure 0.2-0.7[cm^5/daNs]; p- loss pressure 4-6 [daN/cm^2]; V – hydraulic volume of the motor 500- 1000 [cm^3]; m- reduced mass on the motor axis 0.1-0.6 [daNs^2/cm]; b_m- gradient of loss forces proportional with velocity 0.8-1.8 [daNs/cm]; F – resisting forces 10-30[daN].

Relation (6) is the real output and will be change in to the follwing form, if the all input data will be step type:

$$Y(s) = c^T[sI - A]^{-1}\frac{x_0}{s} + c^T[sI - A]^{-1}B\frac{U}{s} + D\frac{U}{s} \quad (8)$$

Finally, after changes of the product in the sume and after applied the inverse Laplace transformation the relation for the velocity of LHM will be:

y1=k(1/psi$_2$)*q*(1-(1/e^(omega*psi*dt))*(1/psi$_2$)*sin(omega*psi$_2$*dt+atan(psi$_2$/psi)))-(F+a$_0$)*(a$_m$/b$_0$)*(1-1/e^(b$_0$*dt/ (a$_m$*m)))

a$_{00}$= k*q*(1/psi$_2$)-((F+a$_0$)*(a$_m$/b$_0$))

a$_0$=p*A$_1$

b$_0$=((A$_1$**2)*0.86)+a$_m$*b$_m$

b$_1$=M*a$_m$+(A$_1$*c*b$_m$/(30000)) (9)

b$_2$=M*A$_1$*c/(30000)

b$_{00}$=A$_1$*0.86

k=b$_{00}$/b$_0$

psi=b$_1$/(2*sqrt(b$_2$*b$_0$))

omega=sqrt(b$_0$/b$_2$)

psi$_2$=sqrt(1-psi^2)

The results after the simulation step and the experimental research of the LHM were obtained the characteristics from the fig.1.

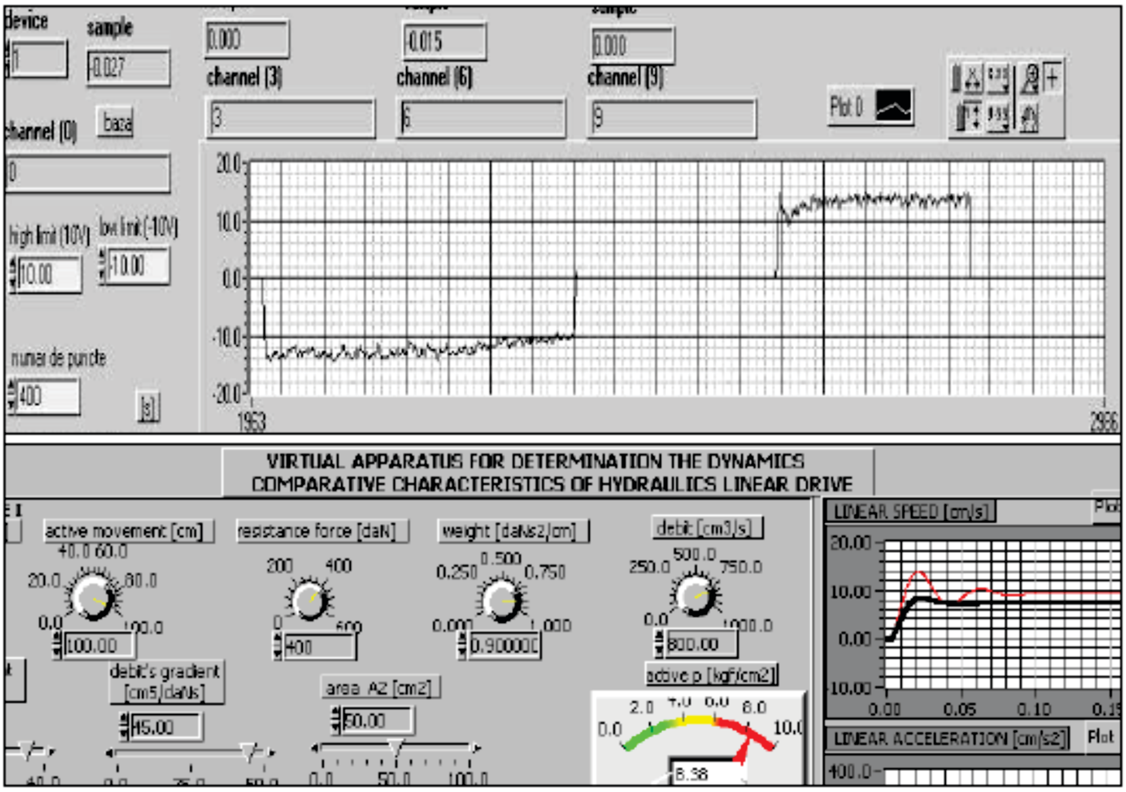


Fig.1. *Validation of the LHM mathematical model- comparative analyze of the experimental and simulation results*

4. Assisted optimisation of the LHM using the propre LabVIEW instrumentation

The assisted optimisation used the validated mathematical model of the LHM and by changing some constructive or functional parameters. In the figs.2-4 were changed the flow loss and the force gradients, a_m, b_m, the active area A_1, the movement of the motor stem, c.

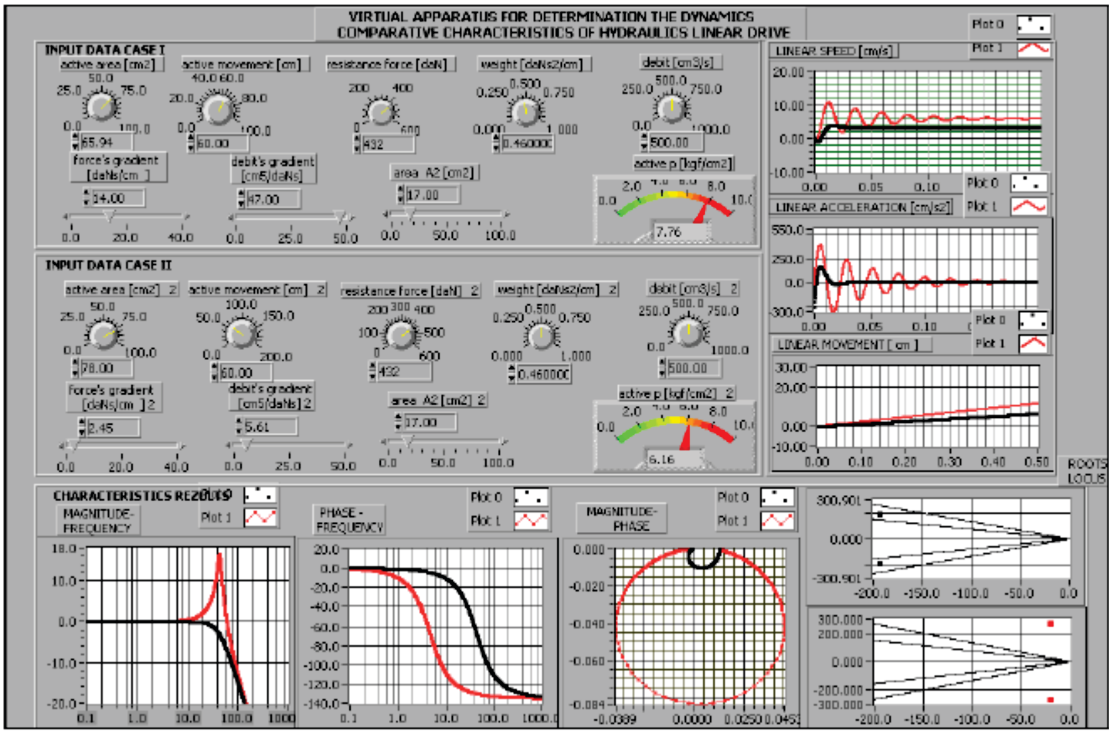


Fig.2. *Front panel of the virtual LabVIEW LHM instrument for the comparative analyze, when was changed the flow and resistance force gradients, a_m, b_m*

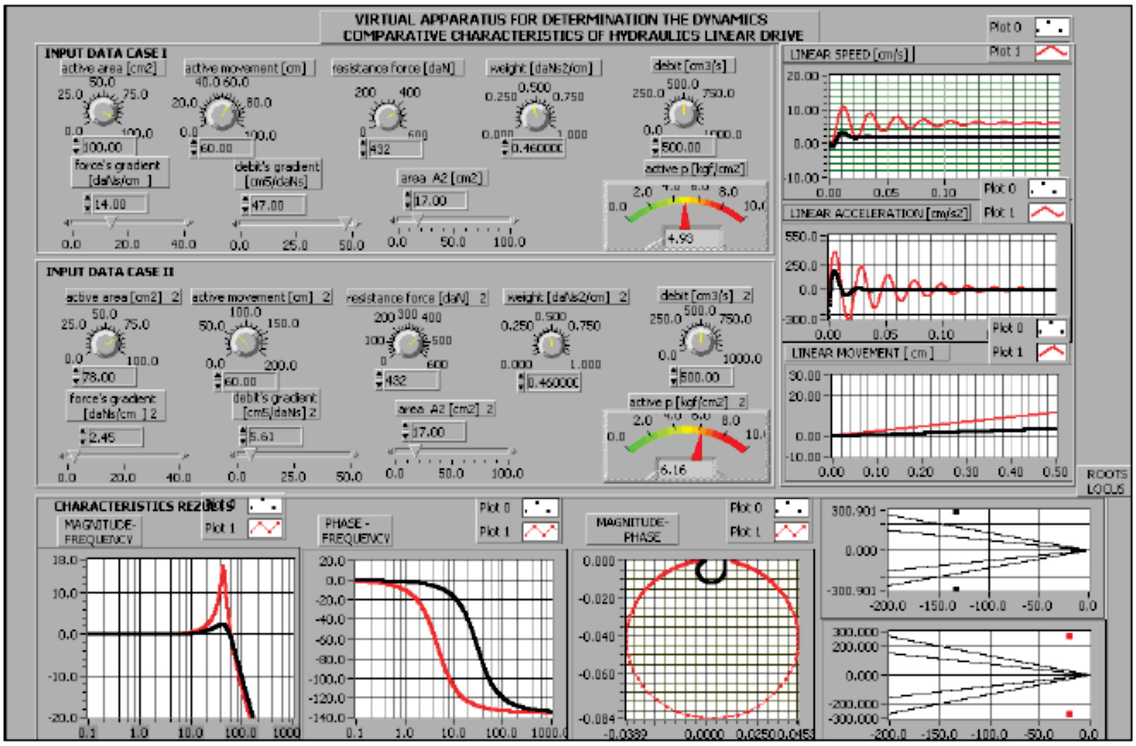


Fig.3. Front panel of the virtual LabVIEW LHM instrument for the comparative analyze, when was changed the active area, A_1

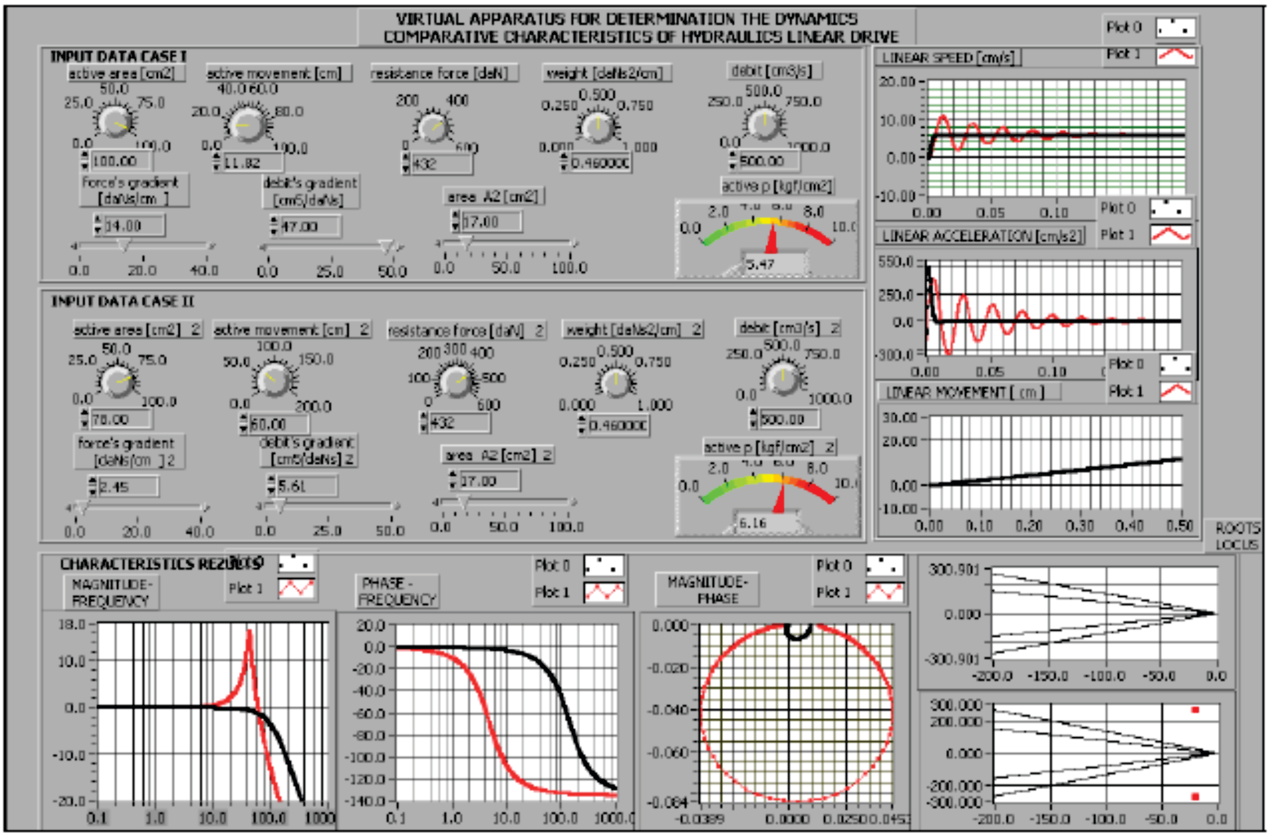


Fig.4. *Front panel of the virtual LabVIEW LHM instrument for the comparative analyze, when was changed the active area and the movements of motor steam, A_1, c*

Analyzing the optimization applied LHM LabVIEW proper *VI* results the following remarks: by increase the flow and force gradients were obtained some transfer of the poles in the plane poles- zeros to the stability field, velocity were obtained without any vibrations, fig.2; by increase the active area was obtained the displacement of the poles outside of the precision – stability field but one magnification of the answer with decrease of the acceleration time with the effect in to the increase of the movement precision, fig.3; by decrease of the active movement of the LHM steam was obtained one magnification of the velocity output with the same acceleration time with the second example, but without any vibrations of the velocity output, fig.4. By this method is possible to choose the constructive or functional values of the LHM to obtain one good dynamic behavior answer to obtain one good precision, or stability, or better solving the compromise precision- stability problem. Without on-line work of the proper LabVIEW *VI*-s is not possible to obtain these results.

5. Assisted optimisation of the hydraulic systems with many closed loops and different control laws

The assisted optimization of the complex hydraulic systems contents the construct of the complex virtual schema with many elementary transfer functions and some closed loops and different control laws. For that were used some proper LabVIEW sub*VI*-s linked one to other in the magnifying factor. In the paper were simulated the system CFP- LHM (constant flow pump- linear hydraulic motor) [15], [16], [17], [18], VFP- RHM with regulator (variable flow pump- rotate hydraulic motor), CFP- PD- LHM (constant flow pump- proportional distribution- linear hydraulic motor), LHM-OHM (linear and oscillate hydraulic motor). For the control of the command signals were used some proper sub*VI*-s by manually, automat or using the intelligent systems with some neural networks, to control the electrical command signals. All the examples of the numerical simulations of these complex hydraulic servo driving systems were presented in the figs.5-11 and the control of the electrical command signal in the figs.12-13.

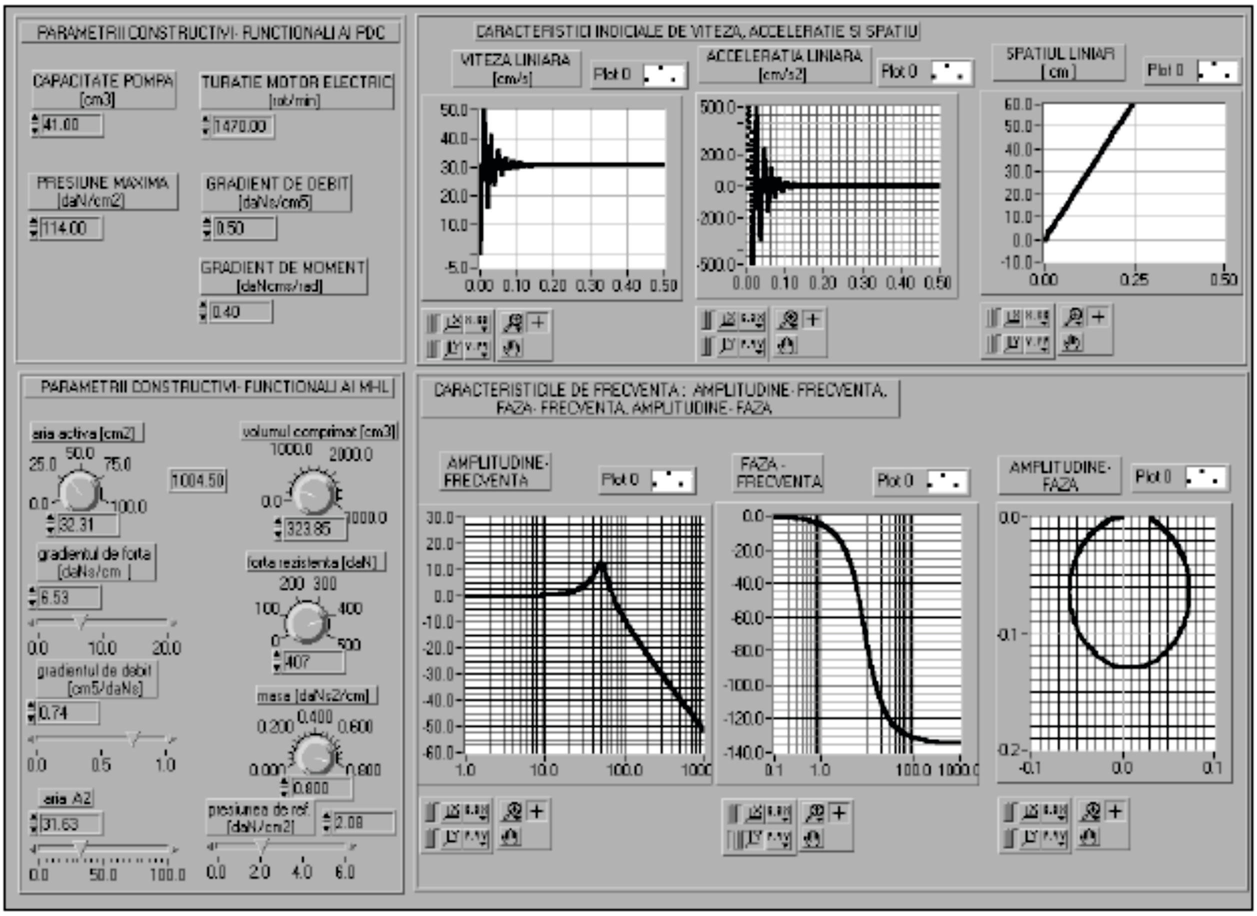


Fig.5. Indicial and frequency characteristics for the servo driving CFP-LHM after changing the inertial mass m

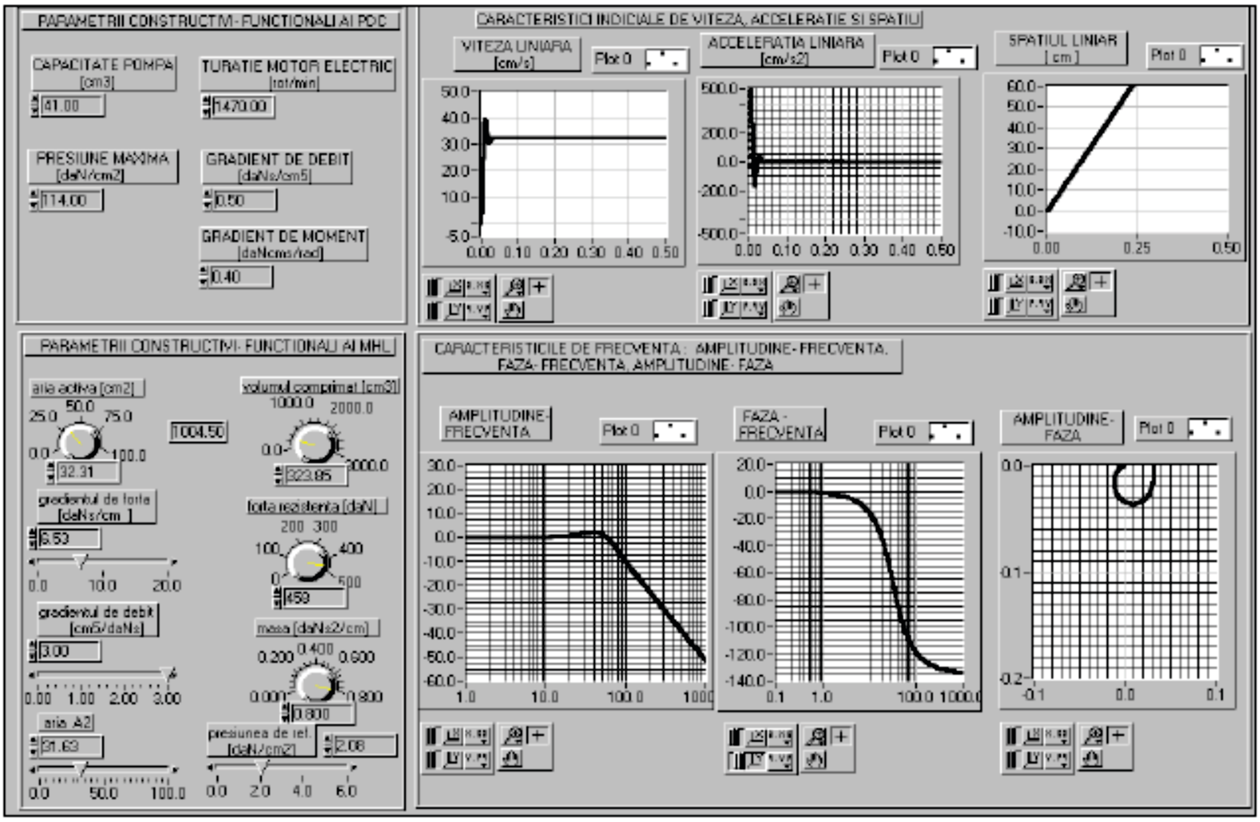


Fig.6. Indicial and frequency characteristics for the servo driving CFP-LHM after changing the flow loss gradient a_m

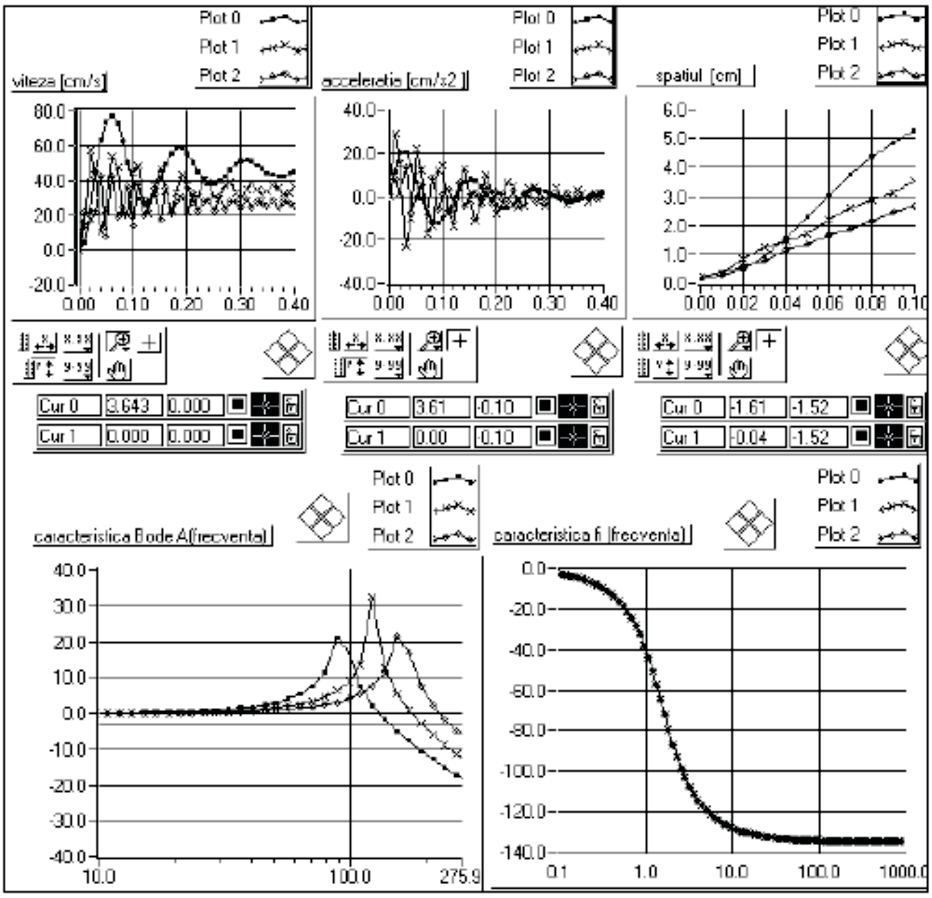


Fig.7. *Indicial and frequency characteristics obtained by changing the diameters of the discrete distribution D_m*

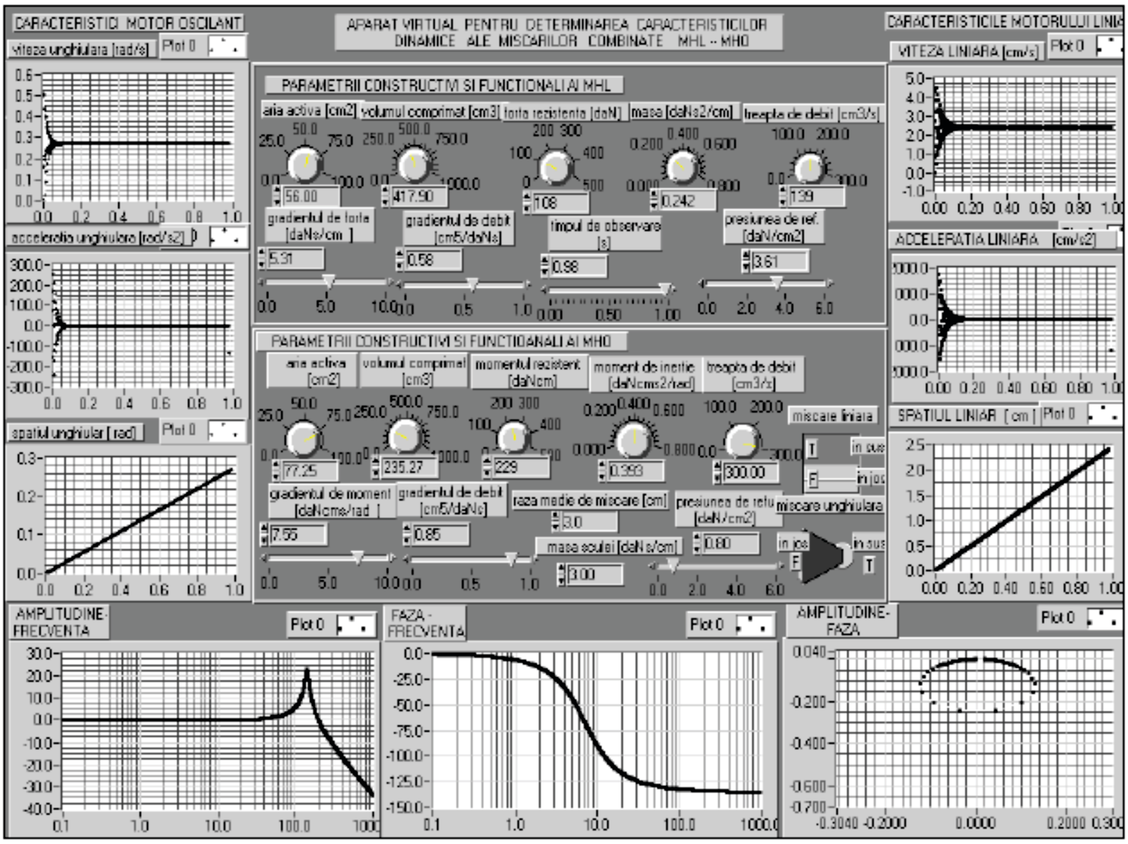


Fig.8. Indicial and frequency characteristics for the servo driving of one mechanical arm for the tools changing magasin

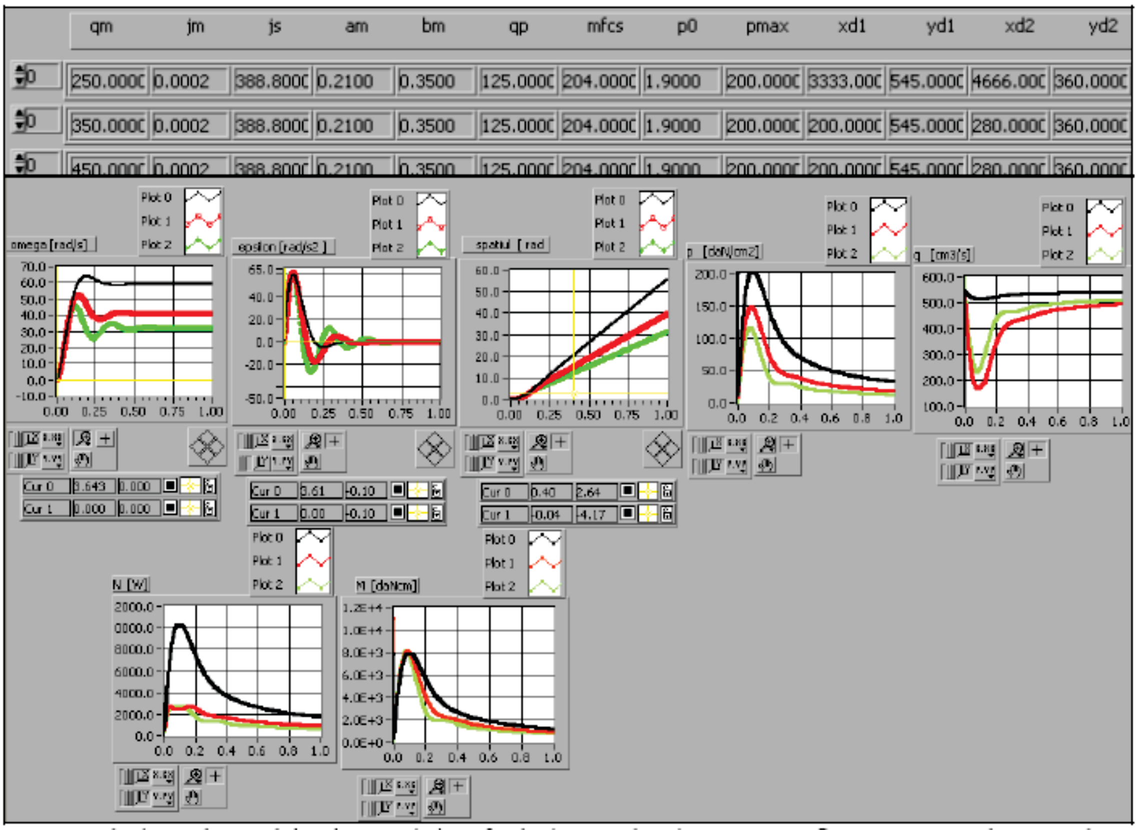


Fig.9. *The input data and the characteristics of velocity, acceleration, pressure, flow, moment and power when was changed the flow*

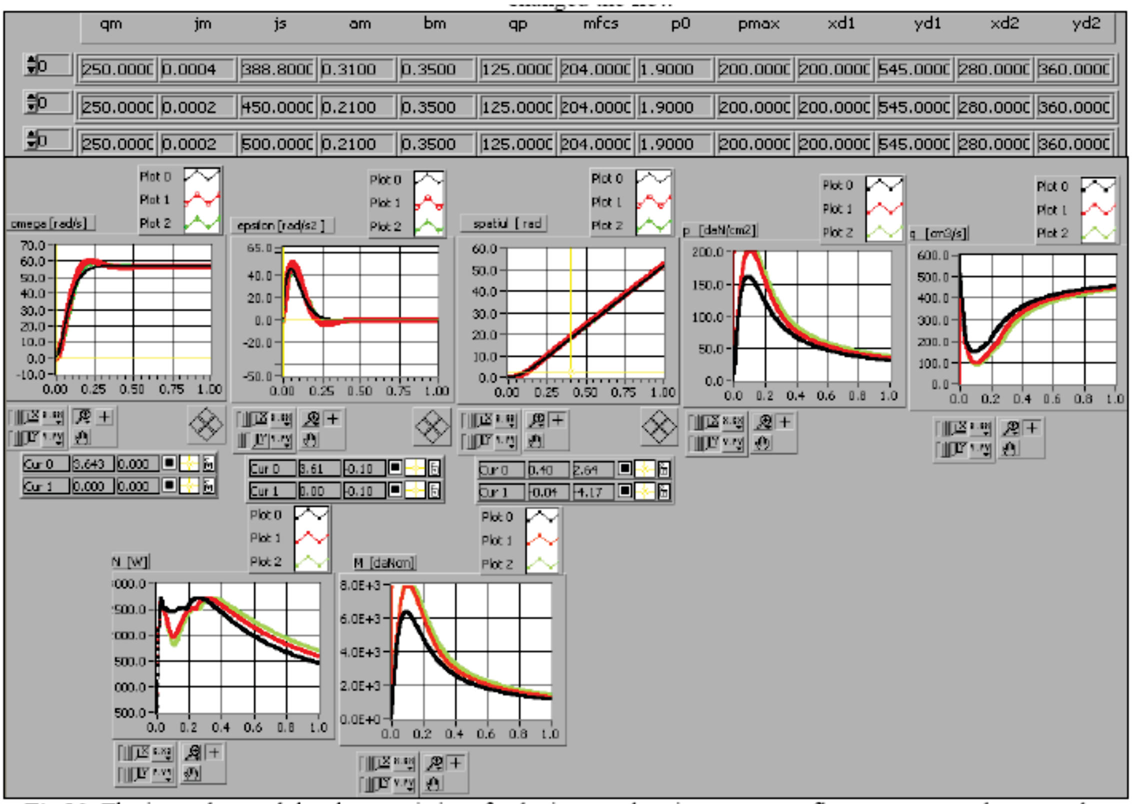


Fig.10. *The input data and the characteristics of velocity, acceleration, pressure, flow, moment and power when was changed the inertial term*

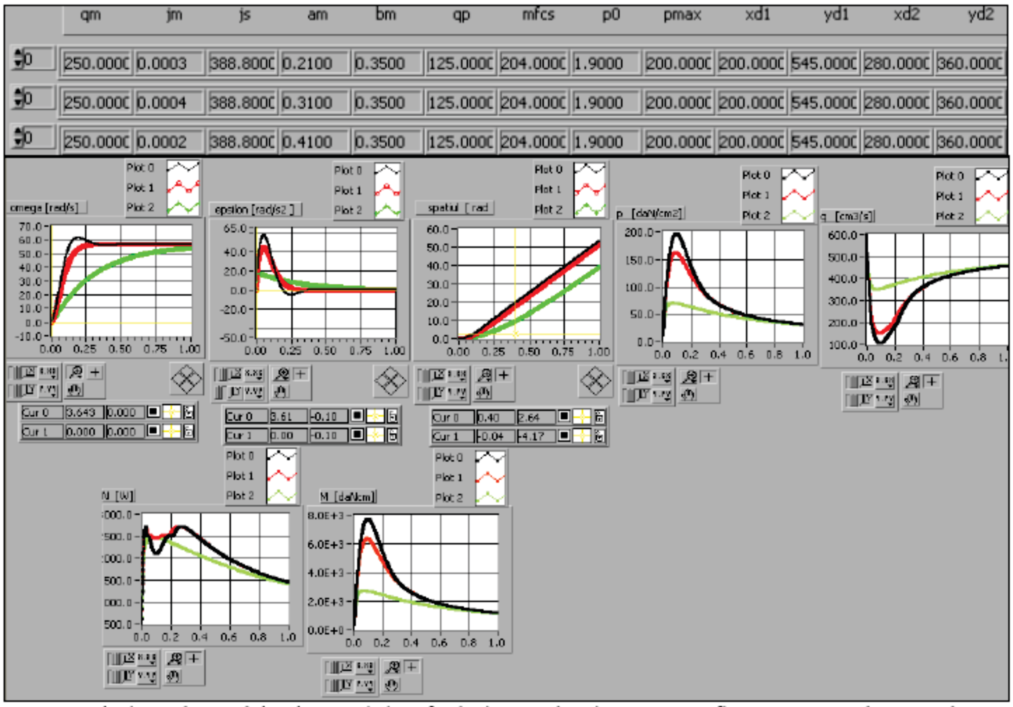


Fig.11. The input data and the characteristics of velocity, acceleration, pressure, flow, moment and power when was changed the loss flow between the motor rooms

After analyzing the results from the figs. 5-11 we can do the following remarks: by changing the inertial mass m we can control the vibrations and the output velocity, fig.5; by changing the flow loss gradient a_m we can determine the atenuation of the vibration with increase of the acceleration time and the damper force, fig.6; by changing of the discrete distribution diameter, D_m we can obtain one increase of the frequency field, of magnitude to the rezonance, and one approach to the stability limits, fig.8. By changing the flow in the servo system VFP-RHM were obtained the decrease of the power magnitude oscilations, fig.9, by increase of the inertial term, increase the power oscillations, fig.10, by increase the flow loss between the motor rooms, determine the decrease of the moment oscilations, and power, fig.11.

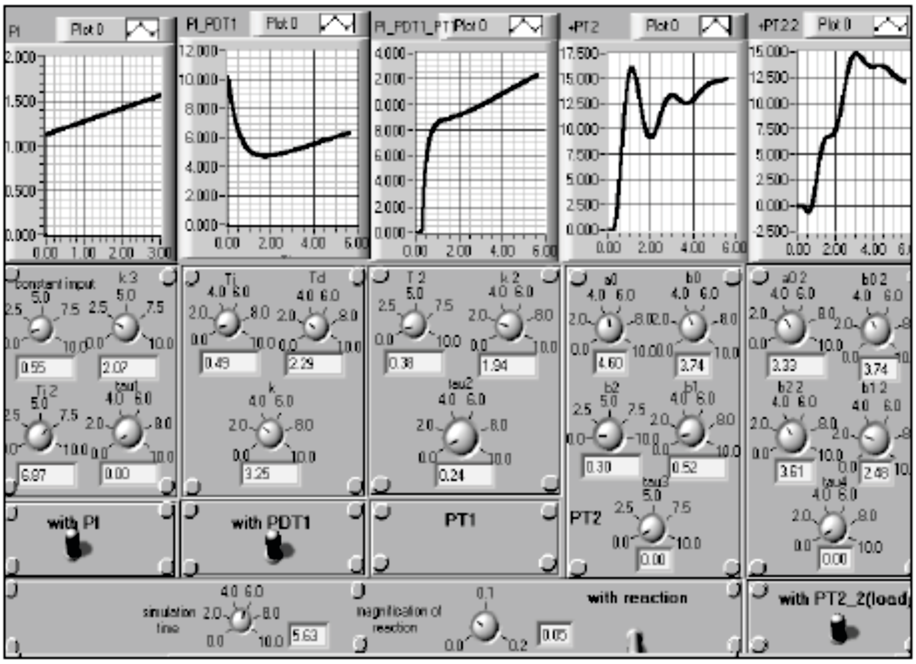


Fig.12. The indicial characteristics for the applied control low to the electrical command signals

To adjust some answer results we can use one complex control schema, fig.12, what assure on-line control of the electrical command signal of elements and systems. This signal we can optimise by on-line work of this VI and by choosing all his parameters. The signal control VI used some transfer functions: PI, PDT_1, PT_1, PT_2, PT_2 in some different variants with or without reaction. The control of the electrical comand signal is possible to adjust using some complex intelligent systems with neural network with Linear or Perceptron neurons and complex neural network schema with three differents layers with differents number of neurons[19] [20].

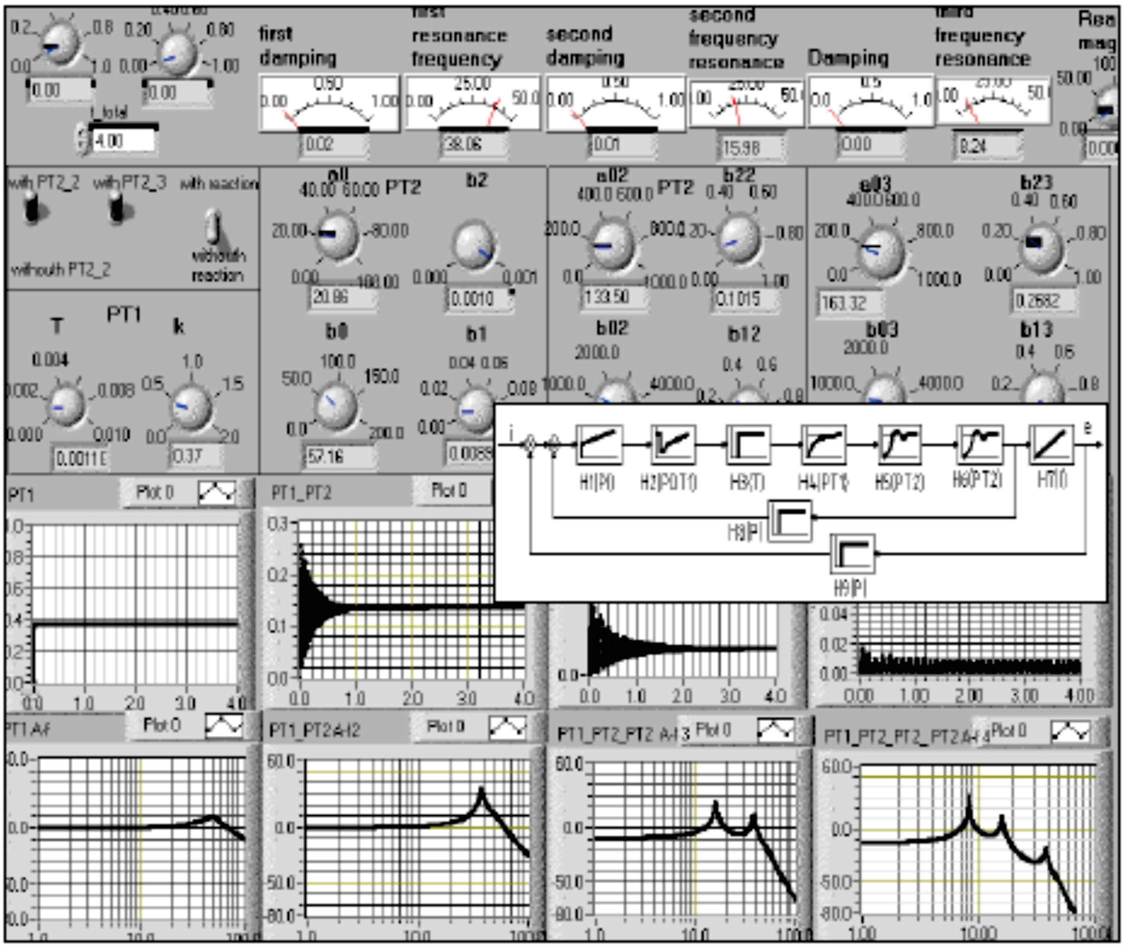


Fig.13. Front panel with the real and frequency characteristics for one complex schema with two closed loops and proportional control low

6. Conclusions

The assisted theoretical and experimenthal results assure for many researchers in this filed some important conclusions what will be possible to apply in the future research activity. The designed propre virtual LabVIEW instrumentation we can use in many other application and the research of many electrical, hydraulic or combinated systems. The transfer function method and the used mathematical model for the LHM or for some other showed systems we can apply in many future research.

The virtual LabVIEW library what contents many hydraulic, electric elements and many servo systems we can use in the theoretical and experimental research to optimise the dynamic behavior answer, to decrease the research time activities and to obtain some good results in to the developing and implementing in the future the intelligent systems.

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