ASSISTED OPTIMIZATION OF THE HYDRAULIC CYLINDER BY USING THE ROOTS LOCUS CHARACTERISTICS AND LABVIEW 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 hydraulic cylinder, using LabVIEW propre instrumentation, roots locus characteristics 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 hydraulic cylinder to obtain one good dynamic answer: maximal acceleration without vibration, minimum answer time and maximal precision. The precizion-stability problem is non compatible problem that will impose to use the Extenics theory and assisted on-line research. 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 and the study case of the hydraulic cylinder. The future research will be show the optimal choose inside of the precision- stability field of the constructive and functional parameters by using the results of the Extenics theory.

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

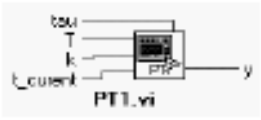
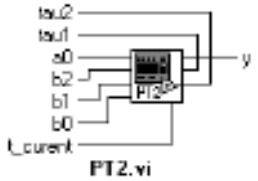
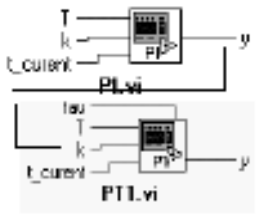
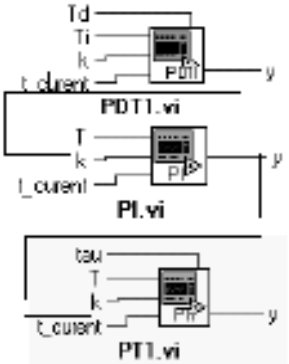
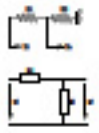
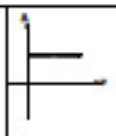
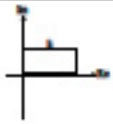
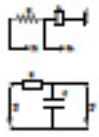
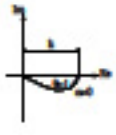
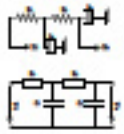
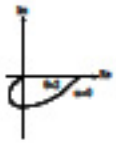
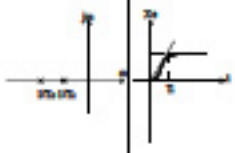
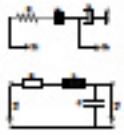
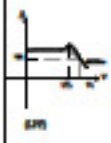
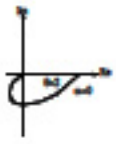
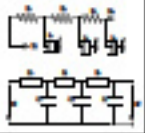
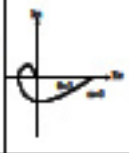
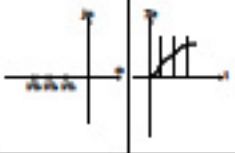
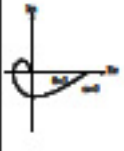
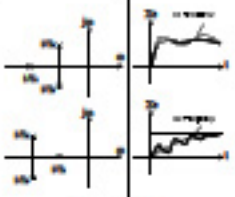
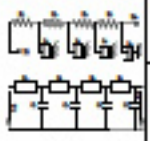
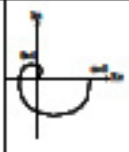
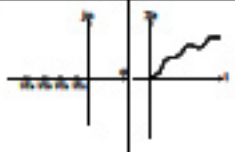
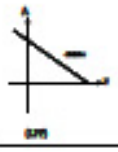
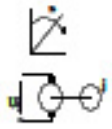
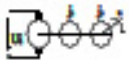
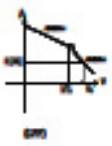
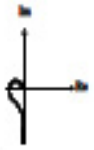
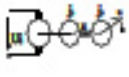
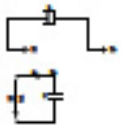
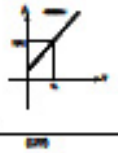
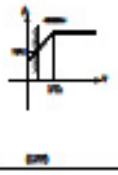
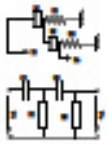
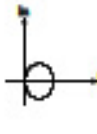
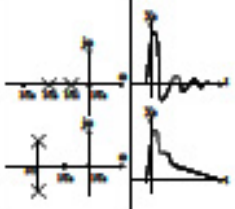
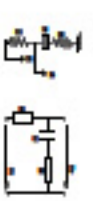
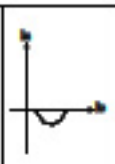
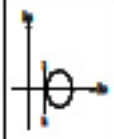
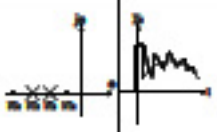
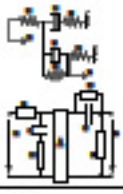
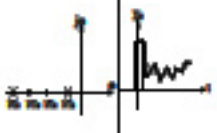
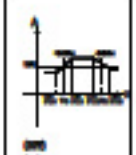
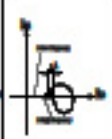
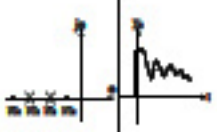
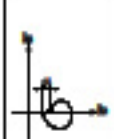
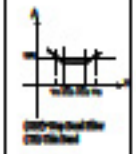
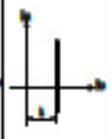
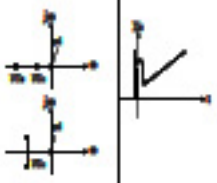
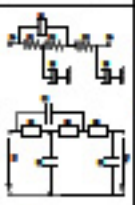
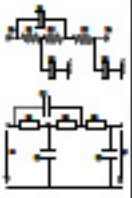
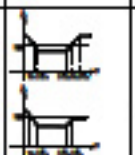
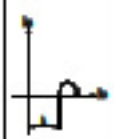
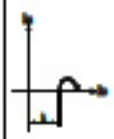
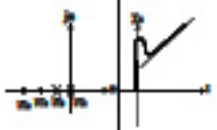
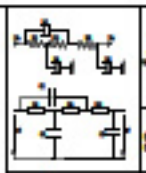
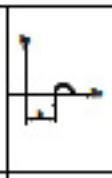
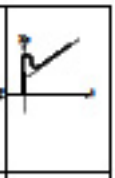
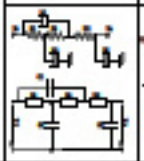
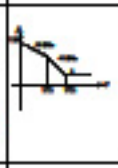
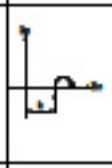
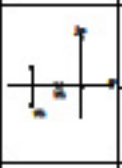
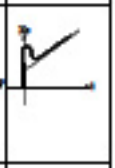
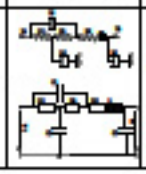
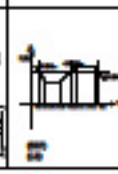
Type	Expresion of transfer function	Virtual LabVIEW instrument
PT_1	$H(s)=\frac{k}{T_1 s+1}$	
PT_2	$H(s)=\frac{k}{(s+a)(s+b)}$ $\xi>1$	
	$H(s)=\frac{k}{s^2+a^2}$ $\xi=0$	
	$H(s)=\frac{k}{(s+a)^2}$ $\xi=1$	
	$H(s)=\frac{k\omega_n^2}{s^2+2\xi\omega_n s+\omega_n^2}$ $0<\xi<1$	
PT_3	$H(s)=\frac{k}{(s+a)(s+b)(s+c)}$	
PT_4	$H(s)=\frac{k}{(s+a)(s+b)(s+c)(s+d)}$	
I	$H(s)=\frac{k}{s}$	
IT_1	$H(s)=\frac{k}{s}\cdot\frac{1}{T_1 s+1}$	
PDT_1	$H(s)=\frac{k(T_d s+1)}{T_1 s+1}$	
DT_1	$H(s)=\frac{T_d s}{Ts+1_1}$	
PID	$H(s)=k(1+T_d s+\frac{1}{Ts_1})$	
PID T1	$H(s)=k(1+T_d s+\frac{1}{Ts_1})\cdot\frac{1}{T_1 s+1}$	

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

P	$H(s)=K$					
PT1	$H(s)=\frac{K}{T_1 s+1}$					
PT2	$H(s)=\frac{K}{(T_{1_1} s+1)(T_{1_2} s+1)}$					
	$H(s)=\frac{K}{(T_{1_1} s+1)(T_{1_2} s+1)}$					
PT3	$H(s)=\frac{K}{(T_{1_1} s+1)(T_{1_2} s+1)(T_{1_3} s+1)}$					
	$H(s)=\frac{K}{(T_{1_1} s+1)(T_{1_2} s^2+T_{1_3} s+1)}$					
PT4	$H(s)=\frac{K}{(T_{1_1} s+1)(T_{1_2} s+1)(T_{1_3} s+1)(T_{1_4} s+1)}$					
	$H(s)=\frac{K}{(T_{1_1} s+1)(T_{1_2} s+1)(T_{1_3} s^2+T_{1_4} s+1)}$					
	$H(s)=\frac{K}{(T_{1_2} s^2+T_{1_3} s+1)(T_{1_3} s^2+T_{1_4} s+1)}$					

I	$H(s)=\frac{K}{s}$					
IT1	$H(s)=\frac{K}{s}\frac{1}{T_1 s+1}$					
IT2	$H(s)=\frac{K}{s}\frac{1}{T_{1_2} s^2+T_{1_1} s+1}$					
IT3	$H(s)=\frac{K}{s}\frac{1}{(T_1 s+1)(T_{1_2} s^2+T_{1_1} s+1)}$					
D	$H(s)=T_D s$					
DT1	$H(s)=\frac{T_D s}{T_1 s+1}$					
D2T2	$H(s)=\frac{T_{D_2} s^2+T_{D_1} s}{T_{1_2} s^2+T_{1_1} s+1}$					
PDT	$H(s)=\frac{K(T_D s+1)}{T_1 s+1}$ $T_D > T_1$					

PDT1	$H(s)=\frac{K(T_D s+1)}{T_1 s+1}$ $T_D < T_1$					
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	$H(s)=\frac{s^2+(a_1+b_2)s+a_1b_2}{s^2+(a_2+b_1)s+a_2b1}$ $a_1b_2=a_2b_1;\ (a_1+b_2)<(a_2+b_1)$					
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	$H(s)=K\left(1+T_d s+\frac{1}{T_i s}\right)\frac{1}{T_1 s^2+T_1 s+1}$					

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 cylinder's mathematical model and the experimental validation [10, 11, 12, 13, 14]

The applied mathematical model, in this case for the hydraulic cylinder, 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:

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

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

$$T_1T_2\frac{dx_e^2}{dt^2}+h(T_1+T_2)\frac{dx_e}{dt}+x_e=kU \tag{2}$$

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

$$\begin{pmatrix}x_1'\\x_2'\end{pmatrix}=\begin{bmatrix}0 & 1\\-\frac{1}{T_1T_2} & -\frac{h(T_1+T_2)}{T_1T_2}\end{bmatrix}\begin{pmatrix}x_1\\x_2\end{pmatrix}+\begin{pmatrix}0\\\frac{k}{T_1T_2}\end{pmatrix}U(t) \tag{3}$$

$$Y=\begin{pmatrix}1 & 0\end{pmatrix}\begin{pmatrix}x_1\\x_2\end{pmatrix} \tag{4}$$

General for of the state space relation will be:

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

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

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

where:

$$T_1 T_2 = \frac{m\frac{A_1 c}{2E}}{A_1^2(1-c_{fu}) + a_m b_m}; h(T_1 + T_2) = \frac{ma_m + \frac{A_1 c}{2E} b_m}{A_1^2(1-c_{fu}) + a_m b_m}; \tag{7}$$

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

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]; Δp- 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:

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

Finally, after changes of the product in the sume and after applied the inverse Laplace transformation the relation for the velocity of the hydraulic cylinder 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 numerical simulation step and the experimental research of the cylinder were obtained the characteristics from the fig.1.

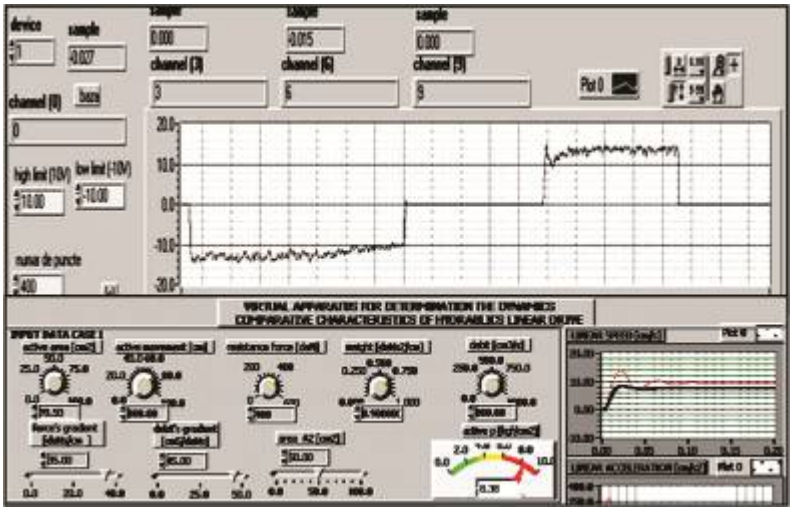


Fig.1. Validation of the LHM mathematical model- comparative analyze of the experimental and simulation results

4. Assisted optimisation of the hydraulic cylinder using the propre LabVIEW instrumentation

The assisted optimisation used the validated mathematical model of the cylinder 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.

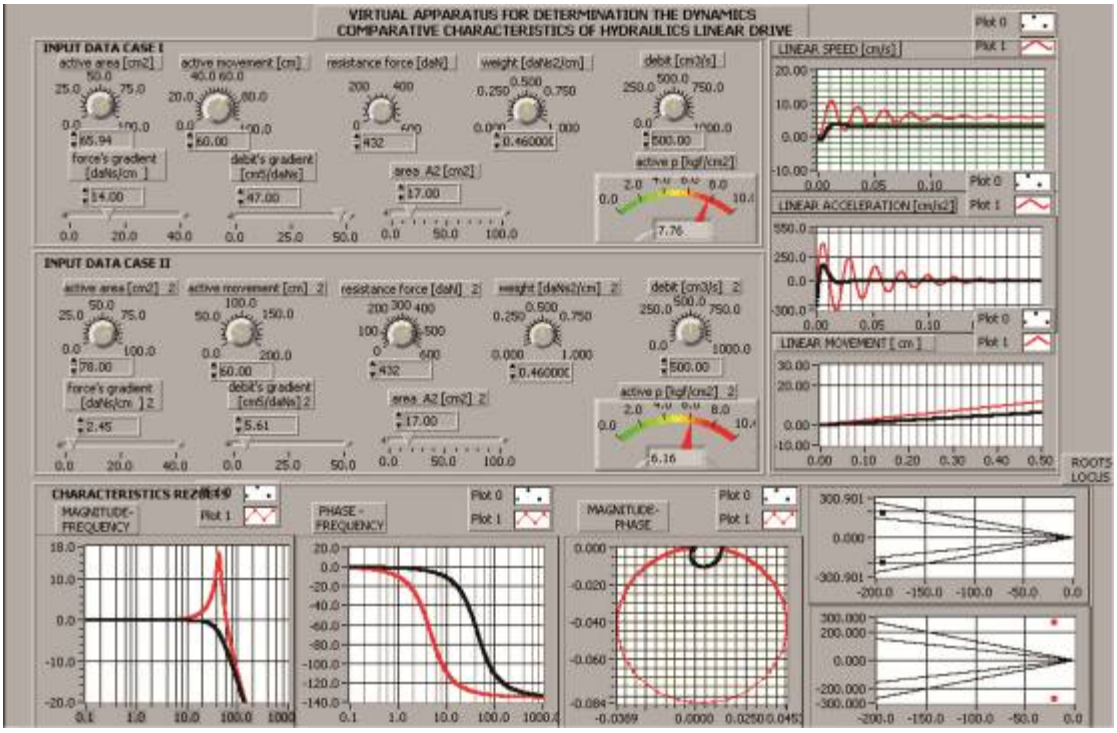


Fig.2. Front panel of the virtual LabVIEW LHM instrument for the comparative analyze, when was changed the flow and resistance force gradients, a_m, b_m

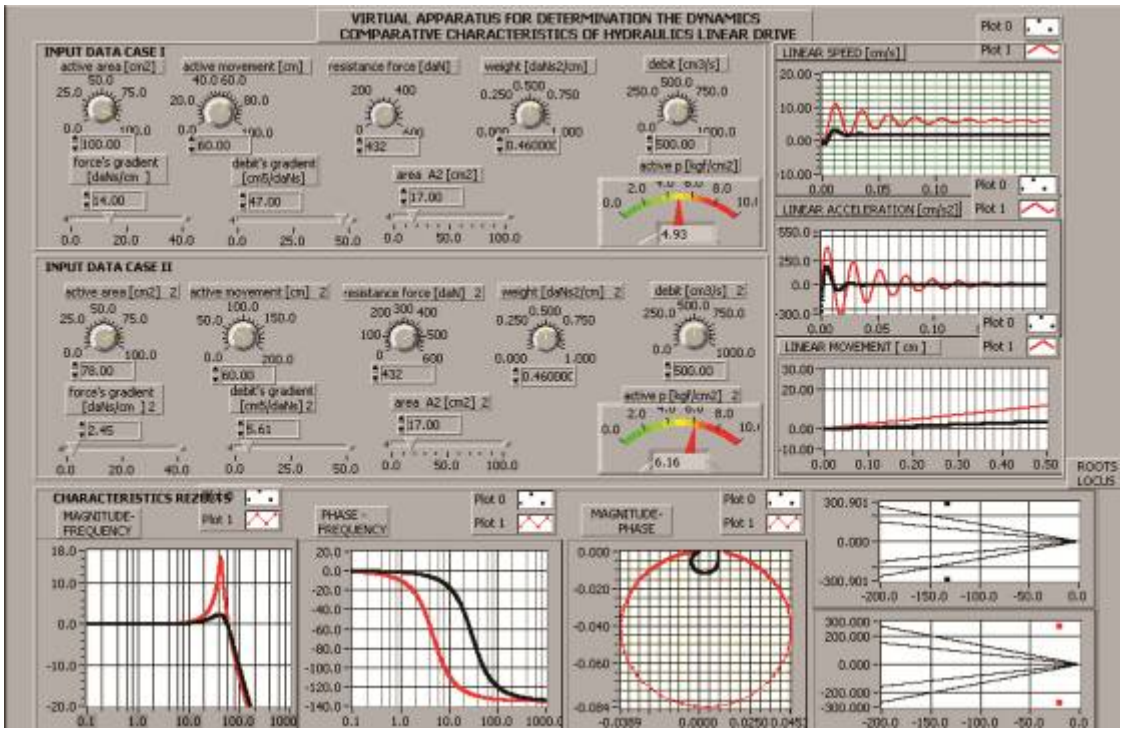


Fig.3. Front panel of the virtual LabVIEW LHM instrument for the comparative analyze, when was changed the active area, A_1

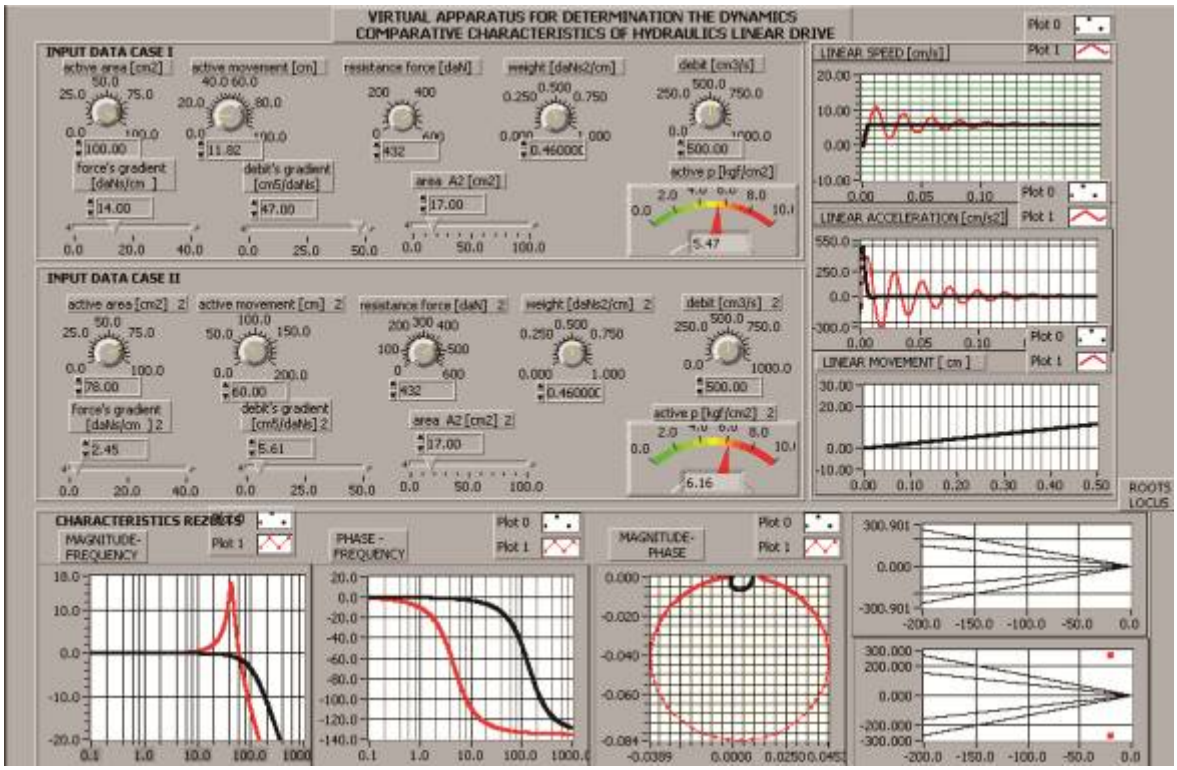


Fig.4. Front panel of the virtual LabVIEW LHM instrument for the comparative analyze, when was changed the active area and the movements of motor steam, A_1, *c*

Analyzing the optimization applied to the hydraulic cylinder 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 hydraulic cylinder 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. The constraints of the precision- stability field is shown in fig.5.
To optimize the dynamic behavior on used the roots locus method are shown in the paper, figs.6-8.

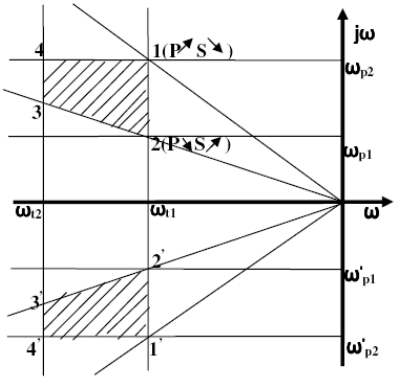


Fig.5. The constraints of the precision-stability field

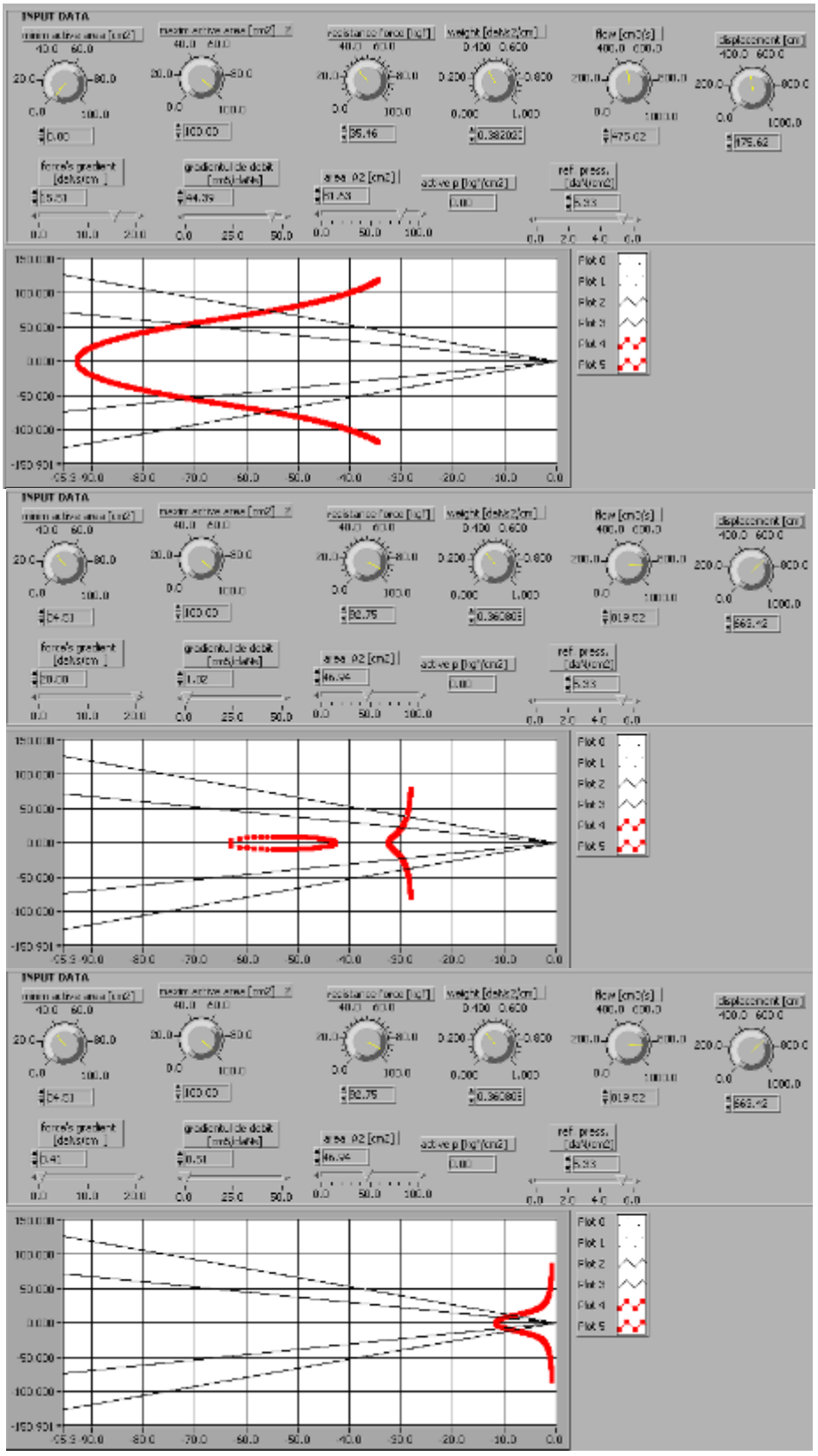


Fig.6. Some results of the roots locus after the numerical simulation when were changed in the functional field: active area and force and flow gradients

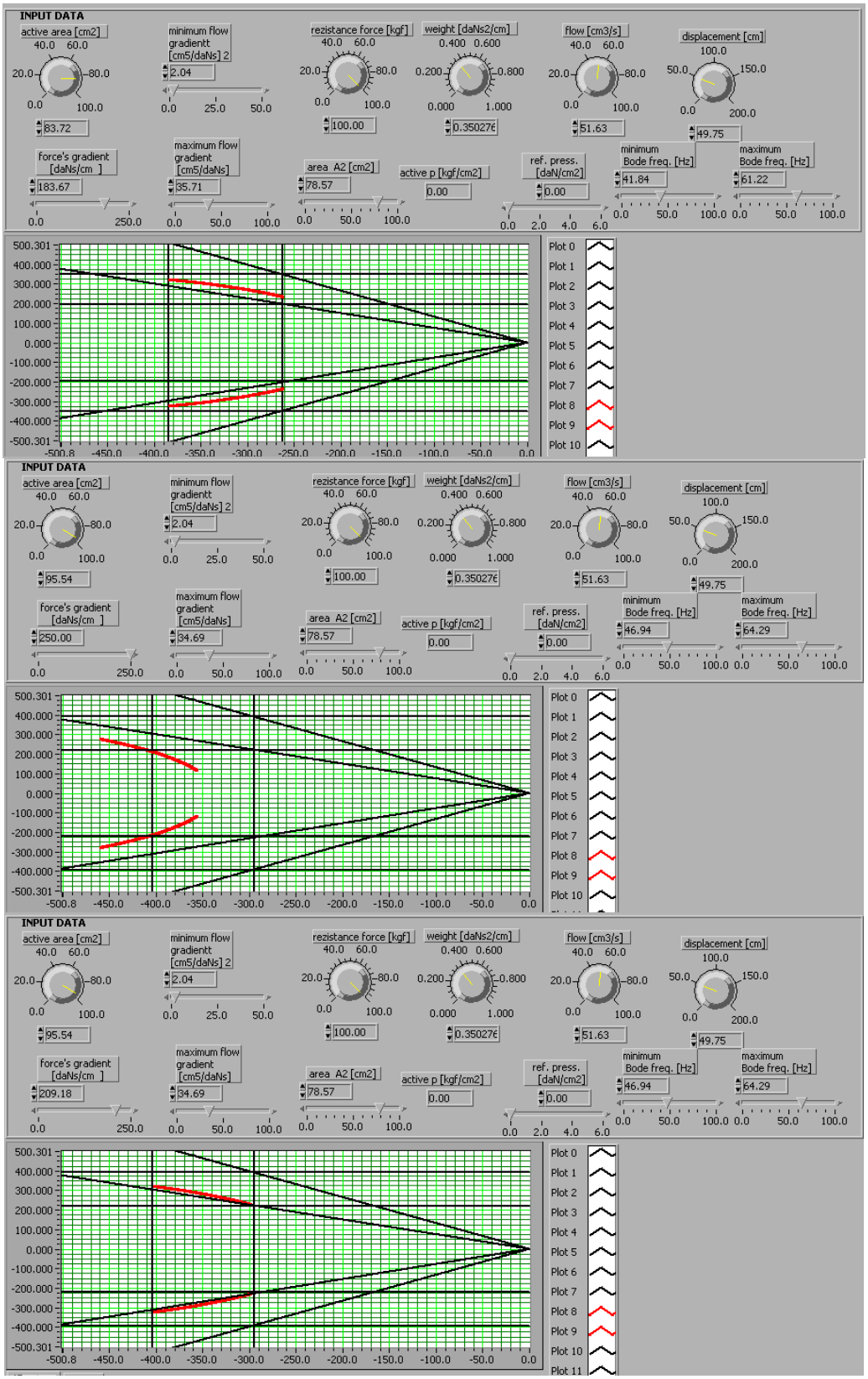


Fig.7. Some results of the roots locus when were changed flow gradient, force's gradient and active area

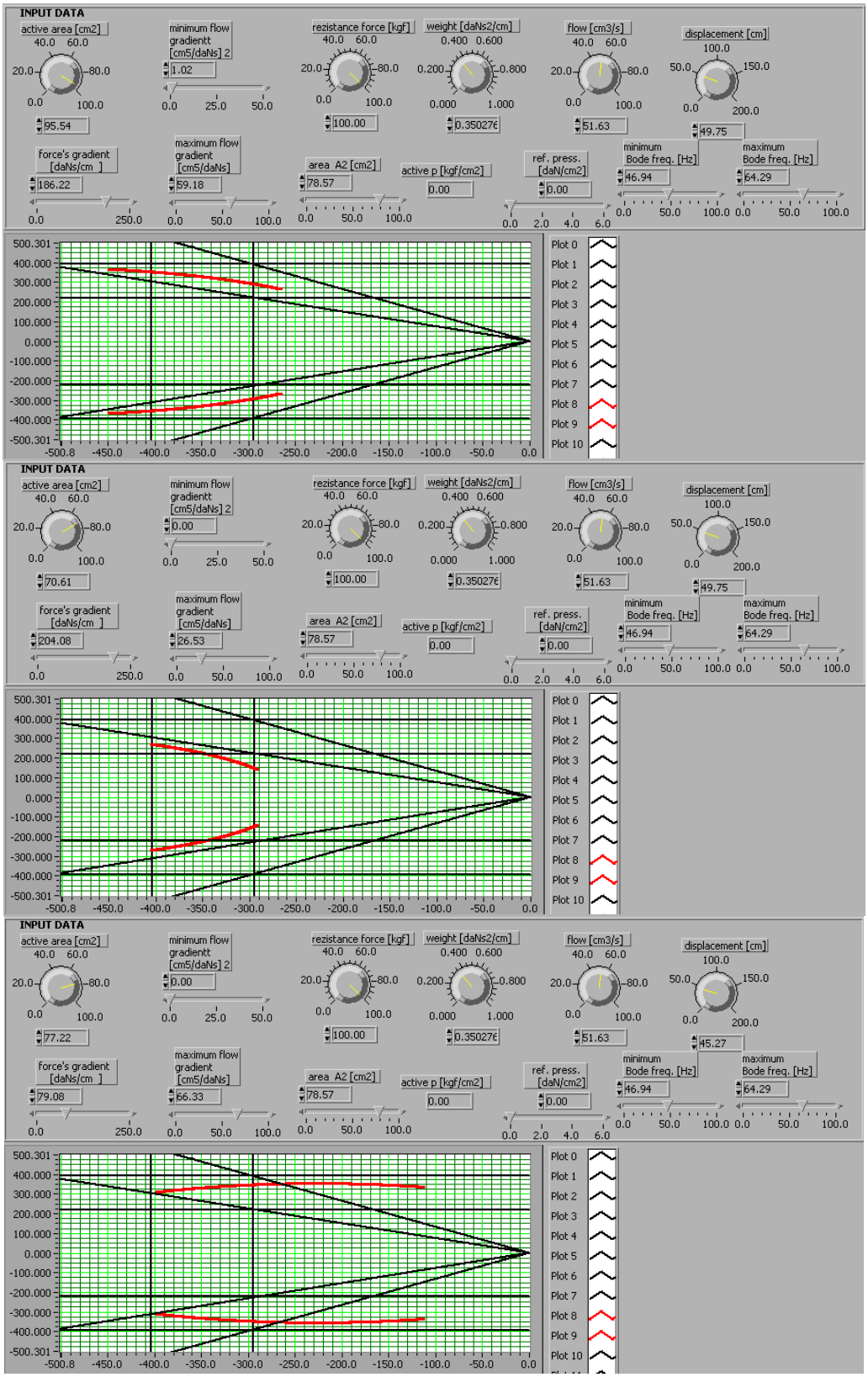


Fig.8. Some results when were changed flow gradient, force's gradient, active area and displacement

The optimal answer of the hydraulic cylinder about the precision- stability criteria using the roots locus method is the case *a* and *c* from the fig.7.
The constraints are the followings:

$$\begin{aligned} &\nu_{t2} \le \nu_t \le \nu_{t1} \\ &\xi_2 \le \xi \le \xi_1 \\ &\nu_{p2} \le \nu_p \le \nu_{p1} \\ &\nu_{n2} \le \nu_n \le \nu_{n1} \end{aligned} \qquad 10)$$

and the conditions will result after the on-line numerical simulation:

$$\begin{aligned} &A_2 \le A \le A_1 \\ &a_{m2} \le a_m \le a_{m1} \\ &b_{m2} \le b_m \le b_{m1} \\ &c_2 \le c \le c_1 \end{aligned} \qquad (11)$$

In the study case the goals were:

$$\begin{aligned} &41 \le \nu_t \le 61 \\ &0.7 \le \xi \le 0.8 \\ &31 \le \nu_p \le 55 \\ &43 \le \nu_n \le 91 \end{aligned} \qquad (12)$$

and the on-line choosing the conditions:

$$\begin{aligned} &83 \le A \le 95 && [\text{cm}^2] \\ &2 \le a_m \le 35 && [\text{cm}^5/\text{daNs}] \\ &183 \le b_m \le 209 && [\text{daNs/cm}] \\ &40 \le c \le 50 && [\text{cm}] \end{aligned} \qquad (13)$$

5. Conclusions

The assisted research with the LabVIEW instrumentation open the way to optimize the dynamic behavior of the elements and systems. In the study case was researched one hydraulic cylinder for what were imposed some goals (constraints) linked to the application. The complex problem of all dynamic behavior of the elements and systems is to optimal solve the contradiction problem between the precision and stability, because if the precision increase, the stability decrease. The optimization method what used to solve this problem was to define some constraints of the precision-stability field and to try put the roots locus inside of this field. After that easily could see the values of the functional and constructive parameters what solve the problem. The research was easily solved by on-line numerical simulation by using the virtual LabVIEW instrumentation. In the future will be applied the Extenics new complex mathematical method and the assisted LabVIEW instrumentation dedicated to this subject, optimal solves the contradictory problem.

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