ASSISTED DYNAMIC BEHAVIOR OPTIMIZATION OF THE ROBOTS SERVO DRIVING

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1. Introduction

The real revolution in the experimental research had begun with the LabVIEW and the graphical programming (G). In 1986 National Instruments it was created version 1.0 of LabVIEW (Laboratory Virtual Instrument Engineering Workbench) with the purpose to assure the researchers one produce, what to contain the best tools of the research and the analyze. We actually pioneered, the virtual instrumentation revolution, a revolution that is changing instrumentation in both, the test and measurement marker, and the industrial automation market, by driving down costs without sacrificing performance.

The virtual LabVIEW instrumentation assures the reduction of the apparatus number, the research time and finally, the cost. In these conditions, all stages of the research are optimized and reduced. Mathematical modeling and analyses of the elements and the systems are better when they are known the dynamic behavior of all components. For this reason, it is necessary to analyze all elementary transfer functions, and create proper simulation LabVIEW programs (VI). In this case, it is possible to apply easily the electrical corrections and regulators and comparing between then the real or frequency characteristics of the output results. In this paper are presented some of the mathematical model for the elementary transfer functions and icon of the virtual LabVIEW instruments [1]. With these instruments, the researchers will have the possibility to analyze, on-line, the influence of some constructive and functional parameters, on the dynamic behavior of elements and robot systems. The paper presents some virtual proper LabVIEW instruments for the hydraulic and the pneumatic motors, the electrical and mechanical corrections, analyze for the some closed loop systems with transfer functions, the different control laws, etc. The present paper shows the assisted method of the dynamic behavior analyzes by using the elementary transfer functions. These functions are coupled in the different way to approximate with small errors the physical robot model. The assisted method of the research, presented below, contents the most important elementary transfer functions. For all have been created the virtual instruments by using LabVIEW soft 6.1 from National Instruments, USA. Many of these (VI), what approximate the dynamic behavior of the robot modulus, have been researched by comparing with the real dynamic behavior obtained by experimental research and data acquisition. The results after this comparison is that the errors of the modeling with the transfer functions are smaller that 10%. For these reason in the most scientific works of the world are used the linear model with the elementary transfer functions.

All the proper LabVIEW instruments offer the large possibilities to show the results, to compare, in a short time, the real with the simulate results, to establish very quickly the constructive or functional optimal parameters for the magnitude coefficient, for the *PID*, PD_2 or for the other control laws parameters, or the place and the type of the applied rheological damper.

2. General mathematical models

The mathematical model for the dynamic behavior of the pneumatic motor and for the hidraulic motor with proportional distribution are presented below.

Functional schema of the linear pneumatic motor LPM, hidraulic system with linear hidraulic motor and proportional distribution LHMPD for the industrial robot are presented in figures 1 and 2 [1], [2]. All these models for the assisted experimental research, by comparing the theoretical with the experimental results, we were validated.

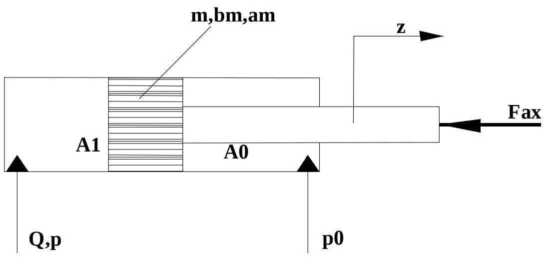


Figure 1: *The functional diagram of the linear pneumatic motor*

The mathematical model of the dynamic behavior determined bases of this functional schema, is given by [1]:

$$Q = A_1 \frac{dz}{dt} + a_m \Delta p + \frac{V}{\chi p} \cdot \frac{d\Delta p}{dt} \qquad (1)$$
$$m \frac{d^2 z}{dt^2} + b_m \frac{dz}{dt} + F_{ax} = A_1 \cdot \Delta p ;\ p \cdot V^{\chi} = ct$$

where the values of the parameters according with the experimental stand are: Q is the air flow 20-100 [cm^3]; A – active motor area 50-80 [cm^2]; z- active movement 30-40 [cm]; a_m- proportional gradient of loss flow with pressure 0.2-0.7[cm^5/daN]; Δp- loss pressure 4-6 [daN/cm^2]; ΔV – air 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_r – resisting forces 10-30 [daN]; χ- adiabatic coefficient 1,4 [-].

The final transfer function between the airflow and the displacement is:

$$H(s) = \frac{z(s)}{Q(s)} = \frac{A_1}{s[\frac{V}{\chi p} \cdot m \cdot s^2 + (\frac{V}{\chi p} \cdot b_m + m \cdot a_m)s + (A_1^2 + a_m b_m)]} \qquad (2)$$

We observe that this transfer function is from the IT_2 type.

For the modeling of the linear hydraulic motor system with proportional distribution (LHMPD), we used the physical schema, figure 2. The mathematical model for this system is given by [2]:

$$k_m i = m \frac{d^2 x_1}{dt^2} + h \frac{dx_1}{dt} + k_e x_1 + 2 c_d{}^2 \pi d x_1 (p_0 - p_1);\ p_1 - p_2 = p_0 \frac{2 \frac{x_1}{x_0}}{1 + (\frac{x_1}{x_0})^2}$$

$$(p_1 - p_2)\frac{\pi D^2}{4} = m_s \frac{d^2 y}{dt^2} + h_s \frac{dy}{dt} + ky + 2 c_d{}^2 \pi D (p_0 - p_1) \qquad (3)$$

$$Q_m = 4 c_d y^2 tg\varphi \sqrt{\frac{2}{\rho}} \sqrt{p_0 - p_s};\ Q_m = A_1 \frac{dz}{dt} + a_m (p_0 - p_r) + \frac{V}{2E} \frac{dp}{dt}$$

$$M \frac{d^2 z}{dt^2} + H \frac{dz}{dt} + c_{fu} \operatorname{sgn}(\frac{dz}{dt})(A_1 p_0 - A_2 p_r) + F = A_1 p_0 - A_2 p_r$$

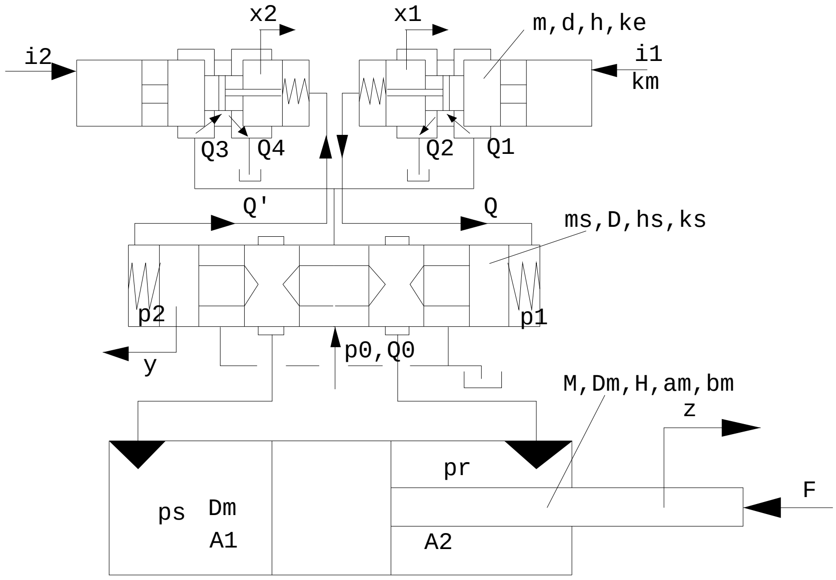
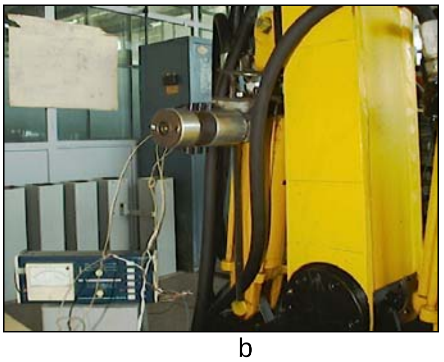


Figure 2: *The physical model of the linear hydraulic motor with proportional distribution*

The values, according with the experimental stand, are: k_m is the gradient of the forces proportional with the electrical intensity of the spools, 2 daN/A; *d* –diameter of the pilot valve, 10 mm; k_e –elasticity constant of the spring valve, 0.0454 daN/cm; x_0 –maximal way of the valve, 0.7 mm; *m* -mass of the valve pilot, 0.000006 daNs^2/cm; *h* –damper coefficient of the valve, 0.04 daNs/cm; m_s –mass of the distribution pilot, 0.0002 daNs^2/cm; p_0 –experimental tested pressure of the system, 20 daN/cm^2; *D* –diameter of the distribution pilot, 16 mm; φ -angle of the triangular flow way, 60^0; D_m- diameter of the linear hydraulic motor (LHM), 63 mm; a_m –linear loss gradient of the flow, proportional with the pressure in LHM, 0.3 cm^5/daNs; b_m –linear loss gradient of the force proportional with the LHM velocity, 0.3 daNs/cm; *V*- internal volume of the LHM, 2500 cm^3; *M* -mass of the load and LHM steam, 0.030 daNs^2/cm; *N* –number of the analyze points; *t* –observation time, s; *dt* – samples period. These values are in a concordance with the physical researched models.

3. Experimental research and validation

To accomplish the proposed objectives we made the experimental stands with some physical hydraulic and pneumatic components, the acquisition board from National Instruments USA and the soft LabVIEW version 6.1 from the same company. All the proper VI has been validated with smaller that 10% error, as we can see in the paper. The experimental stands contains the following components (figs.3 a, b): hydraulic power tank, the LHM with proportional distribution, the central airflow, the LPM, linear inductive transducers, electrical controller of the spools, connectors, cables and PC.



a b

Figure 3: *Experimental stands*

a- stand for the assisted research of the LHM with proportional distribution system;

b- stand for the assisted research of the LHM and LPM

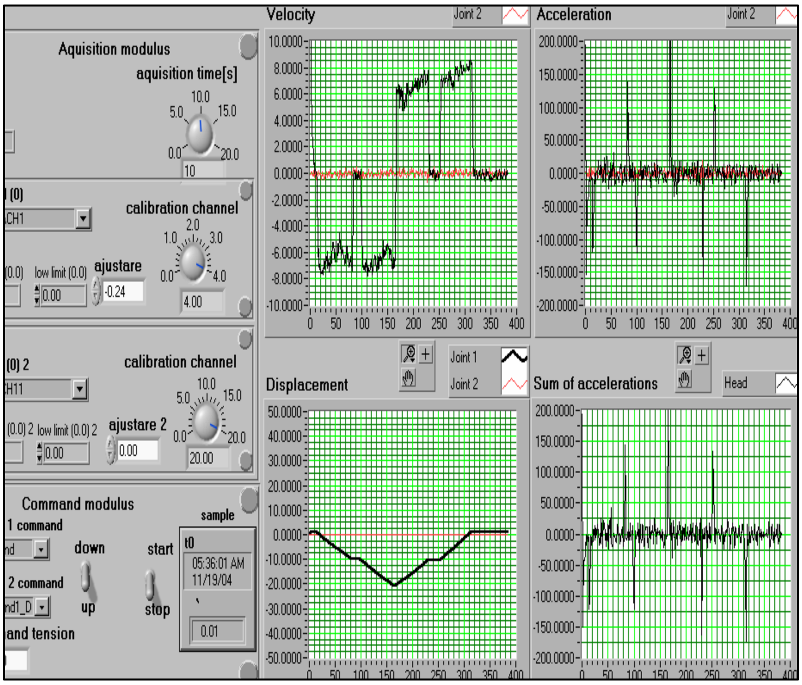


Figure 4: *Front panel, which shows the input data of the command parameters and the real characteristics of the velocity, acceleration and the space for the movement case down_down without delay up_up*

4. <u>Numerical optimization</u>

In this paper, the numerical optimization was made by two ways: the first way – by changing some constructive parameters and comparing the real and frequency characteristics; the second way - by introduction in a system of some electrical or mechanical correction, the different control laws, or some different closed loops.

The method consists in a change of some parameters and the calculus of the influence coefficients after comparing the real and frequency characteristics and choose the optimal value depending of the dynamic parameter.

The influence coefficients we was determined by [2]:

$$C_i = \frac{R_{PCD}}{R_{PCF}} \tag{4}$$

where:

$$R_{PCD} = \frac{PCD_i - PCD_f}{PCD_i} ; \quad R_{PCF} = \frac{PCF_i - PCF_f}{PCF_i} \tag{5}$$

R_{PCD} is the variation raport of the dynamic parameter; R_{PCF} – the variation raport of the constructiv or functional parameter; PCD_i -the initial value of the dynamic behavior parameter; PCD_f – final value of the dynamic behavior parameter; PCF_I – initial value of the constructive- functional parameter; PCF_f – final value of the constructiv- functional parameter. The dynamic behavior results of the LPM and LHMPD, after changing some of the functional or constructive parameters are presented in figs.5…8, respectively figure 9 [1], [2], [3].

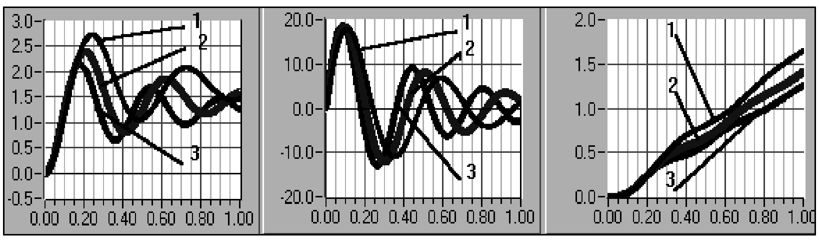


Figure 5: *The real linear velocity, acceleration and displacement characteristics when was changed the active area A: 60, 70 and 80 (cm^2)*

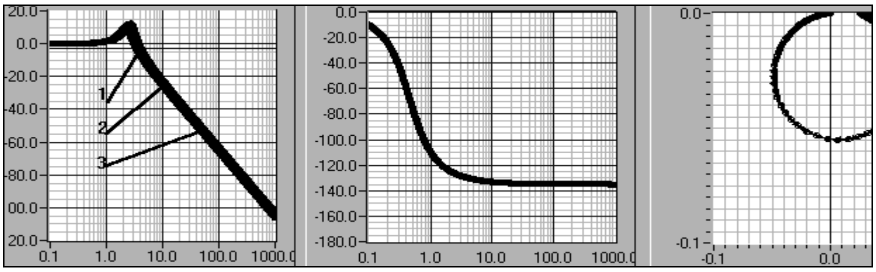


Figure 6: *The Bode magnitude- frequency, phase- frequency and the Nyquist magnitude - phase characteristics when was changed the active area A*

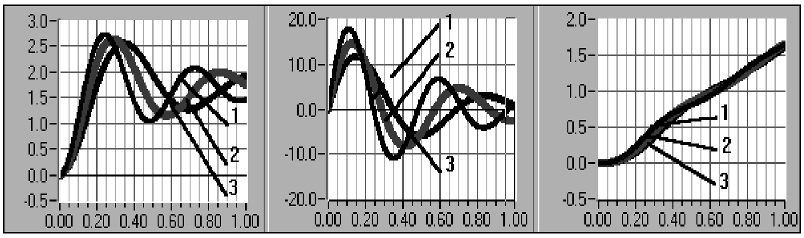


Figure 7: *The real linear velocity, acceleration and displacement characteristics when was changed the active volume V: 500, 700, and 1000 (cm^3)*

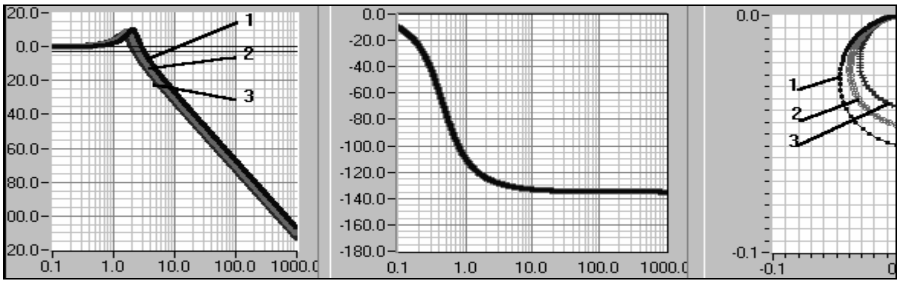


Figure 8: *The Bode magnitude- frequency, phase- frequency and the Nyquist magnitude- phase characteristics when was changed the active volume V*

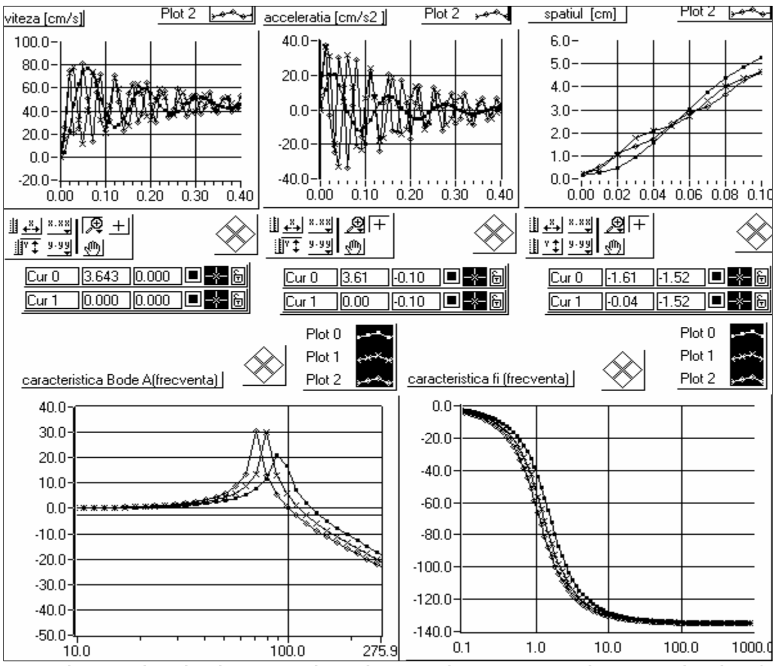


Figure 9: *The real velocity, acceleration and space, Bode magnitude- frequency, phase- frequency characteristics when was changed the mass m of load LHMPD*

This extended assisted research with many others constructive and functional parameters, which have been changed, are presented in the book [2].

After analyzing the real characteristics, figs.5…8, and applying the presented method, results the values of the influence coefficients (table 1).

Table 1:The influences coefficients of the dynamic behavior of the LPM

	t_r	a_{max}	ν_r	ν_c
A 0.15	0.28	0.11	0.3	1.0
	1.86	**0.73**	**2.0**	**6.66**
V 0.40	0.5	0.11	0.25	0.16
	1.25	**0.275**	**0.625**	**0.4**
m 1.0	0.33	0.22	0.25	0.33
	0.33	**0.22**	**0.25**	**0.33**

The analyze, what the constructive and functional parameters influences the dynamic behavior of the LPM, have been made with the reading the bigger value of the influences coefficients in each row, respectively in the each column of the table 1. Reading by rows the bigger values of the influences coefficients on observe: the increases of the active area *A* determines with priority the increases of the critical frequency (6.66), the increases of the volume *V* determines with priority the increases of the answer time t_r (1.25), the increases of the mass *m*, determines with priority the increases of the answer time t_r (0.33) and the critical frequency ν_c (0.33). By reading the bigger values of the influences coefficients for each columns of the table 1, we can observe that all the dynamic parameters are influenced by the active aria *A*. With this method is possible to see and to change on-line all parameters to obtain the optimal answer of the outputs, depending of the dynamic application. For example, if we need one good answer, the small t_r, it is necessary to change the mass *m*, and s.o. Training with these instruments assures one optimal middle in the researcher's hands. The icon and some of the assisted results of the virtual LabVIEW instrument for analyzing the linear hydraulic motor (LHM) are presented in figures 10…13. In the figures 11 and 12 are presented some results after changing the constructive parameters to move in a precision field, the complex roots of the LHM in a roots plane and in figure 13 is presented the results after it was applied the PD_2 control law on the command block of the LHM after changing the complex roots position [3].

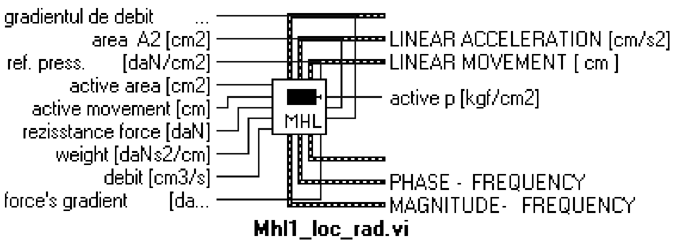


Figure 10: *The icon of the virtual LabVIEW instrument of the assisted dynamic behavior research of the LHM*

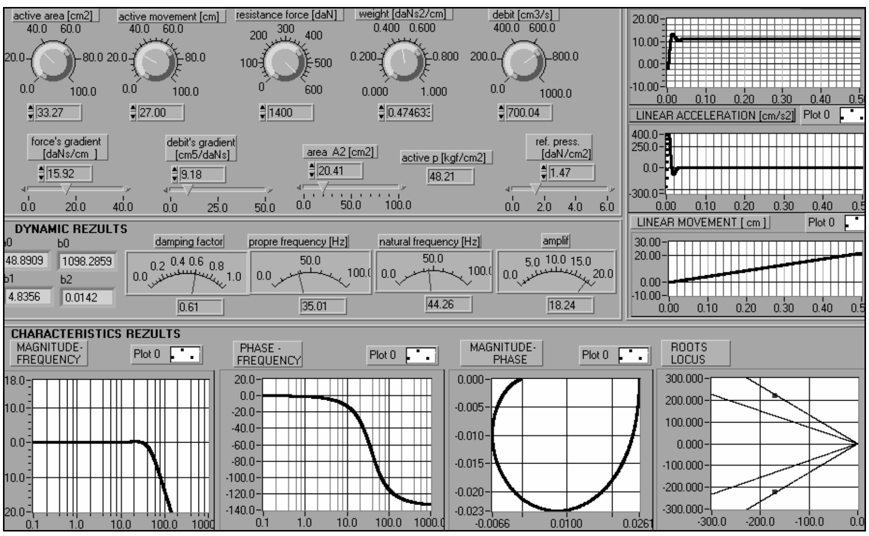


Figure 11: *The front panel with the input data and the results of the LMH when is applied the correction of the gradient loss flow, the roots are in a stability field*

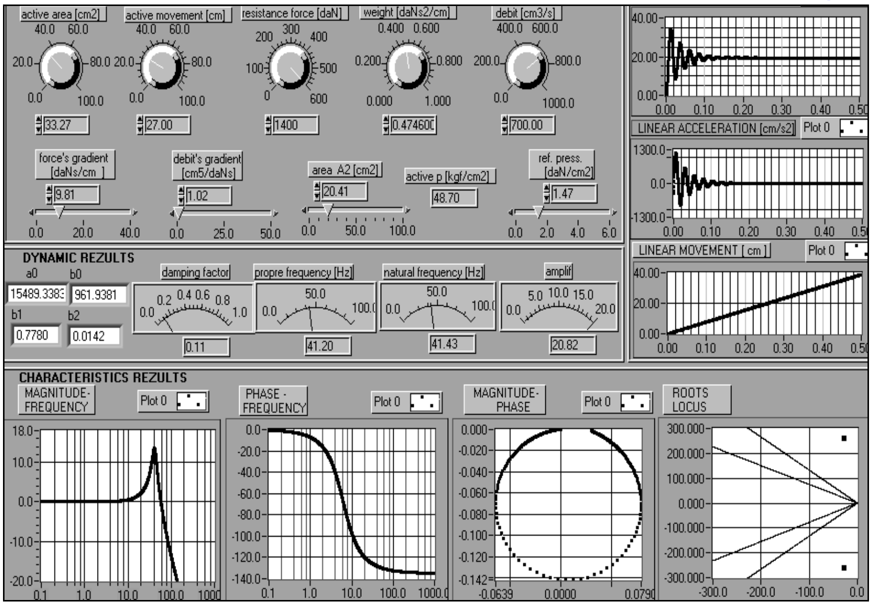


Figure 12: *The front panel with the input data and the results of the LHM without the correction of the gradient loss flow, the roots are out of the stability field*

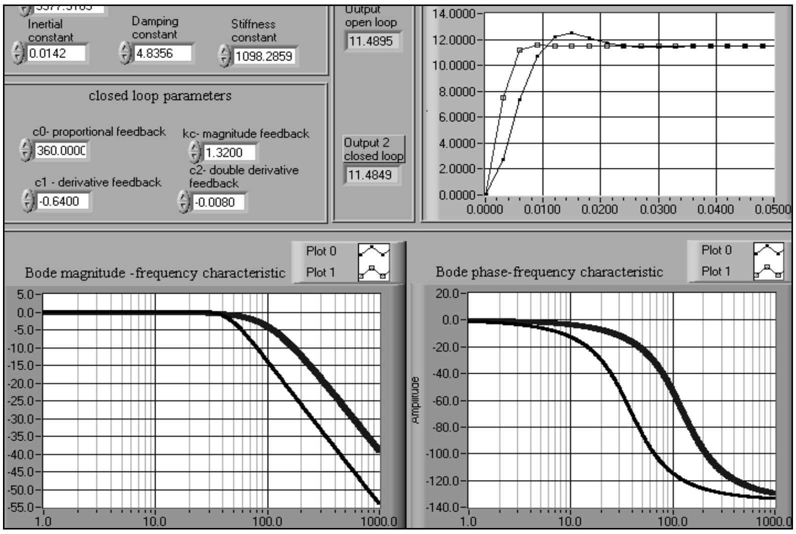


Figure 13: *The front panel of the (VI) with the input data and the results when was applied the PD_2 control law of the command block of the LHM*

From the figure 13 we observe that after application of the PD_2 control law, the acceleration time, the oscillation was reduced by 50%, and the frequency domain was increased by 100%, for the same constructive and functional parameters.

5. Conclusions

The methodology has been applied in this paper is very generally and it is possible to apply in many other mechanical systems. Mathematical models and the presented *VI* from the paper, offers many interesting results. With the presented *VI*, the time and the cost of the research will be smaller and the theoretical and experimental results will be optimum. The present paper assures all conditions for the application in the future of the smart structures in an industrial robot construction.

References

[1] Olaru, A., *Virtual LabVIEW instrumentation in the technical research of the robots elements and the systems,* Bren Publishing House, pp. 77-80, Bucharest, 2002.

[2] Olaru, A., *Dynamic of industrial Robots- Modeling dynamic behavior of the elements and the systems utilized in construction of the industrial robots,* Bren Printing House, pp.167-175, Bucharest, 2001.

[3] Olaru, A., *Aspects about modeling and simulation dynamic behavior servodriving industrial robots*, Proc. of the Int. Conf. on Solid Mechanics, Bucharest, Romanian Academy, pp.241-248, 2002 available at: http://www.dri.pub.ro /