Assisted dynamic behavior optimization with LabVIEW instrumentation

Adrian Olaru[1] and Serban Olaru[2] [+]

University Politehnica of Bucharest

Abstract. The paper presents one new method for the analyze of the industrial robots dynamic behavior. The method consists in on-line simulation of the real and frequency characteristics and compare them with the experimental characteristics obtained by data acquisition with the virtual LabVIEW proper instruments. The paper presents many virtual instruments for analyzing the hydraulic, electric and pneumatic motors, the complex systems with many closed loops, the electrical and mechanical corrections, and some complex schemas with different control laws. All the instruments have the possibility to show on-line, and to see what is happening when changing one of the functional or the constructive parameters. For analyzing and optimization the elements and the systems are presented some instruments for comparative analyze. This method and all created virtual LabVIEW instruments can be applied in many others mechanical systems.

Keywords: dynamic behaviour, assisted research, LabVIEW instrumentation

1. Introduction

Mathematical modelling and analyses of the elements and the systems are better when will be known the dynamic behaviour of all components. For this reason it is necessary to analyze all elementary transfer functions, and create proper simulation LabVIEW programs, *VI* [1]. With these instruments, the researchers can determine on-line, easily, the most important influence of some constructive or functional parameters, for the dynamic behaviour of elements and robot's systems.

The paper presents some virtual proper LabVIEW instruments 8.2 version from National Instruments, USA, for the hydraulic, pneumatic and electric motors, the electrical and mechanical corrections with some closed loops. The analyze of the elements and systems was done with the elementary transfer functions by applying the different control laws. Many of the developed VI-s, used the validated mathematical models, approximate, with maximum 10% errors, the dynamic behaviour of all robot's modulus. The validation of the mathematical linear models were made by comparing the real dynamic behaviour, obtained by experimental research with data acquisition, with the simulated results. 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 amplify coefficient, for the PID, PD2 or for the others control laws parameters, or the place to applied the different rheological dampers.

2. Virtual driving instrumentation

Some results of the on-line optimization, for the dynamic behavior of the pneumatic motor, are presented in the paper. With the proper analyze method of the influence coefficients, presented bellow, have been determined the most important constructive and functional parameters in a dynamic behavior of the motor. Functional schema is presented in figure 1 [1]. The mathematical model is:

[+] Corresponding author.
  E-mail address: (aolaru_51@yahoo.com).

$$Q = A_1 \frac{dz}{dt} + a_m \Delta p + \frac{V}{\chi p} \cdot \frac{d\Delta p}{dt}$$

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

(1)

where: Q is the air flow 20-100 [cm³/s]; A – active motor area 50-80 [cm²]; z- active movement 30-40 [cm]; a_m- proportional gradient of loss flow with pressure 0.2-0.7[cm⁵/daNs]; Δp- loss pressure 4-6 [daN/cm²]; ΔV – air volume of the motor 500- 1000 [cm³]; m- reduced mass on the motor axis 0.1-0.6 [daNs²/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 [-].
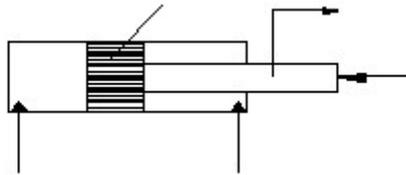

Fig. 1: Functional schema of the linear pneumatic motor

The final transfer function will be:

(2)

The influence coefficients $\quad H(s) = \dfrac{z(s)}{Q(s)} = \dfrac{A_1}{s\left[\dfrac{V}{\chi p} \cdot m \cdot s^2 + \left(\dfrac{V}{\chi p} \cdot b_m + m \cdot a_m\right)s + (A_1^2 + a_m b_m)\right]} \quad$ are determined by:

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

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

(3)

and PCD_i is 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 results after changing some of the functional or constructive parameters are presented in figures 2 and 3.
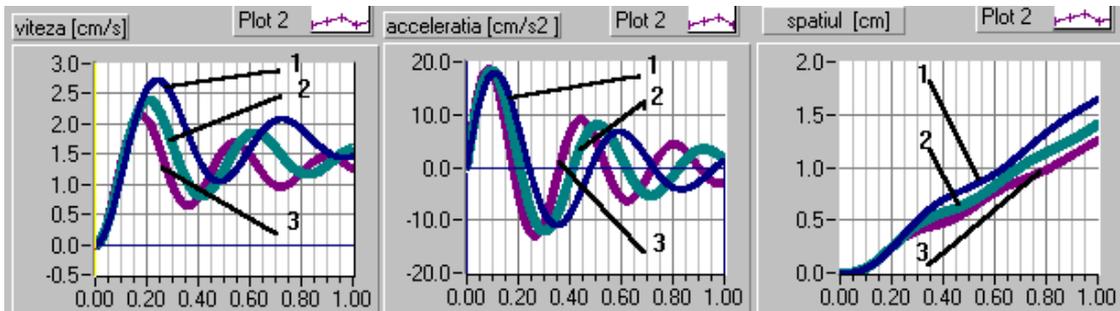

Fig. 2: The real time linear displacement, velocity and acceleration characteristics when was changed the active area A, with the values: 60 (cm²), 70 (cm²), 80 (cm²)
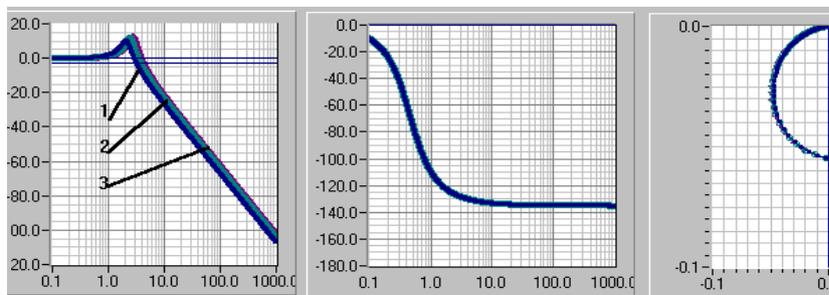

Fig. 3: The Bode and the Nyquist characteristics when was changed the active area A

The results with the values of the influence coefficients relations (3), are presented in the table 1.The mode whit each constructive or functional parameters were changed the dynamic behavior of the pneumatic motor have been made with the reading the bigger value of the influences coefficients in each of rows, respectively in each of columns of the table 1. Reading by rows the bigger values of the influences

coefficients we can observe: the increases of the active area A, determines with priority the increases of the critical frequency, the increases of the volume V, determines with priority the increases of the answer time t_r, the increases of the mass m, determines with priority the increases of the answer time t_r and the critical frequency v_c, where is the most important dynamic parameter because influences the acceleration time in a velocity characteristic. By reading the bigger values of the influences coefficients for each of columns of the table 1, we can observe that the all dynamic parameters are influenced by active aria A. With this method is possible to see and to change on-line all constructive and functional parameters to obtain the optimal answer of the outputs. Training with these instruments assures one optimal middle in the researcher's hands.

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

Table 1: The influence coefficients of the dynamic behavior

The assisted results of the virtual LabVIEW instrument for analyzing the linear hydraulic motor (LHM) are presented in figures 4. In the figure 5 is presented the results after was applied the PD2 control law on the command block of the LHM [1, 3]. Of the figure 5 we can observe that, after application of the PD2 control law, the acceleration time and the oscillation was reduced by 50% for the same constructive and functional parameters. The conclusions after analyzing the results of the LHM simulation, with the virtual LabVIEW instrumentation, are: the position of the characteristic equation's root is difficult to establish in a precision-stability field, without the virtual instrumentation; by changing on-line, the different constructive or functional parameters, with aid of the virtual instrumentation, was possible easily make that; the proportional closed loop determines the increase of the amplitude and the decrease of the answer time; by the introduction of the general control PD2 closed loop law, it was possible to optimize the dynamic behaviour (the answer time and the amplitude are very small, the critical frequency is bigger and the phase is happened in the bigger frequency, see figure 5).

The *VI* for the assisted comparative analyzes use the input data from file, where was changed one parameter. The *VI* works on-line with the possibility to input some others rows of the input data file. With this facility is possible to see, in a comparative way, what some functional or constructive parameters change the real and frequency characteristics and finally choice the optimum value, to obtain the desired output for one typically robot application, when is necessary, for example, good precision, or stability, or a good following capacity.
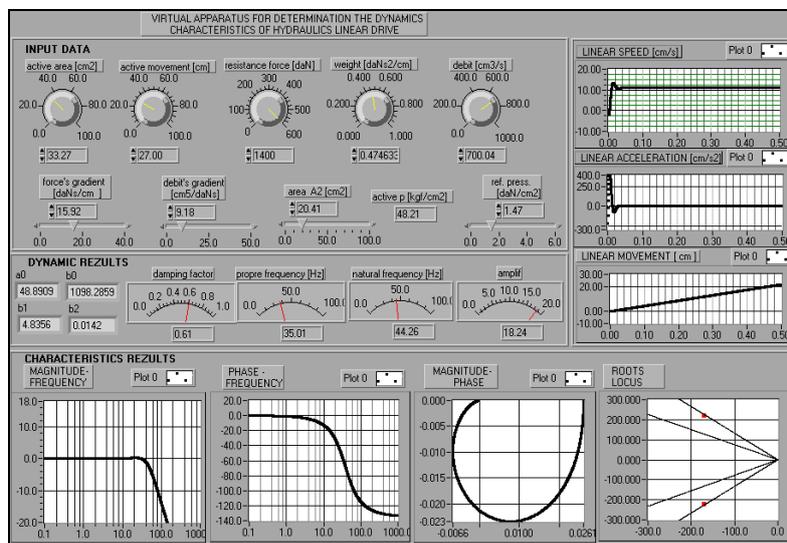

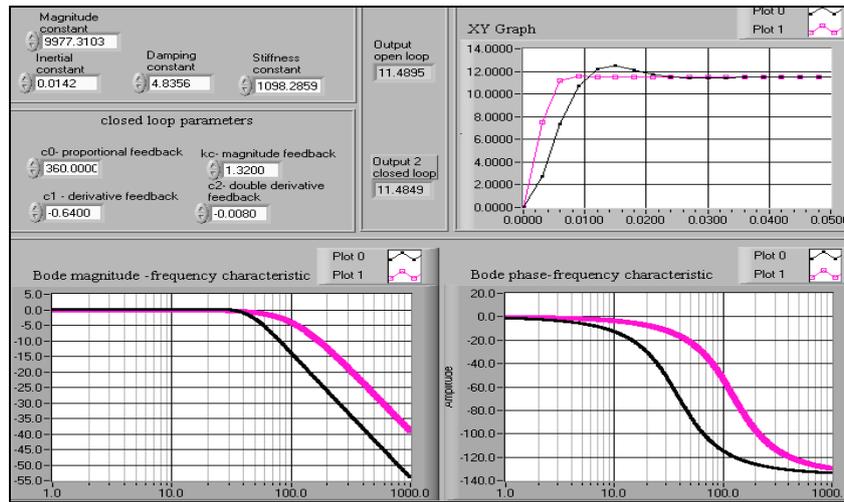Fig.4: Front panel of the VI for the assisted optimization of the LHM

Fig.5: The front panel of the VI for PD2 correction

3. VI-s for automation block schema with many closed loops

For analyzing what is happened in a complex closed loop block schema, it was designed many virtual proper LabVIEW instruments. With the elementary transfer functions it was created the complex block schema for driving modulus of industrial robot [1, 2]. One of the simple schemas is presented in figure 6. Many of the robot's modulus are modelling by using the proportional, proportional-derivative-inertial of the first order, proportional- inertial of the second order transfer functions. With aid of the LabVIEW proper *VI*-s were possible to show the indicial characteristics in all points of these block schema and to choose the optimal values for all coefficients of the components.
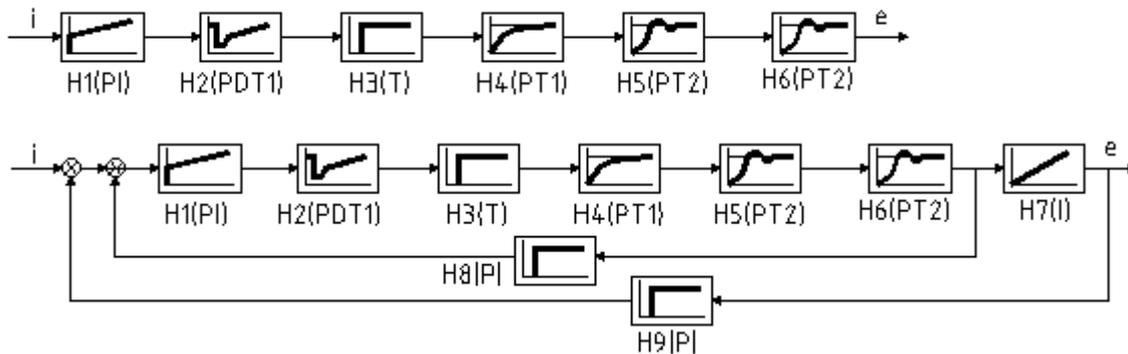

Fig.6: Automation block schema with open and closed loop

This block schema contents the PI regulator and PDT_1 anticipative correction, given by formulas [1]:

$$H_R(s) = \frac{1}{3s}; H_c(s) = \frac{0.9(9.9s+1)}{0.7s+1} \qquad (4)$$

With this *VI* we observe what is happened when isn't applied the correction or regulator and is possible to choose the optimal value for the regulator or correction's parameters. By using this *VI* and by applied the optimal correction and regulator can be obtained the same final indicial characteristic with load or without the load. That is very important for the dynamic behaviour analyze. One of the most important thing in the dynamic behaviour of the industrial robots is the behaviour analyze in the frequency domain. Analyzing the results in the frequency field, figures 7, we can observe all component frequencies, the resonance frequency for each of the components, move it to one desired domain, increase the first resonance frequency because this determines the maximum of the acceleration time of the all systems, increase or decrease one of it Bode magnitude to move the unfavourable behaviour in other work field.

With these instrumentation is possible to optimize the parameters of the correction, regulator or of the closed loop control law. The proportional closed loop determines the increase of the vibration and the decrease of the acceleration and velocity. With this complex analyze in the frequency domain is possible to choose the optimal value for the rheological damper and the place to applied it.

For the assisted research of the magnetorheological damper (MRD) we were created a special *VI* presented in the figure 8. With this complex proper *VI* were possible to determine the dynamic damper characteristics with one small error (near 5%) between the theoretical and experimental one. The complex proper mathematical model of the Bouc-Wen damper model completed by four polynomial relations [3] is:

$$f = c_0(x' - y') + k_0(x - y) + k_1(x - x_0) + \alpha z$$

$$y' = \frac{1}{c_0 + c_1}[\alpha z + c_0 x' + k_0(x - y)]$$

$$z' = -\gamma |x' - y'|z|z|^{n-1} - \beta(x' - y')|z|^n + \delta(x' - y')$$

$$\alpha(i) = \alpha_3 i^3 + \alpha_2 i^2 + \alpha_1 i + \alpha_0 \tag{5}$$

$$c_0(i) = c_{03} i^3 + c_{02} i^2 + c_{01} i + c_{00}$$

$$c_1(i) = c_{13} i^3 + c_{12} i^2 + c_{11} i + c_{10}$$

$$k_0(i) = k_{03} i^3 + k_{02} i^2 + k_{01} i + k_{00}$$

Where: f is the damping force [N]; x and y are the primary, respectively the secondary displacement variables [m]; z

is the internal history dependency variable of the (MRD) [m]; k_0, k_1 are the non linear internal rigidity of the (MRD), [N/m] depending of the current intensity i [A]; c_0 and c_1 are the internal viscous damping parameters of the (MRD) [Ns/m]; α is the internal parameter what have non linear evolution and depend on the magnetic variable field (electrical intensity); parameters β characterize the gain of increasing of the damping force versus velocity; x_0 is the perturbation displacement [m]; δ is the hysteresis parameter.
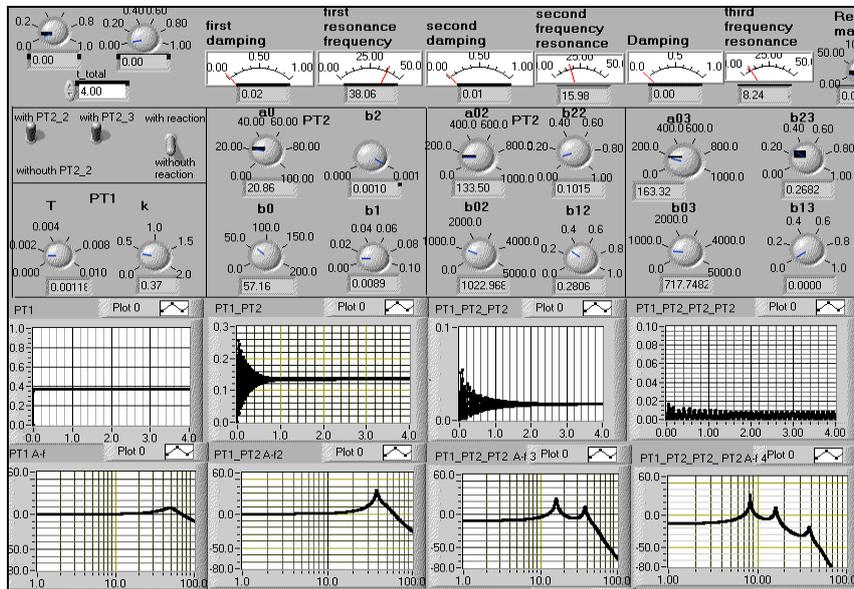

Fig.7: Front panel of the VI for the assisted research of
the open and closed loop automation schema

4. VI-s for the experimental research

For the acquisition we were designed many virtual LabVIEW proper instruments. With these was possible to analyze and validate the theoretical instruments, by comparing the theoretical with the

experimental results. The acquisition instruments assure the cinematic characteristics of acceleration, velocity and space versus time, the frequency characteristics, spectrum of the vibration, Fast Fourier Transform (FFT) of the transfer function, power spectrum density, magnitude and phase of frequency function. One of the results Fourier spectrum is presented in the figure 9. The knowledge of the transfer function (TF) [1, 2, 3, 4] gives the possibility to choose the structure with the proper convenient frequency and with the weak transmissibility of the vibration. Obtaining the approximately same results of the numerical *VI* instruments for the power spectral density is possible to determine the modal vector and to know what is the relative movement between the robot's body corresponding at one resonance frequency [1, 4]. Knowing these modal components, the design detours the robot function from the wrong domain or can introduce some mechanical, electrical or rheological corrections in a command or power modulus.
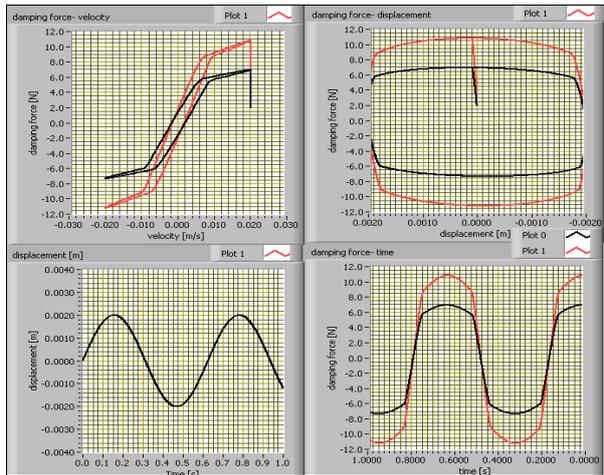

Fig.8: Front panel of the VI for the theoretical research of the magnetorheological damper
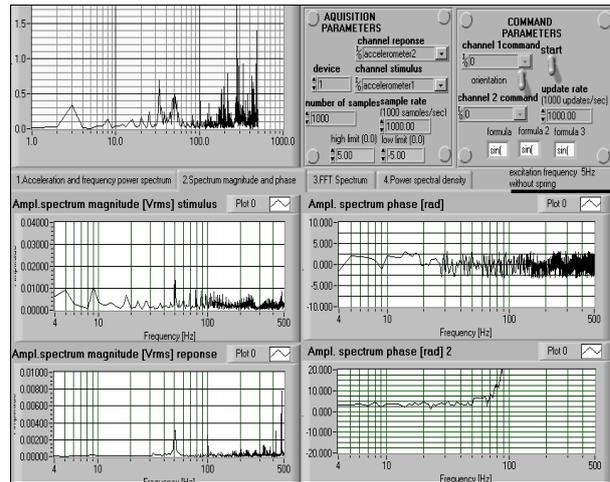
Fig.9: Front panel of the proper Fourier analyser

5. Conclusions

By using the proper *VI*-s and the assisted experimental research by data acquisition, were assured the most important information about the dynamic behaviour. All the instruments have the possibility to compare and validate the theoretical results by the experimental one. The optimization of the dynamic behaviour in this case isn't expensive and is made in a best condition and in a short time. With the *VI*-s are possible to establish very easily, the most important constructive or functional parameters, to move some frequency components in other domain, to obtain the optimum vibration results. By using, the personal *VI*-s and the results of the modal vectors, the vibration proper modes and the vibration spectrum, were established the vibration of all components and the transfer function between some points of the robot's structure.

6. References

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