Modeling, Simulation and Assisted Research with LabVIEW Instrumentation in Robotics

Adrian Olaru, Serban Olaru, and Niculae Mihai

***Abstract*—The field of Robotics is so complicated in the research activity and impose the assisted work by computer, because all equations, all mathematical models are written in matrix form, all movements are in the space and the control of the movements are so difficult. More, the optimization of the dynamic behavior by using the optimal choose of the constructive or functional parameters are very difficult without assisted research, the optimization by apply some electrical or mechanical corrections also are very difficult because must be establishing the place of application, the parameters of all these corrections. The assisted research with one special LabVIEW virtual instrumentation library cover all these actions and assures one easy way to the optimal results.**

***Index Terms*—Transfer functions, virtual instrumentation, dynamic behavior corrections, simulation, assisted research.**

I. Introduction

For the purpose of modeling, searching, animation and validating the mathematical model of the complex robotic structure, in the laboratory of the Dynamic Behavior of Industrial Robots of the faculty I.M.S.T.-U.P.B., there was designed and realized one arm type robot with five degrees of freedom (DOF) and one virtual LabVIEW instrumentation library. The designed stand for the assisted research, figure 1, used for the validation of the Forward Kinematics (FK), Inverse Kinematics (IK) matrix form and also the matrix model with 6x6 components for the dynamic behavior, to solving the Direct Dynamics (DD) and Inverse Dynamics (ID). In a research we can distinguish the following elements: robot with DC motors and encoders; stabilized source of continuous voltage; accelerometers; Geko Drive with PWM and H-bridge devices; amplifying blocks; screen; computer; multimeter; connectors and the National Instruments acquisition board compatible with LabVIEW instrumentation for the acquisition data. This stand is used to determinate exactly the real characteristics of the relative angular velocity and acceleration versus time, the acceleration time and verify the precision of the relative displacement in the joints. Was tested some proper method for command files to control, by using FK and IK together with the Bipolar Sigmoid Hyperbolic Tangent Neural Network with Time Delay and Recurrent Links (BSHTNN-TDRL), the movement of the end-effecter, to touch the space target with the better precision than 0.001mm. Also, we researched the parallel structure with one plate platform in the triangle form with three legs with arm type robots with simetrical base application points. In this case the constraints are the precision in all joints of the platform. To assure the extreme precision and respect strictly the imposed constraints was used proper iterative LabVIEW™ instrument with neural network.

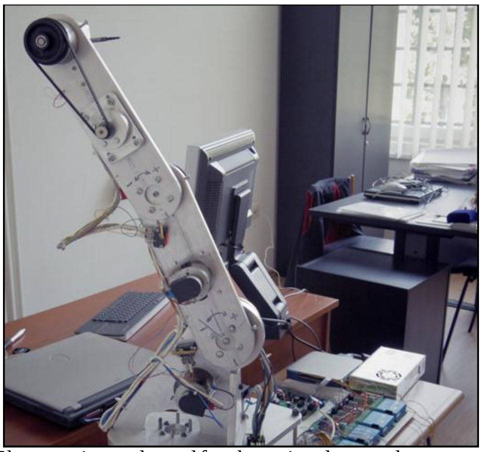

Fig. 1. The experimental stand for the assisted research concerning one didactical arm type robot with Geko Drive, H bridge and controlling with LabVIEW acquisition board.

II. LabVIEW Virtual Instrumentation Library

A. Instrumentation for the Elementary Transfer Functions

The most important thing of one application with robots in a manufacturing system is the dynamic behavior of the robot and what are the resonance frequencies determined by the acceleration time in some phases of the application and compare them with the frequency Fourier spectrum of the manufacturing system. The paper presents one assisted method with the proper virtual LabVIEW instruments (VI) for the assisted of the theoretical and experimental research of the industrial robots with transfer functions of the DC motors. The virtual instruments were achieved in the LabVIEW soft 8.2 from National Instruments, USA. The *VI*-s simulates the open and closed loop of the DC servo systems, and the data acquisition of the Fourier spectrum of the acceleration, the acquisition of the velocity with the final goal to compare the simulate with the real results [1-5]. This method will be possible to be used in the assisted research of the many other mechanical applications where it is necessary to know the dynamic behavior, the vibration spectrum and how the constructive and functional parameters of the DC servo systems and the movements cases (the equilibrium of the robot's arm) determine the major changes of the spectrum and of the dynamic behavior. Now, in the world, all the dynamic determination of the dynamic behavior, of the

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vibration spectrum are made with some complex apparatus with the expensive cost.

The actual research in the world does not approach the assisted virtual instrumentation for the optimization of the robot's dynamic behavior [6-15].

The mathematical matrix model of the dynamic behavior in the movement time it is presented below [1]:

$$\begin{pmatrix} F^0 \\ M^0 \end{pmatrix} = \begin{bmatrix} z_u & 0 \\ 0 & z_u \end{bmatrix} \begin{pmatrix} D_{0,i}F_R^i \\ D_{0,i}M_R^i \end{pmatrix} - diag\left[sign\frac{v_u^i}{\left|v_u^i\right|} m_{u_i} \quad sign\frac{\omega_u^i}{\left|\omega_u^i\right|} J_{g_i} \right] \cdot \begin{pmatrix} \left(a_{i,0}^i\right) + \left[\widehat{\omega}_{i,0}^i\right]^2 \left(r_{g_i}^i\right) \\ \left(\varepsilon_{i,i-1}^i\right) + \left[\omega_{i-1,0}^i\right]\left(\omega_{i,i-1}^i\right) \end{pmatrix} +$$
$$+ \begin{bmatrix} z_u & 0 \\ 0 & z_u \end{bmatrix} \cdot \begin{pmatrix} (0) \\ \left[G_{i,k}\right]\left(\widehat{b}_{i,k}\right)\left(\left(D_{0,i}F_R^i\right) - diag\left[sign\frac{v_u^i}{\left|v_u^i\right|} m_{u_i} \right] \cdot \left[D_{0,i}\right]\left(\left(a_{i,0}^i\right) + \left[\widehat{\omega}_{i,0}^i\right]^2 \left(r_{g_i}^i\right)\right)\right) \end{pmatrix}, \qquad (1)$$
$$\left(M^0\right) = \left[k_{m_i}\right]\left(i_{a_i}\right)$$
$$\left(U_i\right) - \left(e_i\right) = \left[R_{a_i}\right]\left(i_{a_i}\right) + \left[L_{a_i}\right]\left(\frac{di_{a_i}}{dt}\right)$$

where: $\boldsymbol{F^0}$ is the active forces matrix in a Cartesian fixed system; $\boldsymbol{M^0}$- the active moment matrix in a Cartesian fixed system; $\boldsymbol{z_u}$- joint bodies matrix; $\boldsymbol{D_{i-1}}{}^{i}$- transfer matrix between i-1 and i body; $\boldsymbol{F_R}$- resistant forces matrix; $\boldsymbol{M_R}$ – resistant moments matrix; $\boldsymbol{m_i}$- mass matrix of bodies; $\boldsymbol{J_{gi}}^{0}$- inertial tensor matrix of bodies; $\boldsymbol{a_{i,o}}^{i}$- absolute dual acceleration matrix in a i body Cartesian system; $\boldsymbol{\omega^{\wedge}{}_{i,0}}^{i}$- non symmetric absolute angular velocity matrix in a i body Cartesian system; $\boldsymbol{\varepsilon_{i,i-1}}^{i}$- angular relative acceleration matrix in a i body Cartesian system; $\boldsymbol{\omega_{i,i-1}}^{i}$- angular relative velocity in a i body Cartesian system; $\boldsymbol{B}^{\wedge}$- modified arm type matrix; $\boldsymbol{k_{mi}}$ – matrix of gradient moment- intensity of the DC motors; $\boldsymbol{i_{ai}}$- matrix of the current intensity of all DC motors; $\boldsymbol{U_i}$ – matrix of electrical tensions; $\boldsymbol{e_i}$ – matrix of DC internal tensions; $\boldsymbol{R_{ai}}$- matrix of rotor DC resistance; $\boldsymbol{L_{ai}}$ – matrix of the DC inductances.

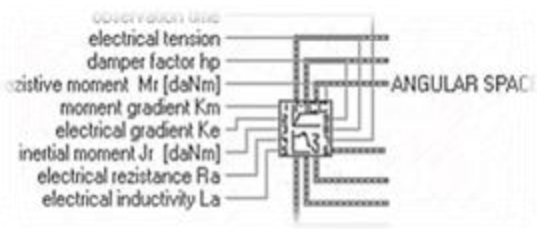


Fig. 2. The icon of the DC motor *VI*-s.

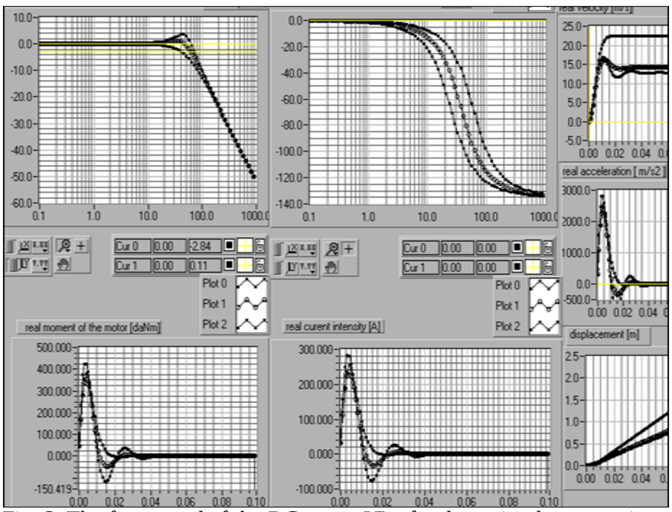


Fig. 3. The front panel of the DC motor VI-s for the assisted comparative positions, velocities, accelerations characteristics versus time and Bode frequencies characteristics when was changed the electrical resistance. R_a: 0.33, 0.5 and 0.8 (Ω).

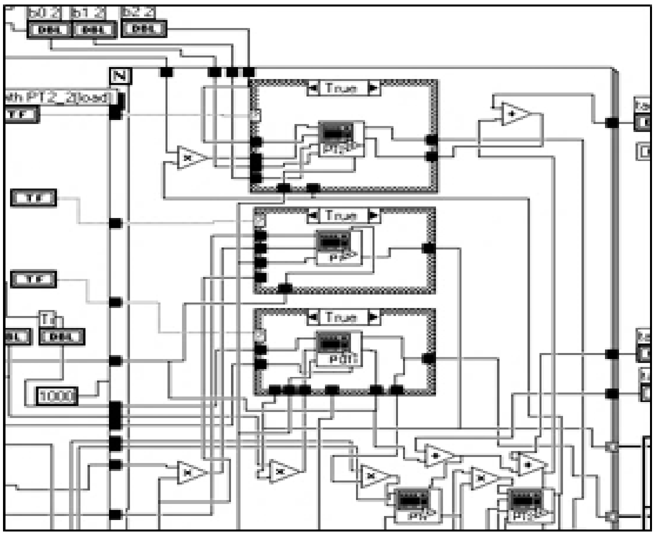


Fig. 4. Block schema of the complex *VI*-s that simulate the automation complex schema with the PT2, PI, PDT1, PT1, PT2 transfer functions.

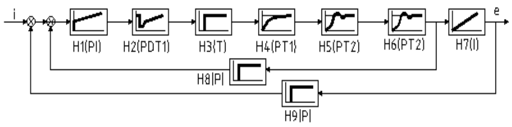


Fig. 5. Block schema of the DC servo system.

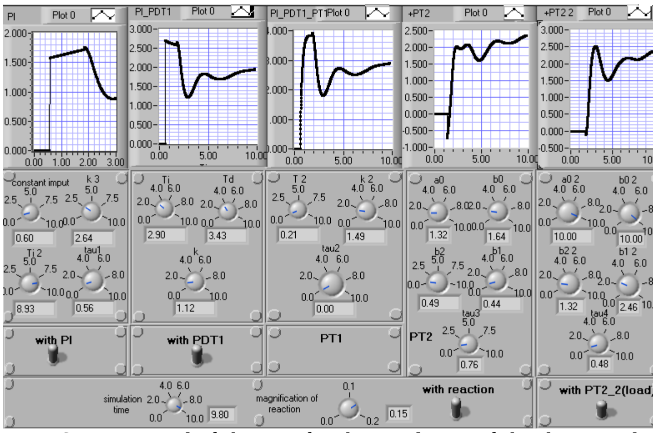


Fig. 6. Front panel of the VI-s for the simulation of the theoretical characteristics with the transfer functions from the DC block schema, fig.5.

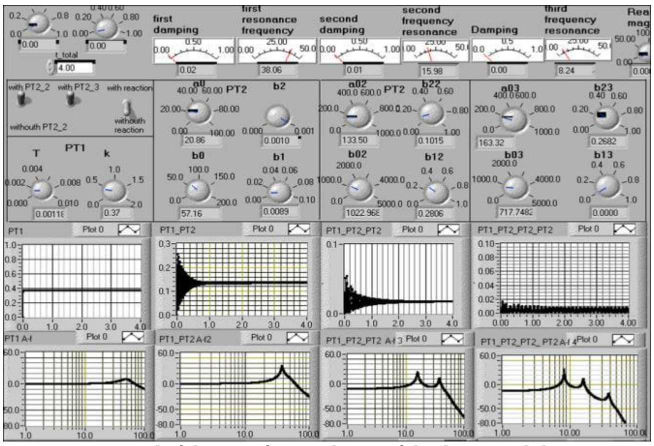


Fig. 7. Front panel of the VI-s for simulation of the theoretical characteristics of the dynamic behavior with DC transfer functions of the fig.5.

With this instrumentation is possible to optimize the parameters of the correction, regulator or 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 values for the rheological damper parameters and the optimal place to applied it in the robot's structure. The amplification value of the proportional reaction can wrong modify the velocity answer and Bode characteristics, Fig. 8. For one better establishing of this value must be run on-line the specific created *VI* and follow what was happened.

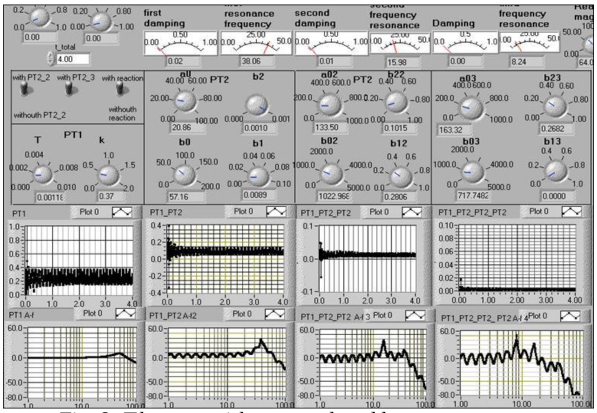


Fig. 8. The case with wrong closed loop parameters.

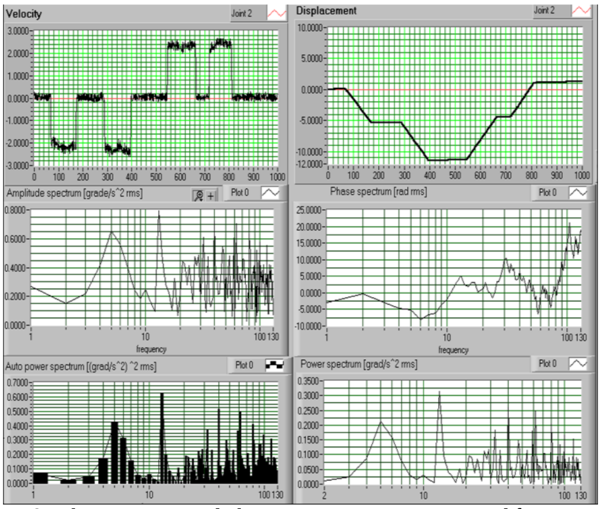


Fig. 9. The experimental characteristics versus time and frequency.

With the experimental assisted research will be possible to compare the theoretical and experimental results and to modify the mathematical model. We can observe that the experimental results, Fig. 9 are similarly with the theoretical one for some system's parameters, Fig.7. From the Bode theoretical characteristics of the didactical arm type robot we can remark that not all application of the proportional reaction is good, or the value of the proportional reaction was good determined. With the created *VI* will be possible to choose the optimal values for this reaction's parameters to obtain the desired answer, Figs.7 and 8.

One good information we can obtain from the experimental research with the proper virtual Fourier analyzer in a movement of the robot's arm. The study cases were: the movement in two directions with or without delay between the movement senses, or the delay inside of one movement, Fig. 9.

The delay, between the senses or inside of the movement, transfer the Fourier spectrum to the high frequency, (Fig.7. compare with Fig. 8, in the study cases: the first frequencies from the Fourier spectrum were moved to the 6-7Hz; the frequency domain is bigger, 8Hz and with delay was 0-8Hz and 12-80Hz, that mince the component with the delay work like one slow stop band filter in a slow frequency and open band filter in the high, and the component without delay work like slow stop band filter). In figure 9 is show the results of the data acquisition of the robot arm velocity in the two cases with and without magnetorheological damper MRD. We can remark that in a movement with MRD the vibration of the velocity was attenuated and the velocity characteristic like trapezoidal.

With the special virtual LabVIEW instrumentation for the assisted research of the systems will be possible to determine the parameters of the mathematical model of the system to obtain the velocity characteristic with the better answer. After compare the theoretical results with the real one we can remark that the errors are in the 1% field.

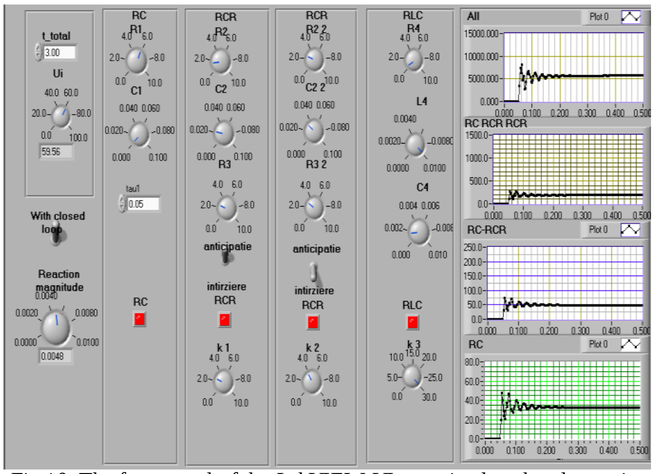


Fig.10. The front panel of the LabVIEW VI-s to simulate the electronic correction with RC, RCR anticipation, RCR delay, RLC oscillation signal.

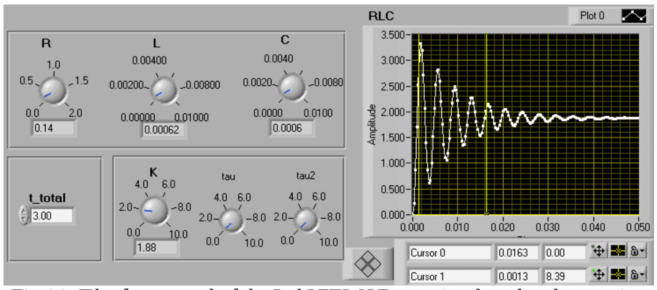
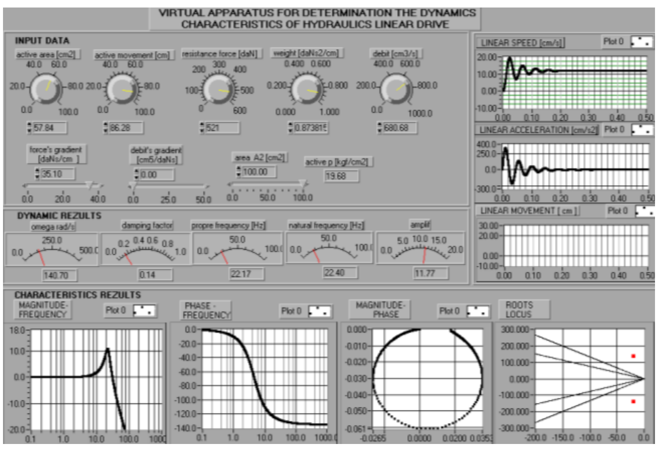


Fig.11. The front panel of the LabVIEW VI-s to simulate the electronic devise RLC

B. Instrumentation for the Theoretical Research of the Hydraulic Cylinder



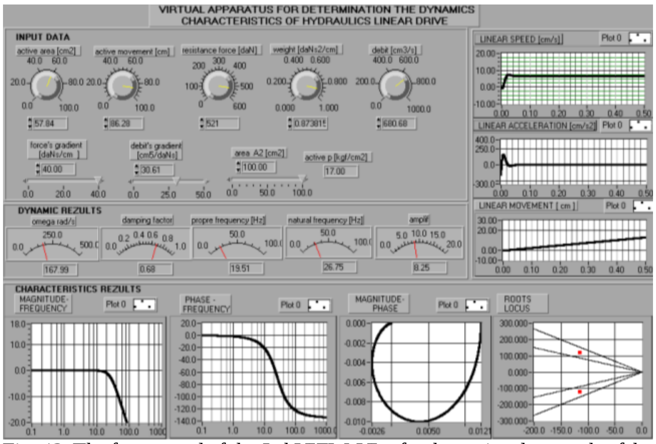


Fig. 12. The front panel of the LabVIEW VI-s for the assisted research of the hydraulic cylinder; a- limits of stability answer when the poles are outside of the required area; b- good dynamic behavior answer when the poles are inside of the required area.

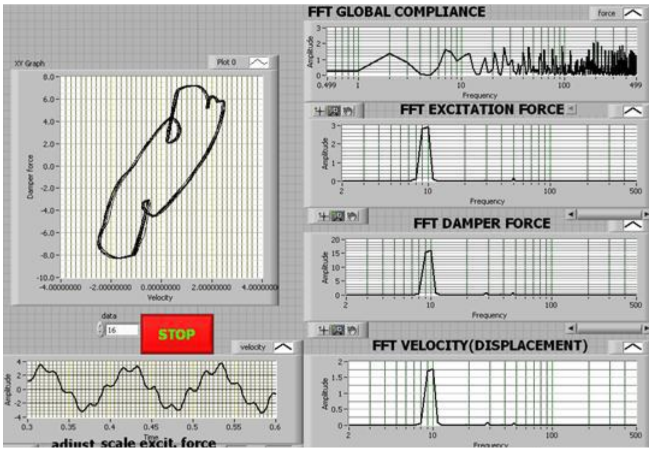


Fig.13. The experimental research of the Magneto Rheological Damper (MRD.

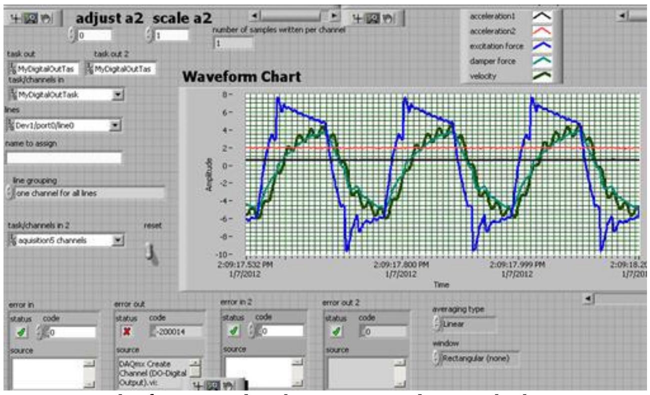


Fig.14. The front panel with experimental research characteristics

C. Instrumentation for the Electrical Corrections

The LabView intrumentation for the electrical correction is used to choose the electrical components inside of the corrections, to simulate the answer and to choose the best solution to correct some of the dynamic behavior answer of the system. The virtual instrument has the possibility to put inside or remove some of the electrical components, or change the closed loop magnitude and to say what is happend with the final electrical answer.

This virtual instrument from the proper library assures to the researchers possibility to choose the constructive and functional parameters of the hydraulic cylinder for one very good dynamic behavior. Using this library some hydraulic components will be analyzed before construct the hydraulic schema.

D. Instrumentation for the Experimental Research

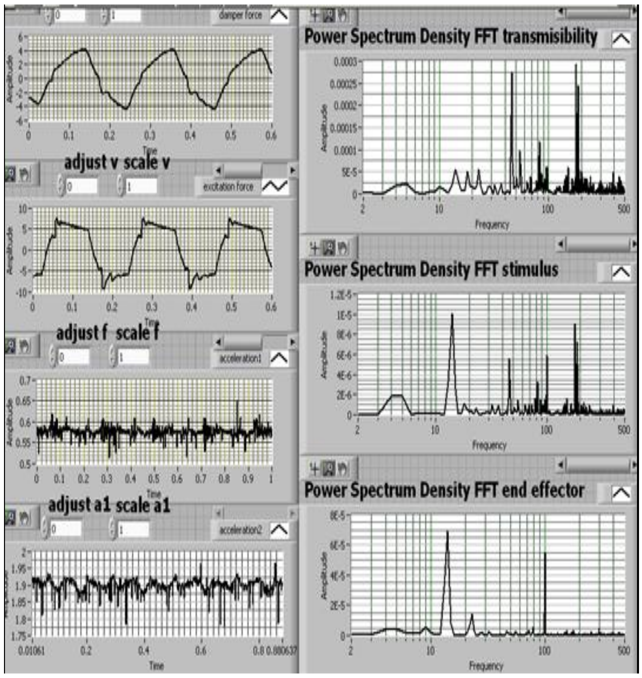


Fig.15. Front panel with data acquisition results of the damper force, excitation force, acceleration on the robot's base and end-effecter, transmissibility Fourier spectrum, FFT of the exciter device and of the end-effecter

The instrumentation for the experimental assisted research used to compare the theoretical characteristics with the real one and to decide when we can put the rheological damper, what must be his characteristics, what it is the transmissibility Fourier spectrum between the robot's base and end-effecter, what is the compliance Fourier spectrum or the transfer function of the damper.

III. Some Results after Applied Assisted Methods

By apply the proposed LabVIEW library we can obtain the followings: (i) very easy we can simulate the dynamic behavior of some components of the system and choose the optimal constructive or functional parameters; (ii) we can compare the experimental characteristics with the theoretical one and adjust the mathematical model to copy the real model; (iii) one very short time of the research and one good choose of the constructive and functional parameters of the system; (iv) the optimization of the dynamic behavior of the systems; (v) was possible to optimize and chose the optimal parameters of the damper for one application and the place to insert him; (vi) the cooperation work of the robots in one complex application will be easily to apply after animation of his working space and determine the optimal base point; (vii) this virtual library will be used also for organize the multi robots application with serial, parallel and complex robot's structures with global word coordinates (GWC), local word coordinates (LWC) and also with robot coordinates (RC); (viii) determine the position of the end-effecter to describe 3D space trajectory to avoid the singular space points in different Euller planes by using the matrix form of the

Forward Kinematics; (ix) adapt the general mathematical matrix model to the application when it is used one or multi robots; (x) design the robot structure by using the special virtual LabVIEW^{TM} instrumentation, by specific data concerning the robot's dimensions and the type of the robot's modules; (xi) generating the internal coordinates for single robot or in complex form of the parallel structure for a known external position by using the Forward and Inverse Kinematics; (xii) generating the internal coordinates for all known external coordinates of the imposed space curve of the parallel robot's platform by using the proper instrumentation and Iterative Pseudo Inverse Jacobian Matrix Method algorithm with neural network controlling; (xiii) generate the 6x6 matrix form of the forces and moments to determine the peak of moment and the required torque of all motors of the robot's joints; (xiv) animation of the robot's structure by read the generating file to validate the applied kinematics algorithms and control the singularity and avoid these points.

IV. Conclusion and Future Work

The proposed LabVIEW library is general and could be used in all mechanical application and the assisted research. In the future will be designed one LabVIEW instrument that will connect all this library inside only one and by answer at some general questions about what must to do or research, to choose the optimal way to the instrumentation that you need. By using this library will be possible to reduce the time of the research and will be obtained the optimal results.

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