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ASSISTED RESEARCH OF THE DAMPED DYNAMIC BEHAVIOR OF THE INDUSTRIAL ROBOTS

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Abstract: *The paper show the assisted research of the rheological damper and the influences to the dynamic behavior of the industrial robots. The research contents the assisted theoretical simulation of the new mathematical model, the parametrization of the known characteristics ot the rheological damper and the assisted establish of the influences of the model coefficients to the characteristics parameters. In the assisted experimental research were established the values of all coefficients of the proper mathematical model to assure the concordance between the experimental and theoretical characteristics. By knowing the real mathematical model of the damper will be possible to develop the next research of the global dynamic behavior of the industrial robot with the damper.*

Key words: *rheological damper, dynamic behavior, assisted research, LabVIEW instrumentation.*

1. INTRODUCTION

The paper describes one new mathematical model of the magnetorheological damper (MRD) and one new method to establish, after the assisted experimental research, all model coefficients. The research has been made in the Dynamic Behavior Robots Laboratory from IMST Faculty, University Politehnica of Bucharest. In the research, we used the didactical arm type robot and one MRD, between the base and the end effector of the didactical robot. In the paper was researched one complex damper model with many functional and constructive parameters [1, 2, 3, 5]. The complex mathematical model was the Bouc-Wen modified model [4, 5] completed by new four polynomial expressions of the third order. The virtual LabVIEW created apparatus especially for these research, is generally, it is possible to use in many others mechanical applications. The virtual instrumentation presented in the paper, are special for these determinations where assure one small cost and one short time of the research. The paper contains the assisted research of the MRD to know some dynamic characteristics of the damper, like forces versus velocity and displacement, and finally to determine the damper energy and decreasing the transmission of the vibration between the floor to the tool center point (TCP) of the robot. In this paper was researched the structure of one didactical arm type robot with U profile of the arms. The research has been made by exciting, with the electromagnetic exciter, the robot base modulus and by data acquisition of the exciting force and of the displacement of the TCP. For that on used one experimental setup presented below.

2. RESEARCH SET UP

For the determination of some important characteristics of the MRD joints in to the structure of the didactical robot, on used one experimental setup presented in figures 1and 2. Now, in the world, more and more is necessary to use the LabVIEW instrumentation to assure the data acquisition and the virtual simulation of the dynamic behavior. The experimental stand contains the following components: didactical arm type robot; the electromagnetic exciter type 11075 from RFT Germany; connector type CB- 68 LP from National Instruments USA; acquisition board type PCI 6024E from National Instruments USA; function generator type POF-1 from KABID Poland; amplifier type LV 102 from MMF Germany for the generator; personal computer from Taiwan; inductive displacement transducer type 16.1 IAUC Romania; Hottinger apparatus type KWS/T-5 from Germany and proper MRD.

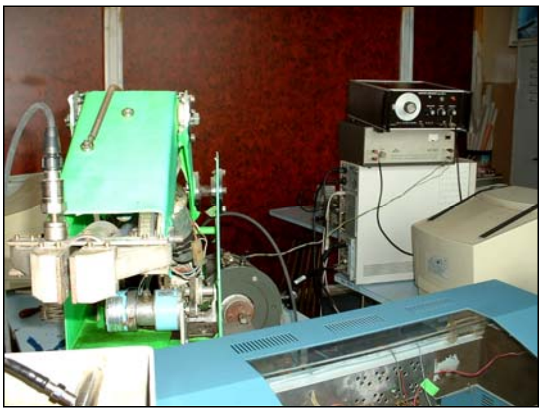

Fig. 1. The experimental research set up.

Fig.2. Magnetorheological damper with inductive transducer.

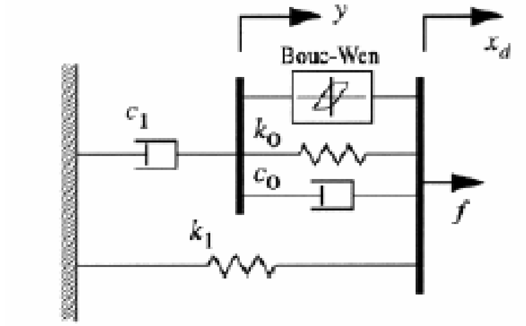

Fig.3. Mechanical model of the MR-damper based on the Bouc-Wen model (Dyke et al., 1998).

3. ASSISTED THEORETICAL RESEARCH

The mathematical approached model was the Bouc-Wen modified model (Duke, Spencer et al., 1997) completed by new four relations of the third order for the internal rigidity, dampers and hysteresis. With the complex mathematical model with many parameters (18 parameters, with new 12 parameters) was possible to approximate better the experimental dynamic damper characteristics.

The complex mathematical model of the Bouc-Wen damper, completed by the new polynomial relations is:

$$
\begin{aligned}
&f = c_0(x' - y') + k_0(x - y) + k_1(x - x_0) + \alpha z \\
&y' = \frac{1}{c_0 + c_1}[\alpha z + c_0 x' + k_0(x - y)] \\
&z' = -\gamma |x' - y'| z |z|^{n-1} - \beta(x' - y')|z|^n + \delta(x' - y') \\
&\alpha(i) = \alpha_3 i^3 + \alpha_2 i^2 + \alpha_1 i + \alpha_0 \\
&c_0(i) = c_{03} i^3 + c_{02} i^2 + c_{01} i + c_{00} \\
&c_1(i) = c_{13} i^3 + c_{12} i^2 + c_{11} i + c_{10} \\
&k_0(i) = k_{03} i^3 + k_{02} i^2 + k_{01} i + k_{00} \\
&\delta = \sum \delta_{0i} \sin(2\pi \upsilon_i + \varphi_i)
\end{aligned} \qquad (1)
$$

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); parameter β characterize the gain of increasing of the damping force versus velocity; x_0 is the perturbation displacement [m]; δ is the histeresys parameter.

With the mathematical model we created the virtual LabVIEW instrumentation for the assisted analyze of the influences of the functional or constructive of MRD parameters versus the dynamic characteristics. It was studied the evolution of the damper forces versus velocity, or displacement, the periodical damper force vs. time. All these characteristics were show comparative for the different values of the parameters. All these comparative characteristics were being show for the different values of some parameters. In this paper is present for the first time the assisted on-line method to choose these parameters with virtual instrumentation by compare these characteristics with the experimental. Some of the comparative results are being show in Figs. 4 – 5 and the parametric characteristic in Fig. 6.

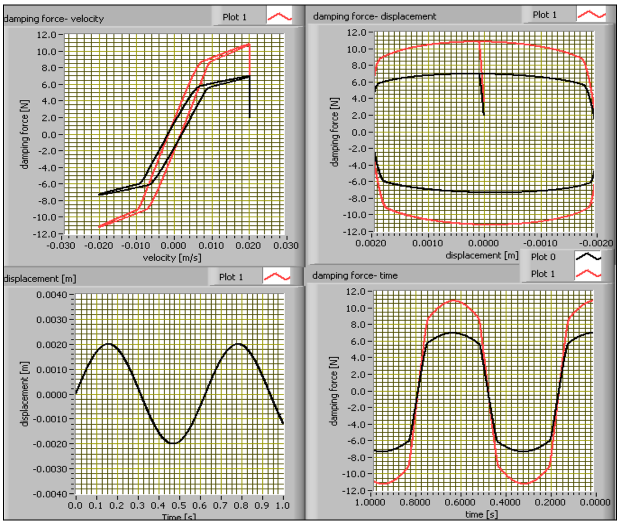

Fig.4. The damping force vs. velocity characteristic of the researched magnetorheological damper when was changed the intensity from 1.2 to 1.5A.

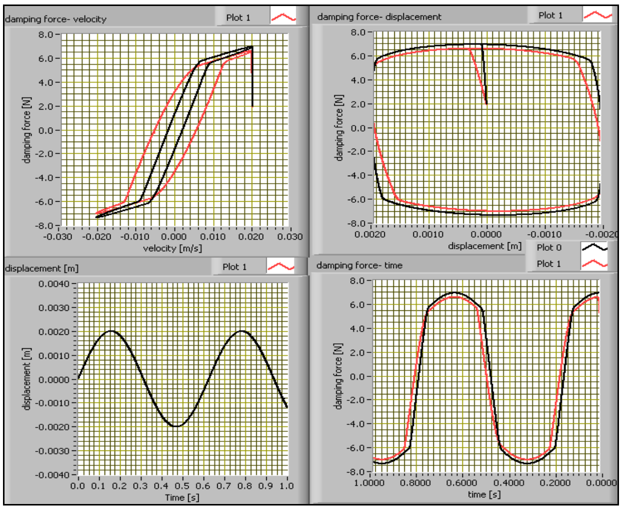

Fig.5. The MRD's characteristics: damper force vs. velocity, displacement, time, velocity vs. time in the case when was changed δ from 20000 to 5000.

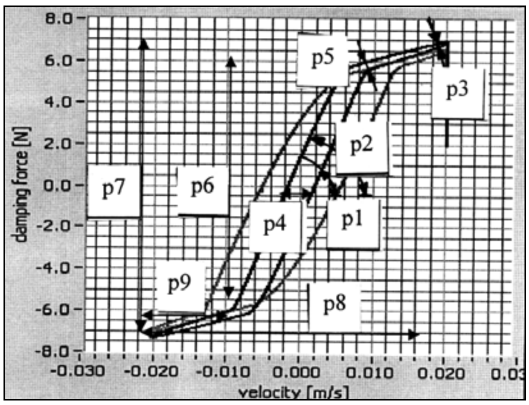

Fig.6. The parametric characteristic of damping force vs. velocity of the MRD.

After the analyze of the numerical simulation we can remark the followings: the change of the current intensity determines the change of the parameters p_1, p_2, p_6, p_7; the change of the perturbation displacement x_a determines the change of the parameters p_3, p_5; the change of the internal coefficient γ determines the change of the parameters p_3, p_5; the change of the magnitude of the vibration x determines the change of the parameters p_7, p_8, p_9; the change of the global rigidity k_1 determines the change of the parameters p_3, p_4, p_5, p_7; the change of the damping force gain β determines the change of the parameters p_3, p_6, p_7; the change of the histheresys term δ determines the change of the parameters p_1, p_2, p_3, p_4, p_5, p_9; the change of the internal coefficient of the second order α_2 determines the change of the parameters p_3, p_6, p_7; the change of the internal coefficient of the first order α_1 determines the change of the parameters p_3, p_6, p_7, p_9; the change of the viscose damping parameter of the second order c_{02} determines the change of the parameters p_3. All the coefficients of the mathematical model were changed and were analyzed the influences to the parametrical force vs. velocity damper characteristic [1].

4. EXPERIMENTAL RESEARCH

The experimental research had been made by exciting the base of the didactical robot modulus by the periodical force and by data acquisition of the exciting force, damping force, displacement and velocity of the end effector.

The experimental research had been made with the proper virtual LabVIEW instrumentation. Some of the results characteristics are being show in the Figs. 7 – 9.

The experimental research has been make by exciting the base of the didactical robot with the periodical excitation force and by data acquisition of the damper force of the MRD and of the displacement with the inductive transducer from the robot end effector. The velocity was determined by the derivation of the displacement signal.

The experimental determinations offers some information about the damping force in the real and frequency domain, very important to establish the real values of the mathematical model coefficients.

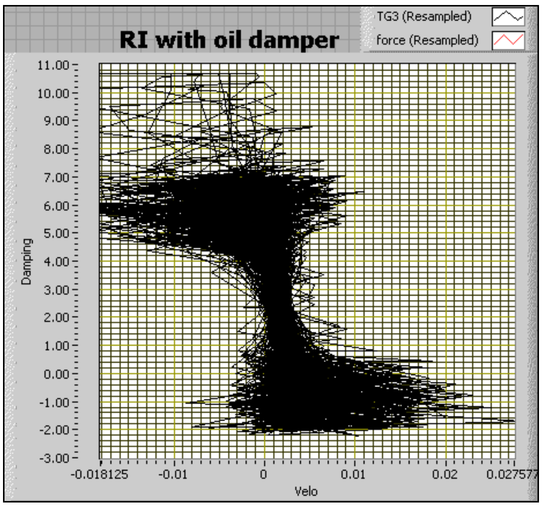

Fig.7. The experimental characteristic damper force vs. velocity of the MRD.

After the analyze of the experimental results we can remark the followings: the damper force vs. velocity of the MRD is very complex and contents oscillations what can see in the FFT of the damper force, Fig. 8; some oscillations are determined by the vibration of the didactical robot structure what we can see in FFT of the global dynamic compliance, Fig. 8; oscillations of the damper force vs. time are shown in the Fig. 9- excitation force is close to the sinus form, but the damper force of the MRD contents many other components with different frequencies and magnitude, see FFT, Fig. 8; with the real characteristic of the damper force of the MRD vs. velocity will be possible with the numerical simulation of the proper mathematical model, to determine the real coefficients of the model. This real validated mathematical model will be used in the optimization of the global dynamic behavior of the robot with the MRD.

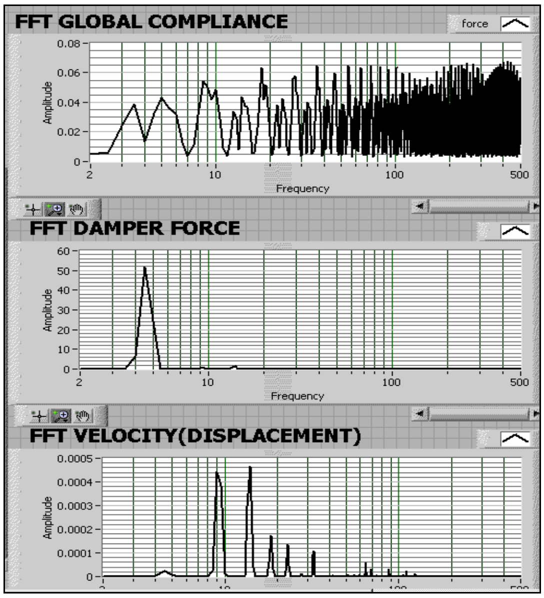

Fig.8. The experimental FFT characteristics of the damper force, velocity and global dynamic compliance

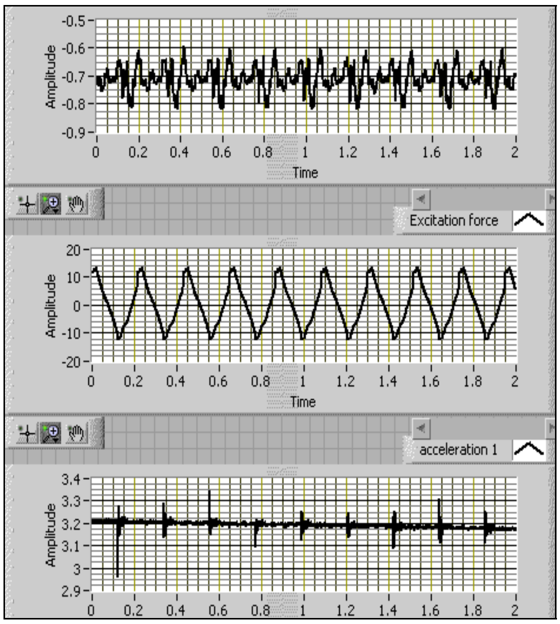

Fig.9. The experimental characteristics of the acceleration stimulus, excitation force and damper force vs. time.

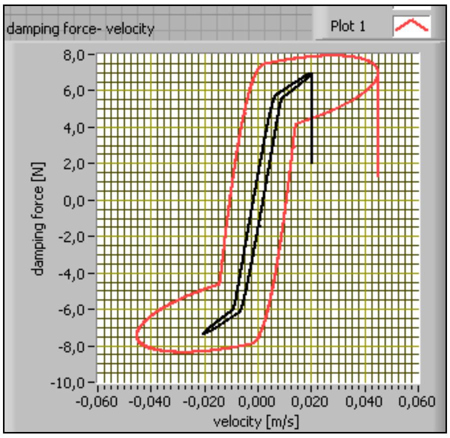

Fig.10. The damper force vs. velocity when were changed the coefficients $c_{13}, c_{12}, c_{10}, k_{03}, k_{02}, k_{01}, k_{00}$.

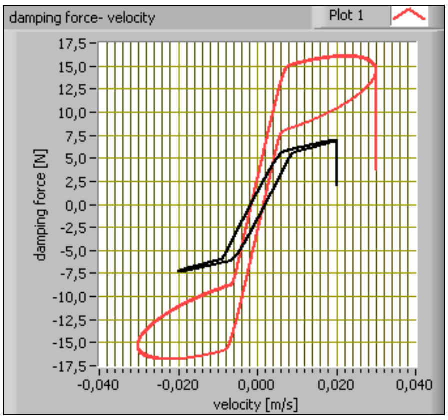

Fig.11. The damper force vs. velocity when were changed the coefficients i , x, δ, $c_{02}, c_{13}, c_{12}, k_{02}, k_{01}, k_{00}$.

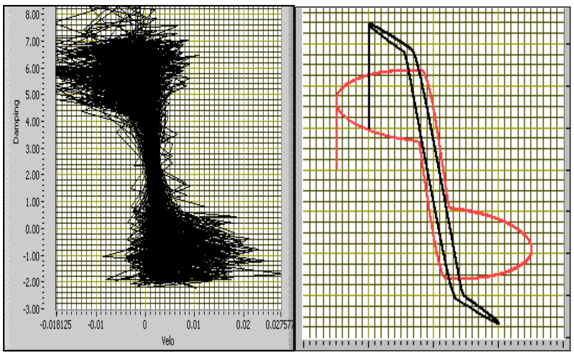

Fig.12. The comparison between the real and the simulate characteristic of the MRD damper force vs. velocity.

5. IDENTIFICATION OF THE PROPRE MRD MODEL

The identification of all coefficients of the proper mathematical model was contents the changing of the coefficients of the mathematical model knowing his effects to the parametric characteristic of the damping force vs. velocity of the MRD from the analyze step and compare them with the real one. Some of the simulating results to try obtain one characteristic close to the real one, are shown in the Figs. 10 – 11.

After the comparison of the real characteristic with the simulated (Fig. 12) results the real values of all coefficients of the model. The real mathematical model of the proper MRD will be:

$$
\begin{aligned}
& f = c_0(x' - y') + k_0(0.003 - y) + 100(x - 0.002) + \alpha z \\
& y' = \frac{1}{c_0 + c_1}[\alpha z + c_0 x' + k_0(0.003 - y)] \\
& z' = -747|x' - y'|z|z|^{n-1} - 1047(x' - y')|z|^n + 40000(x' - y') \\
& \alpha(i) = 0.9i^3 + 1.1i^2 + 0.9i + 0.9 \\
& c_0(i) = 60i^3 - 70i^2 + 19i + 7 \\
& c_1(i) = -i^3 + 300i^2 + 5i + 1000 \\
& k_0(i) = 200i^3 + 100i^2 + 100i + 300 \\
& \delta = 50\sin(10\pi + 0.21) + 1.1\sin(18\pi + 0.31) + \\
& + 1.4\sin(30\pi + 0.62)
\end{aligned}
\qquad (2)
$$

With this new real model of the proper MRD will be possible to optimize the global dynamic behavior of the robot in his application with MRD.

6. DISCUTION AND FINAL CONCLUSIONS

The assisted method of the research of the MRD open the way to optimize the global dynamic behavior of the industrial robots by on-line application of the active MRD. We can see that by changing, on-line, the intensity of the current, i will be possible to change the characteristics of the damper. The assisted metod and the virtual LabVIEW instrumentation are generally, we can apply in many other mechanical application. The future work will be the assisted research of the robot by using the proper mathematical model.

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