# SOME CONTRIBUTIONS ON THE MAGNETORHEOLOGICAL DAMPER ASSISTED RESEARCH

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**Abstract.** The paper shown one new assisted research of the magnetorheological damper (MRD) used in the on-line optimization of the dynamic behavior of the mechanical applications. To operate with these intelligent elements was necessary to developing the proper research of some dynamic parameters and new mathematical model of the damper. The original contribution of the research was to complete the Bouc-Wen modified model with new four equations and to simulate the rheological damper characteristics. With these new research was possible to know the influence of the changed parameters to the dampers characteristics and to move some of the frequencies in to the attenuation frequency bandwidth of the Fourier spectrum. Method and the results can be used in all others mechanical research.

**Keywords:** Magnetorheological damper, assisted research, LabVIEW instrumentation

## 1. INTRODUCTION

In all mechanical systems one of the more important thing is to know the vibration behavior, the viscose global dynamic damper coefficient, VGDDC of his structure and how the dynamic variation of acceleration determine the mechanical vibrations, to ovoid the resonance frequency of the spectrum. More, in the paper are study some influences of the rheological damper parameters into the equivalent coefficient value of the viscose global dynamic damper coefficient, VGDDEC.
The paper presents one proper assisted method using the proper virtual LabVIEW instruments for the assisted research of the VGDDEC. The virtual instruments achieved in the LabVIEW soft 8.2.0 from National Instruments, USA, simulate the VGDDEC for one mechanical structure with rheological damper (Bouc-Wen modified model, 2002),[2, 4] completed with proper four equations. In the world, all determinations of the dynamic compliance and of the damper influences were made without the modern virtual LabVIEW instrumentation like show in this paper.

The virtual instrumentation presented in the paper, is special for these determinations and assures one small cost and one short time of the research. The paper contains the assisted research of the magnetorheological damper (MRD) by changing some constructive or functional parameters, to know how where changed the dynamic characteristics of the damper: force versus velocity and displacement, and finally to determine the damper energy and decreasing the transmission of the vibration between the base to the structure. The research was made by exciting, the base robot structure, and data acquisition of the exciting force and of the displacement in one point of the structure. For that on used one experimental setup presented below.

Vibration isolators or dampers are commonly used to mitigate vibrations in structures of robots. The isolators are typically passive and they are designed to reduce the vibration of the most undesired frequency. However, in many applications, the excitation frequency varies across a large range. In a semi-active device, the stiffness or damping can be adjusted during operation. Changing the stiffness of the support device can be exploited by moving the eigenfrequency of the system to bypass the resonance. Reliable control of the support device requires monitoring of a critical point of structure and knowledge about the frequency response of the system. This kind of adaptive isolator can change operation conditions according to dominant loading resulting in improved vibration isolation capability compared to passive systems. Undesired vibrations are reduced in different loading conditions, a large frequency range is covered. Magnetorheological (MR) fluids are a class of smart materials whose rheological properties are rapidly varied by applying a magnetic field.

This change is in proportion to the magnetic field applied and is immediately reversible. MR-fluids exhibit rapid, tuneable and reversible transition from a free-flowing state to a semi-solid state upon the application of an external magnetic field. MR-material provides simple, quiet and rapid-response interface between the electronic control and mechanical system to mitigate the vibration of the robots structure (Choi and Lee, 2001)[4]. Several articles presenting the results of experimental testing and mathematical models have been published recently [5, 6, 7]. In the paper was researched one complex damper, Bouc- Wen modified model, completed with new four polinoms of thethird order with many new functional and constructive parameters [6]. MR-materials usually consist of micron-sized (3.8μm) magnetizeable particles suspended in a liquid. A typical MR-fluid consists of 20.40% by volume of relatively pure iron particles suspended in a carrier liquid such as mineral oil, synthetic oil, water, or glycol. A variety of proprietary additives similar to those found in commercial lubricants are used to discourage gravitational settling and promote particle suspension, enhance lubricity, change initial viscosity, and inhibit wear (Encyclopedia of Smart Materials). A critical particle volume concentration (CPVC) defined by Lokander and Stenberg (2003) depends on the apparent density of powder containing the iron particles.

The MR-effect does not increase much with increasing particle content above the CPVC. Magneto Rheological Fluids (MRFs) are magnetically-controlled fluids. MR Fluids find more and more industrial applications in actuation functions. These include shock absorbers, semiactive dampers, clutches, brakes, haptic actuators & devices. These functions are used in automotive & bike applications such as engine mounts, shock absorbers, suspensions and seat dampers [1,2,3]. They are seriously considered in anti-seismic dampers in civil engineering structures. To design such an application as well as some others being studied by Cedrat Technologies for its industrial customers, a device-oriented test bench has been developed in order to characterise the magnetomechanical properties of MRF such as the magnetisation curve, the fluidic behaviour by different experiments. In the figure 1 is presented one of the three posibility of the including the control in the structure dynamics.

Magnetorheological liquids (MRF) are substances that, under the influence of a controlled magnetic field, change from a liquid to a nearly solid state within a matter of milliseconds. Damping technology that is based on such fluids is particularly suitable for applications in areas in which large vibration fluctuations occur, such as in the damping of drivers' seats. MRF dampers independently take over the regulation of damping by adapting themselves automatically to the varying impacts or vibrations and changing the damping force correspondingly up to 500 times per second.

The controller of the MRF damper actively determines the damping according to each individual vibration and there prevents the breakdown of the damper in case of vibration peaks. An adjustment, for example according to particular road conditions, is no longer necessary with the MRF damper. Magnetorheological substances, marketed under the name RheoneticTM Fluids, provide product development in the area of vibration isolation and the electronic regulation of movement occurrences a completely new dimension.

The paper contains the assisted research of the Magneto Rheological Damper (MRD) to know some dynamic characteristics of the damper forces versus velocity, damper forces versus displacement and finally to determine the damper energy and decreasing the transmission of the vibration between the floor to the TCP of the robot. In this paper was researched the structure of one didactical arm type robot RBA2.5 with U profile of the arms. The research we 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. Now, in the world more and more is used the LabVIEW instrumentation to assure the data acquisition and the virtual simulation of the dynamic behavior.

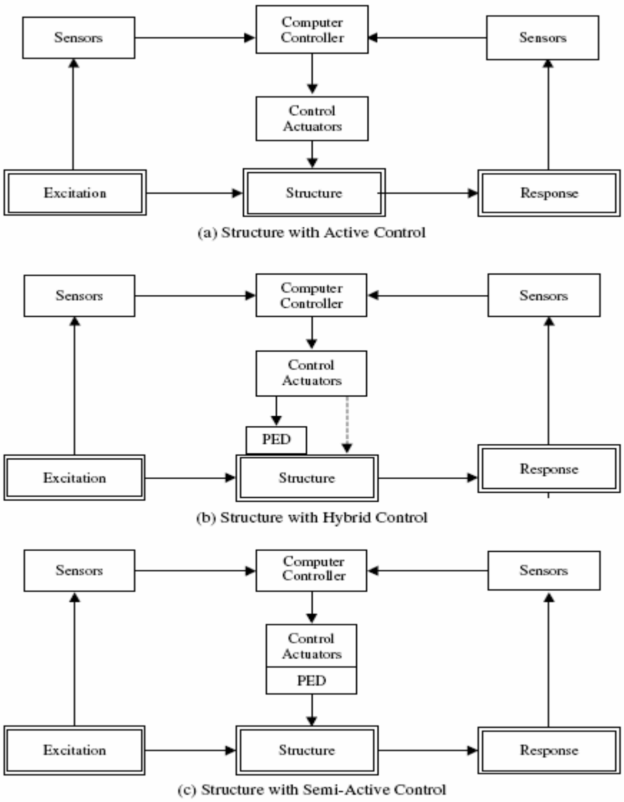


Fig.1 Structure with various active control schemes (PED: passive energy dissipation)

## 2. EXPERIMENTAL SETUP

The experimental stand contains the following components (fig.2): didactical arm type robot; magneto rheological damper; 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 traducer type 16.1 IAUC Romania; Hottinger apparatus type KWS/T-5 from Germany.

Fig.2 Experimental setup

## 3. MATHEMATICAL MODELS OF THE DAMPERS

Bingham's model on based on the Bingham.s rheological model, one
can idealize a simplified mechanical model to simulate the MR-damper. The parallel friction and dashpot elements illustrated in Fig. 3 can be applied to simulate the force-displacement behaviour reasonably, but the force-velocity behaviour is not captured, especially for the velocities close to zero. In addition, this kind of model does not exhibit the non-linear force-velocity behaviour. Therefore, a more advanced model is needed.

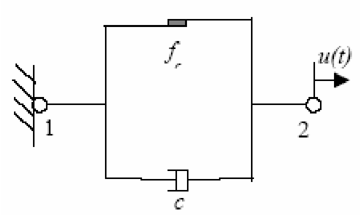


Fig.3 Mechanical model containing a friction and dashpot element to simulate Bingham's model

Bouc-Wen's model is the most extensive model for modelling a hysteretic system, as shown in Eq. (1). It is a versatile but also complicated model that needs a closed-loop control algorithm (Dyke et al., 1998, Yang et al., 2002, Liao and Lai, 2002) [9, 10].

The equations describing the Bouc-Wen algorithm for the MR-damper behaviour (fig.4) , can be written as follows [4 , 6, 11, 12]:

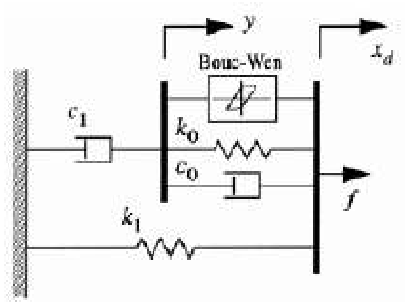


Fig. 4 Mechanical model of the MR-damper based on the Bouc-Wen model (Dyke et al., 1998)

$$
\begin{aligned}
f &= c_1\dot{y} + k_1(x_d - x_0) \\
\dot{z} &= -\gamma|\dot{x}_d - \dot{y}|z|z|^{n-1} - \beta(\dot{x}_d - \dot{y})|z|^n + A(\dot{x}_d - \dot{y}) \\
\dot{y} &= \frac{1}{c_0 + c_1}\{\alpha z + c_0\dot{x}_d + k_0(x_d - y)\}
\end{aligned}
\quad (1)
$$

where the force $f$ is described by the primary displacement variables, $x_d$ and $y$, and an evolutionary variable $z$ that takes into account the history dependency. Viscous damping parameters $c_0$ and $c_1$ as well as the parameter $\alpha$ depend on the field variable (voltage). Parameters $\beta$ and $x_0$ are constants. The characteristics are in the fig.5.

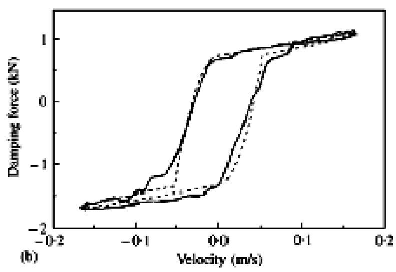


Fig. 5 Hysteresis plots in the velocity domain. comparison between experiments (solid line) and simulations (dashed line) with different models (Choi et al., 2001)

Li's model (2000) presented a model in which the MR-material operates in two rheological domains: the pre-yield and post-yield regions. It is considered that, in the pre-yield region, deformations are viscoelastic and in the post-yield region, the deformations are viscoplastic. The mechanical model is presented in Fig.6.

$$\begin{aligned} F &= F_{ve} + F_s, & |F| \le F_c, \ \text{preyield} \\ F &= C_V \dot{x} + R\ddot{x} + F_C \operatorname{sgn}(\dot{x}), & |F| > F_c, \ \text{postyield} \end{aligned} \tag{2}$$

in which $F_c$ is the yield force, $C_V$ is the viscous damping coefficient and $R$ is the equivalent inertial mass. The viscoelastic force $F_{ve}$ needs to be determined separately according to visco-elastic theory. Li et al. (2000) made experimental tests of the dynamical properties of the MR-damper. A sinusoidal displacement controlled loading was applied at certain amplitude and frequency. The relationships of the MR-damper response force versus displacement and force versus velocity, various magnetic fields are shown in Eq(2). All the data were collected from the stable cycle. The Bingham-type behaviour was observed in the force-velocity hysteresis cycles.

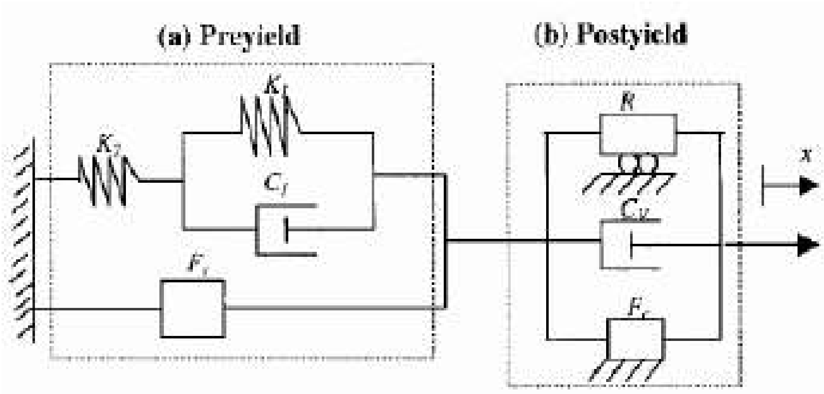


Fig.6- Viscoelastic-plastic model of the MR-damper according to Li et al (2000)

None of these hysteresis loops is elliptical, indicating that the MR-damper operates in the postyield region rather than pre-yield one. Therefore, damping is more likely frictional and not viscous.
Oh and Onoda's model (2002) [4, 6], fig.7 and 8., designed and manufactured a variable MR-fluid damper to demonstrate vibration mitigation in a truss structure.

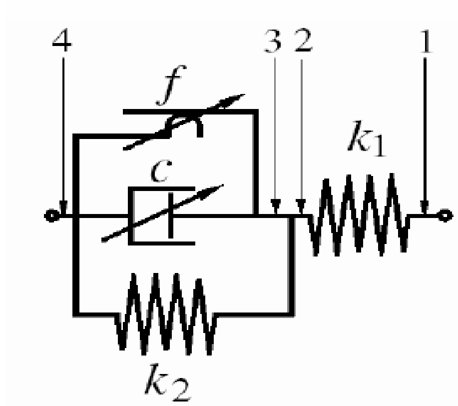


Fig. 7- Equivalent mechanical model consisting of elastic springs, dashpot and friction component describing the MR-damper according to Oh and Onoda (2002)

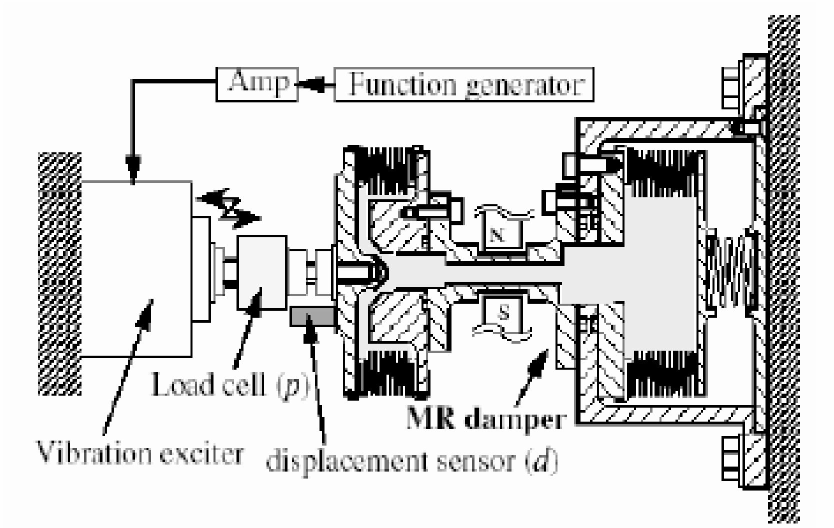


Fig. 8- Experimental set-up for dynamic tests of the MR-damper (Oh and Onoda, 2002)

Choi's et al. model (2001)[8] describ the force-velocity relation in an MR damper. They realized that with existing models (Bingham and Bouc-Wen) it is very difficult to carry out a control system (open-loop or closed-loop) to achieve desirable tracking control performance of the field-dependent damping force. Therefore, they proposed a sixth-order polynomial model in which the damping force is expressed by:

$$F_d = \sum_{i=0}^{6} a_i v^i \tag{3}$$

The parameters $a_0...a_6$ are defined from the experiments as having different values for the positive acceleration and as well as the negative. $v$ is the velocity power of $i$.

## 4. PROPOSED MATHEMATICAL MODEL

The proposed mathematical model of the Bouc-Wen damper model, completed by the four polynomial relations of the third order is:

$$\begin{aligned}
& f = c_0(x' - y') + k_0(x - y) + k_1(x - x_0) + \alpha z \\
& y' = \frac{1}{c_0 + c_1}[\alpha z + c_0 x' + k_0(x - y)] \\
& z' = -\gamma|x' - y'|z|z|^{n-1} - \beta(x' - y')|z|^n + \delta(x' - y') \\
& \alpha(i) = \alpha_3 i^3 + \alpha_2 i^2 + \alpha_1 i + \alpha_0 \\
& c_0(i) = c_{03} i^3 + c_{02} i^2 + c_{01} i + c_{00} \\
& c_1(i) = c_{13} i^3 + c_{12} i^2 + c_{11} i + c_{10} \\
& k_0(i) = k_{03} i^3 + k_{02} i^2 + k_{01} i + k_{00}
\end{aligned} \tag{4}$$

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]; $\alpha$ is the internal parameter what have non linear evolution and depend on the magnetic variable field (electrical intensity); parameters $\beta$ characterise the gain of increasing of the damping force versus velocity; $x_0$ is the perturbation displacement [m]; δ is the histeresys parameter.
After the indentification of the parameters by assisted research, by compare the real characteristics with the simulate, result the propre mathematical model. This model will be:

$$
\begin{aligned}
& f = c_0(x' - y') + k_0(x - y) + k_1(x - x_0) + \alpha z \\
& y' = \frac{1}{c_0 + c_1}[\alpha z + c_0 x' + k_0(x - y)] \\
& z' = -7|x' - y'||z||z|^{n-1} - 5(x' - y')|z|^{n} + 2000(x' - y') \\
& \alpha(i) = 10i^3 + 14.1i^2 + 9.1i + 10.1 \\
& c_0(i) = 40i^3 - 50i^2 + 4i + 5.01 \\
& c_1(i) = -45i^3 + 18i^2 + 24i + 4 \\
& k_0(i) = -20i^3 + 2i^2 + i + 4
\end{aligned}
\tag{5}
$$

The assisted researched characteristics of the damper are show in the fig. 9.

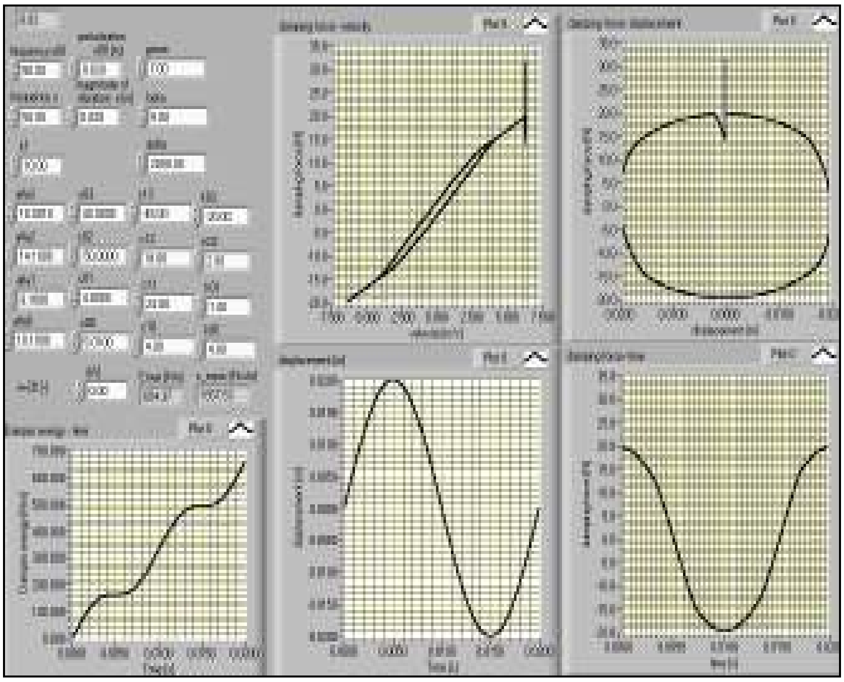

Fig.9. The real characteristics of the researched damper

## 5. NUMERICAL SIMULATION AND ASSISTED RESEARCH OF THE PROPOSED DAMPER

By appling the matematical model was created one virtual LabVIEW instrument for the assisted research of the of the influences of the functional or constructive of MRD parameters versus the dynamic characteristics. We studied the evolution of the damper forces versus velocity, or versus displacement, the periodical damper force vs. time. All these characteristics were show comparative for the different values of the parameters. This step of the research assures the good choose of these parameters to approximate with the smaller errors the experimental MRD characteristics. Many researchers in the world determined the coefficients of the non-linear mathematical model by compare the experiments with the theoretical characteristics without the assisted research. Some results are shown in figures 10…11.

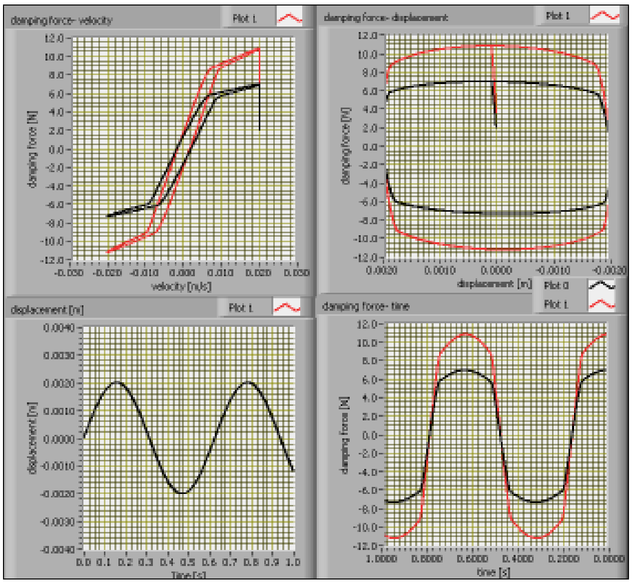

Fig.10. The simulate characteristics of the researched damper when was changed current intensity *i* from 1.2 to 1.5A

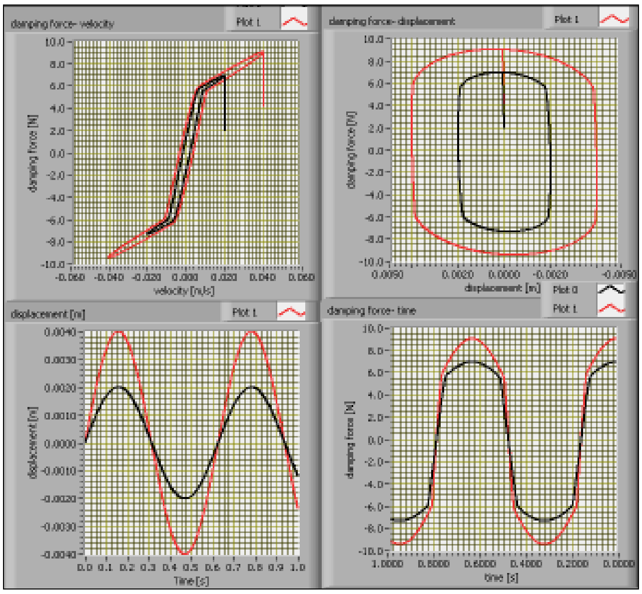

Fig.11. The simulate characteristics of the researched damper when was changed the magnitude of the vibration from 0.002 to 0.004m

**6. DISCUTIONS AND CONCLUSIONS**

The assisted research of the GDC, VGDDC, VGDDEC and of the influences of MRD parameters open the way to optimise the vibration Fourier spectrum in all resonance frequencies. By applying the MRD we can do easily the move of the bad resonance frequencies in to the attenuation bandwidth. The assisted establish of the MRD parameters with the virtual LabVIEW instrumentation assures the reducing of the errors between the numerical model and the real one. The method, the virtual instrumentation and the assisted results assure the optimisation of the dynamic behaviour of all mechanical structures. In the future will be researched the vibration Fourier spectrum for some stimulus frequencies with and without the MRD's, applied in different joints of the robot structure. The shown method and the LabVIEW instrumentation are generally, we can be applied in many others mechanical applications.

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