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ASSISTED RESEARCH OF THE INDUSTRIAL ROBOTS GLOBAL DYNAMIC COMPLIANCE WITH LABVIEW INSTRUMENTATION

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Abstract: *Future industrial robots have to be highly dynamic systems to sustain the required productivity, accuracy and reliability. Both the joints and robots bodies system are necessary to be optimized for their usability performance to meet the productivity requirements of the tool center point (TCP). The global dynamic compliance (GDC) is one of the most important dynamic parameters of the dynamic behavior and with this parameter is possible to determine the viscose global dynamic damper coefficient (VGDDC) to obtain finally the desired dynamic behavior. The knowledge of the GDC and the transfer function (TF) between the displacement of the TCP and the applied force, is very important to chose the rigidity in the joints, to establish the optimal mechanical form of the bodies, to obtain one power vibration spectrum in concordance with the manufacturing application.*

Key words: *global dynamic compliance, viscose global dynamic damper coefficient, global dynamic damping ratio, dynamic behavior, assisted research, virtual instrumentation.*

1. INTRODUCTION

The GDC is one of the most important parameter in the dynamic behavior of the industrial robot. In the manufacturing systems is necessary to know the vibration behavior of the robot, the VGDDC of his structure and how the dynamic variation of acceleration determines the damped mechanical vibrations, to avoid the resonance frequency of the spectrum. The paper presents one assisted method with virtual LabVIEW instruments for the assisted research of the GDC of the industrial robots. The virtual instruments achieved in the LabVIEW software 6.1 from National Instruments, USA, simulate the GDC. This virtual apparatus is generally used in many others mechanical applications. Now, in the world, all determinations of the dynamic compliance is made with modern analyzer apparatus like showed in this paper. This apparatus, presented in the paper, is a special virtual apparatus for these determinations, which assures one small cost and short time of the research.

The paper contains the assisted research of the GDC to know the transmission of the vibration between the floors to the TCP of the robot. In this paper was researched the structure of one didactical arm robot with U type cross section of links. The research was 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 the used experimental setup is below presented. 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.

2. EXPERIMENTAL SETUP

The experimental stand contains the following components (Fig. 1): 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 traducer type 16.1 IAUC Romania; Hottinger apparatus type KWS/T-5 from Germany.

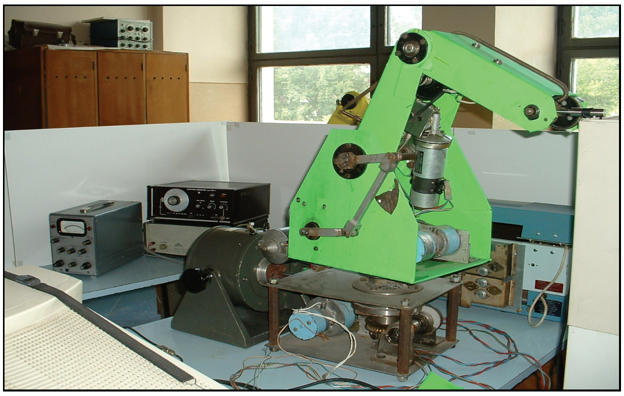

Fig. 1. Experimental stand for the assisted research of the vibration spectrum.

The experimental research consists in a excitation on the base of the modulus with periodical forces and data acquisition of the displacement of the TCP. After that with the virtual LabVIEW own instrumentation was determined the transmissibility between the floor and the TCP, and the dynamic global viscose damping value *c* and the global dynamic damping ratio ξ.

3. MATHEMATICAL MODELING

Every mechanical robot structure consists of multiple mechanical components which are coupled together and can be represented in a dynamic mechanical model as multiple mass, spring and damping elements (Fig. 2). While the mass and the spring stiffness determine the natural frequency ν_n of the system, the damping element, represented by the GDDR, ξ, governs the resonance

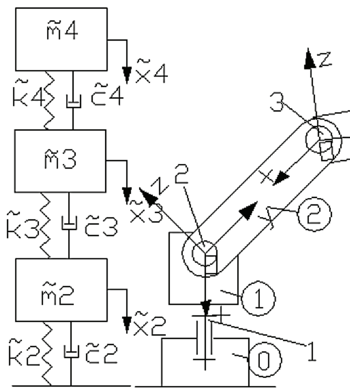

Fig. 2. Mechanical model of the robot structure.

amplitude of the vibration and with it, the dynamic system stiffness. Modal testing theory has been successfully used for calculating the frequency spectrum of robots structure [7]. A frequency spectrum includes the amplitude-frequency characteristic (dynamic compliance) and the phase-frequency characteristic of the mechanical robot structure. Frequency characteristic analysis is important to understand the dynamic performance of the bodies-joints robot system.

If the dynamic impact with one periodical force on the base of the robot structure is $F(t)$, the displacement response of the TCP is $x(t)$, then the GDC of the TCP is defined as:

$$\frac{1}{k(\mathrm{j}\omega)} = \frac{\int_0^T x(t)\mathrm{e}^{-\mathrm{j}\omega t}\mathrm{d}t}{\int_0^T F(t)\mathrm{e}^{-\mathrm{j}\omega t}\mathrm{d}t} = \frac{FFT(x)}{FFT(F)} = \frac{E_x(\mathrm{j}\omega)}{E_F(\mathrm{j}\omega)}, \qquad (1)$$

where $E_F(\mathrm{j}\omega)$ and $E_x(\mathrm{j}\omega)$ are complex spectrum of energy of the input force on the base robot modulus and respectively output displacement of the TCP. The complex power spectrum is possible to obtain by dividing the energy spectrum with the integration time T. The integrated relations are the Fourier transform expressions and can be calculated [8] by FFT algorithm (Figs. 3, 4).

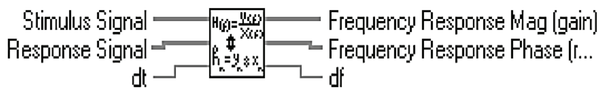

Fig. 3. Icon of the LabVIEW instrument for the transfer function.

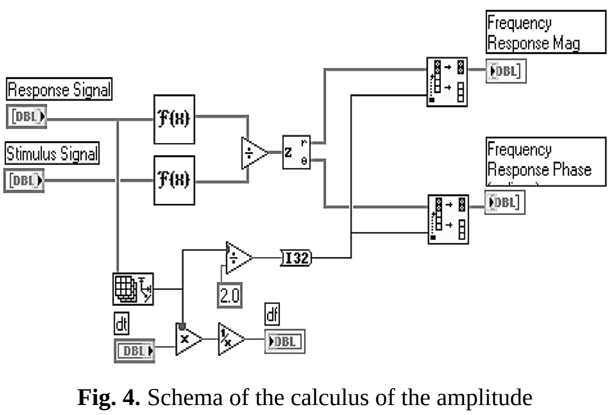

Fig. 4. Schema of the calculus of the amplitude and phase of the dynamic compliance.

After expansion with the complex conjugate, the GDC can be expressed as:

$$\frac{1}{k(\mathrm{j}\omega)} = \frac{E_x(\mathrm{j}\omega)E_F^*(\mathrm{j}\omega)}{E_F(\mathrm{j}\omega)E_F^*(\mathrm{j}\omega)} = \mathrm{Re}(\omega) + \mathrm{j}\ \mathrm{Im}(\omega), \qquad (2)$$

where E_F^* is the complex conjugate of E_F.

Magnitude of the GDC is calculated by:

$$\frac{1}{k(\omega)} = \sqrt{\left(\mathrm{Re}\left\{\frac{1}{k(\mathrm{j}\omega)}\right\}\right)^2 + \left(\mathrm{Im}\left\{\frac{1}{k(\mathrm{j}\omega)}\right\}\right)^2}. \qquad (3)$$

The viscose damping value c can be calculated with:

$$c_i = 2\xi_i \frac{k_i(\omega)}{\nu_{n_i}}, \qquad (4)$$

where ν_{ni} is the natural frequency.

The damping ratio for each resonance frequencies ξ_i can be obtained by:

$$\xi_i = \frac{\nu_{i1} - \nu_{i2}}{2\nu_{iR}}, \qquad (5)$$

where ν_{i1} and ν_{i2} are the frequencies obtained by the $\sqrt{2}$ method [5] for each resonance frequencies.

4. VIRTUAL LABVIEW INSTRUMENTATION

The created virtual instrument with LabVIEW software 6.1 is the proper virtual Fourier analyzer and used for assisted determination of the GDC, GDDR and VGDDC. In comparison with the real analyzer, this one assures the many real and frequency characteristics, some rapid changes of the input data and the presentation of the comparative results. The virtual analyzer assures the acquisition data on many input channels, the rapid change of the scale, or of the domain, the assisted comparison between the real and the frequency characteristics, the assisted calculus of the dynamic compliance, damping ratio and viscose damping coefficient for each resonance frequencies so necessary for the dynamic optimization of the robot structure. The icon and the front panel of the virtual instrument are presented in Figs. 5, 6, 7 [1, 2, 3]. The complex virtual Fourier analyzer assures the complete analyze of the structure damping vibration. The knowledge of the TF [4] gives the possibility to choose the structure with the proper convenient frequency and with the small transmissibility of the vibration between the floors to the TCP. The virtual instrument assures also the change of the acquisition channel,

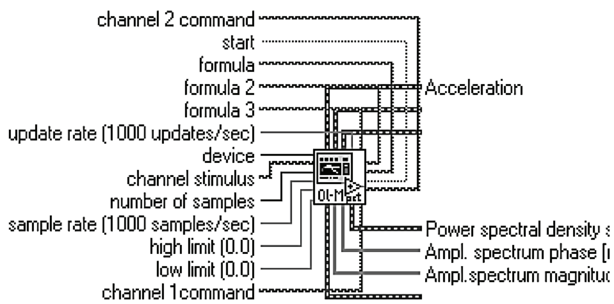

Fig. 5. The icon of the Fourier proper VI.

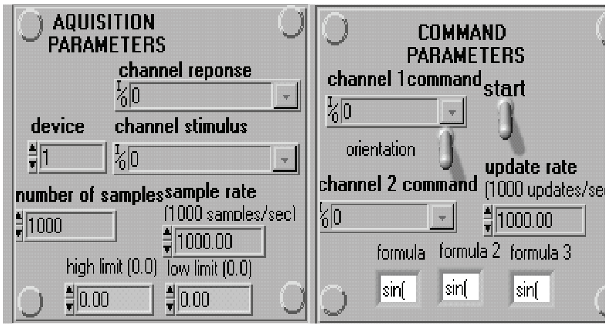

Fig. 6. The front panel of the Fourier proper VI with the input and acquisition parameters.

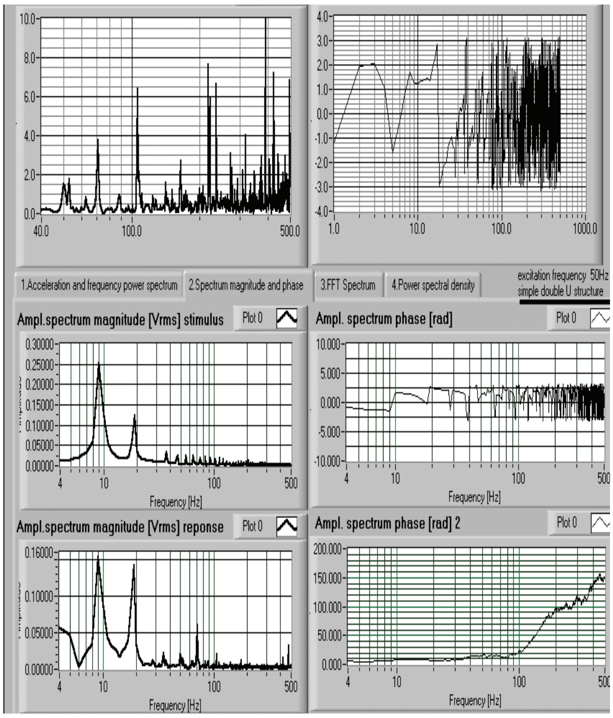

Fig. 7. The front panel of the Fourier proper analyzer with some characteristics results when the base of the robot was excited with 9Hz periodical force.

the command channel, the formula of the command function and the characteristics results of the TF, the GDC and the VGDDC.

5. REZULTS AND DISCUSSION

In all researched cases the robot's modulus was excited in a range between 5…70 Hz. In all the cases have been designed the presented real and frequencies characteristics. In Figs. 7, 8, 9 and Tables 1, 2, 3 are presented some of these results to make the comparative analysis.

After the comparative analyze of the characteristics, results the following remarks: the increase of the stimulus frequency determine the movement of the higher rigidity to the small resonance frequencies; the VGDDC of the robot structure is bigger to the small resonance frequencies, when the force frequencies stimulus increase; the VGDDC decrease with the increase of the resonance frequencies for all stimulus frequencies. The curve of the maximum of the VGDDC is the same in all cases except for the two small excitation frequencies.

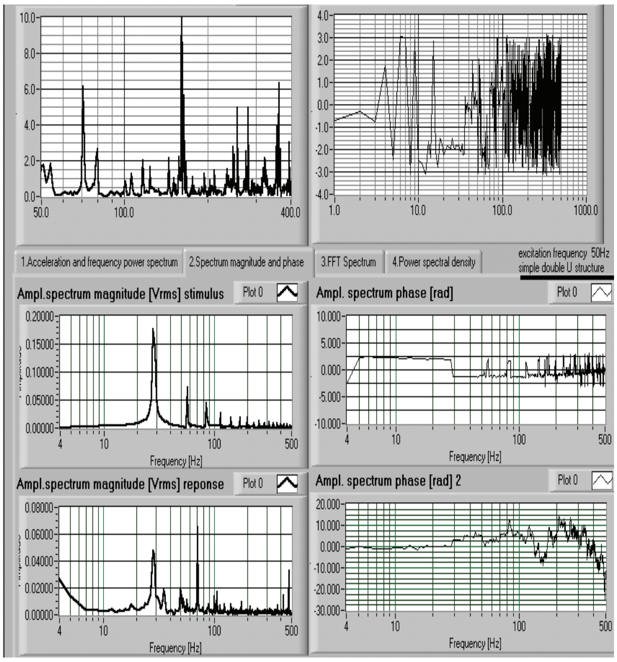

Fig. 8. The front panel of the Fourier proper analyzer with some characteristics results when the base of the robot was excited with 30Hz periodical force.

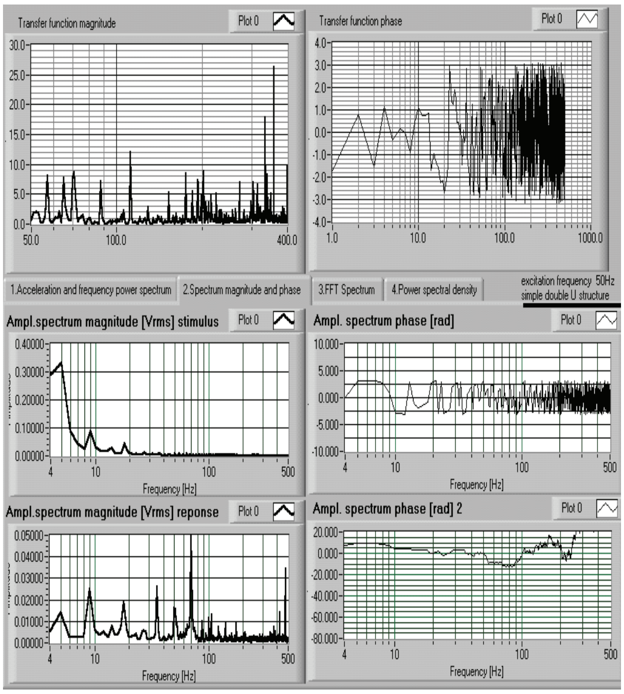

Fig. 9. The front panel with some characteristics results when the base of the robot was excited with 5Hz.

The 3D diagrams of the GDR (Figs. 10, 11) and of the VGDDC are very important to choose the optimal values of the acceleration to avoid the bad resonance frequencies. The determined values of the VGDDC could be used in many other mechanical applications.

6. CONCLUSIONS

The virtual Fourier analyzer and the calculus of the VGDDC are very important for the assisted research of the vibration spectrum in all different mechanical appli-

Table 1

Global Dynamic Compliance of the Robot Structure(GDC)

	rezonance frequencies												
	50	65	70	80	90	100	110	120	130	160	170	180	200
csi	0.4	0.307692	0.285714	0.25	0.222222	0.2	0.181818	0.166667	0.153846	0.125	0.117647	0.111111	0.1
	0.6	0.6	0.6	0.01	0.5	0.01	0.01	1.2	0.1	0.5	0.8	0.5	0.01
	0.18	0.2	0.4	0.01	0.1	0.01	0.65	0.01	0.01	0.1	0.25	0.1	0.01
	0.2	0.2	0.6	0.25	0.01	0.1	0.1	0.2	0.18	0.01	0.01	0.01	1.2
1/k	0.01	0.01	0.7	0.01	0.1	0.1	0.1	0.01	0.11	0.1	0.2	0.2	0.05
	0.01	0.01	0.8	0.1	0.1	0.2	0.2	0.01	0.4	0.01	0.25	0.25	0.15
	0.01	0.01	0.25	0.01	0.05	0.1	0.1	0.01	0.1	0.2	0.01	0.2	0.45
	0.01	0.01	0.1	0.01	0.1	0.25	0.25	0.01	0.25	0.4	0.4	0.4	1.2

Table 2

Global Dynamic Rigidity of the Robot Structure (GDR)

	1.666667	1.666667	1.666667	100	2	100	100	0.833333	10	2	1.25	2	100
	5.555556	5	2.5	100	10	100	1.538462	100	100	10	4	10	100
	5	5	1.666667	4	100	10	10	5	5.555556	100	100	100	0.833333
k	100	100	1.428571	100	10	10	10	100	9.090909	10	5	5	20
	100	100	1.25	10	10	5	5	100	2.5	100	4	4	6.666667
	100	100	4	100	20	10	10	100	10	5	100	5	2.222222
	100	100	10	100	10	4	4	100	4	2.5	2.5	2.5	0.833333

Table 3

Viscose Global Dynamic Damper Coefficient of the Robot Structure (VGDDC)

	0.026667	0.015779	0.013605	0.625	0.009877	0.4	0.330579	0.002315	0.023669	0.003125	0.00173	0.002469	0.1
	0.088889	0.047337	0.020408	0.625	0.049383	0.4	0.005086	0.277778	0.236686	0.015625	0.005536	0.012346	0.1
	0.08	0.047337	0.013605	0.025	0.493827	0.04	0.033058	0.013889	0.013149	0.15625	0.138408	0.123457	0.000833
c	1.6	0.946746	0.011662	0.625	0.049383	0.04	0.033058	0.277778	0.021517	0.015625	0.00692	0.006173	0.02
	1.6	0.946746	0.010204	0.0625	0.049383	0.02	0.016529	0.277778	0.005917	0.15625	0.005536	0.004938	0.006667
	1.6	0.946746	0.032653	0.625	0.098765	0.04	0.033058	0.277778	0.023669	0.007813	0.138408	0.006173	0.002222
	1.6	0.946746	0.081633	0.625	0.049383	0.016	0.013223	0.277778	0.009467	0.003906	0.00346	0.003086	0.000833

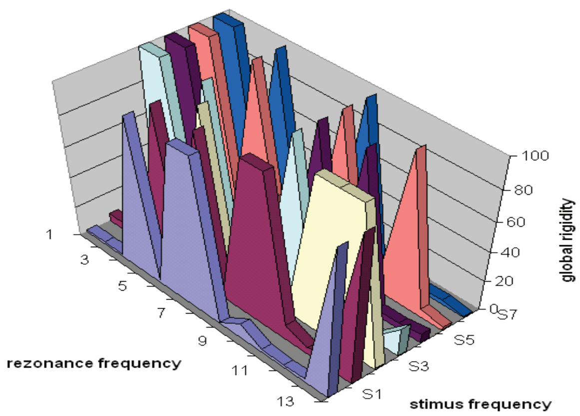

Fig. 10. The 3D characteristic for the global dynamic rigidity of the robot structure (GDR).

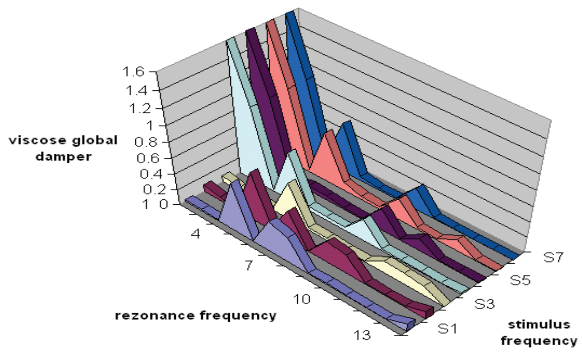

Fig. 11. The 3D characteristic for the viscose global dynamic damper coefficient (VGDDC).

cations. The results, the comparative possibility of the analysis and the price of the research confirm that.

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