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STUDY THE DYNAMIC BEHAVIOR OF THE BOX OF PRECISION MEASURING EQUIPMENT, ATTACHED BY CONTAINER TO VIBRATING BASE

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Abstract: This report explores the dynamics of the box of measuring equipment for non-mechanical measurements, which in certain cases performs high-frequency vibrations. The vibrations with larger amplitudes and accelerations andrelated with them inertia forces may influence to the measurement precision. To determine the limits of change of these characteristics and to recommend measures for their limitation was done study of the system box measuring equipment, container for storing and vibrating base. The dynamic model for study of the system consists of two mases, modelling respectively the box and container, with elastic-viscous connection between them. The link between first mass and vibrating base is elastic-viscous, too. The mathematical model of the vibrating structure is a system of two inhomogeneous differential equations with two unknown accelerations, derived by the method of Lagrange of the second order. The solution of the system of the differential equations is realized in geometric environment for solving of such systems MATLAB/SIMULINK. Finally has been conducted experimental research of the problem. This was done through use of Stand for modular dynamic testing of the construction, subjected on seismic impact. The stand is part of the experimental base of the Lab for numerical and experimental dynamic modelling, one of the big labs at the UACEG, Sofia, Bulgaria. Based on the combined study were made recommendations on and variability of the characteristics of connections, depending on the magnitude of the masses and characteristics of the external impact.

Keywords: dynamic model, mathematical model, simulation model, experimental set

INTRODUCTION

Much of the mobile building construction and equipment – construction cranes, construction machinery (Fig. 1)and others areequipped with precise measuring technology. Part of the equipment intended for mechanical tests - displacement, acceleration, inertia is hard connected to the moving parts of the equipment for the purpose of precision measurements. For equipment intended for non-mechanical measurements - temperature, humidity, light, etc. The hard connection is not always appropriate.Large as amplitude and frequency vibration of the equipment can affect of the precision work of the last and accuracy of measurements, performed with them.



Figure 1. Constructional installations and technics with measuring equipment on them

With purpose protection from direct mechanical damage to the measuring equipment is placed in special containers (Fig. 2), attached to a movable, most often vibrating part of the constructions. The attachment of the containers to the vibrating structure can be hard or elastic. The attachment of the measuring technique to the container also can be hard or elastic.

The elastic attachment elements - rubber pads, elastic ropes [2], springs and almost always possess certain dissipative properties, related to the vibrations of the system.

In the report, the system - vibrating base, container and measuring equipment are modeled based on certain simplifications such as vibrating system of two bodys with a viscous-elastic connections between them.To make relevant analytical, numerical and experimental research to refine the characteristics for connections based on the external impact and requirements of equipment for the maximum value of the kinematic and power characteristics in them.

Figure 2. Storage containers for measuring equipment

Discussed was forced a damped vibrations of the system, caused by cinematic interferences, modeled in sinusoidal or random form.

ANALYTICAL, NUMERICAL AND EXPERIMENTAL PROCEDURE

Dynamic model

The steps of modeling of the real system are shown in (Fig. 3). The dynamic model consists of two bodies vibrating in a horizontal direction (container and a measuring instrument). It is assumed vibrations on one axis, container performs horizontal translation about the vibrating structure and measuring techniques performs translation about the container (Fig. 3a).

The external and internal forces of dry friction between the components of the vibrating system are ignored. It has been recorded dissipative forces of internal friction as a result of viscous nature of some of the links.

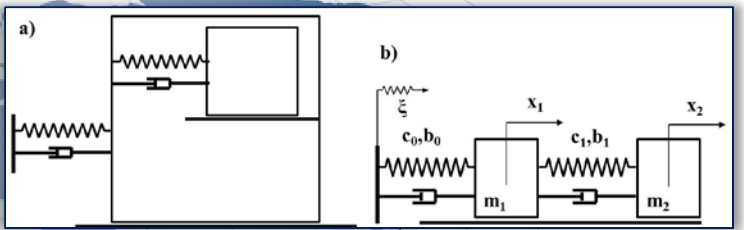

Figure 3. Dynamic model of vibrating system

In the dynamic model (Fig. 3b) the motion of the bodies is accepted in one axis without this to change the mathematical law of motion of the system from Fig. 3.a. The masses of the bodies are respectively m_1 – simulating the weight of the container and m_2 – simulating the mass of the measurement techniques. The link between the first body and the vibrating platform is modeled with elastic-viscous pair with coefficients c_0и b_0, and connection between two bodies, respectively by a pair with coefficients respectively c_1 and b_1.

The motion of the vibrating structure is given in two ways – like a sine wave and a uniform random signal.

$$\xi = \xi_0 \bullet \sin(\theta \bullet t) \tag{1}$$

$$\xi = \xi_0 \bullet \mathrm{rand}(1, \mathrm{length}(t)) \tag{2}$$

The recording of the random function in formula (2) is given based on the recording in Matlab programming system [3].

Mathematical model

Mathematical model of the two-bodies vibrating system is created by Lagrange equations of the second order

$$\frac{\partial}{\partial t}\left(\frac{\partial E_k}{\partial \dot{x}_j}\right) + \left(\frac{\partial \Phi}{\partial \dot{x}_j}\right) + \left(\frac{\partial E_p}{\partial x_j}\right) = 0 \tag{3}$$

where j=1,2.

The kinetic energy, expressed by the velocity of the two bodies of the system has the following quadratic form

$$E_k = \frac{1}{2} \bullet m_1 \bullet \dot{x}_1^{\,2} + \frac{1}{2} \bullet m_2 \bullet \dot{x}_2^{\,2} \tag{4}$$

The potential energy, expressed by the displacements of the two bodies and the kinematic interference from the vibrating base has the form

$$E_p = \frac{1}{2} \bullet (c_0 + c_1) \bullet x_1^{\,2} + \frac{1}{2} \bullet c_1 \bullet x_2^{\,2} + c_1 \bullet x_1 \bullet x_2 - c_0 \bullet \xi \bullet x_1 + \frac{1}{2} \bullet c_0 \bullet \xi^2 \tag{5}$$

In the expression of the potential energy is observed elastic connection between the two generalized coordinates, while in the expression of the kinetic energy inertial connection between the respective velocities misses.

Expression for dissipative function as structure looks like a Formula 5, as the coordinates are replaced by the velocities and elastic coefficients with the dissipative ones.

$$\Phi = \frac{1}{2} \bullet (b_0 + b_1) \bullet \dot{x}_1{}^2 + \frac{1}{2} \bullet b_1 \bullet \dot{x}_2{}^2 + b_1 \bullet \dot{x}_1 \bullet \dot{x}_2 - b_0 \bullet \dot{\xi} \bullet \dot{x}_1 + \frac{1}{2} \bullet b_0 \bullet \dot{\xi}^2 \qquad (6)$$

After substitution of the derivatives in Equation 3, is obtained the system of two differential equations with two unknowns – the accelerations of the two bodies.

$$\begin{aligned} m_1 \bullet \ddot{x}_1 + (b_0 + b_1) \bullet \dot{x}_1 - b_1 \bullet \dot{x}_2 + (c_0 + c_1) \bullet x_1 - c_1 \bullet x_2 &= c_0 * \xi \\ m_1 \bullet \ddot{x}_2 - b_1 \bullet \dot{x}_1 + b_1 \bullet \dot{x}_2 - c_1 \bullet x_1 + c_1 \bullet x_2 &= 0 \end{aligned} \qquad (7)$$

Simulation model

The solution of the system of differential equations is realized in the area of the symbolic modeling SIMULINK [3]. For this purpose, equation 6 is decided in respect of the accelerations

$$\begin{aligned} \ddot{x}_1 &= -\frac{(b_0 + b_1)}{m_1} \bullet \dot{x}_1 + \frac{b_1}{m_1} \bullet \dot{x}_2 - \frac{(c_0 + c_1)}{m_1} \bullet x_1 + \frac{c_1}{m_1} \bullet x_2 + \frac{c_0 * \xi}{m_1} \\ \ddot{x}_2 &= +\frac{b_1}{m_2} \bullet \dot{x}_1 - \frac{b_1}{m_2} \bullet \dot{x}_2 + \frac{c_1}{m_2} \bullet x_1 - \frac{c_1}{m_2} \bullet x_2 \end{aligned} \qquad (8)$$

The general appearance of the simulation model is shown in Fig. 4.

The input signals are stimulated by generators of sine wave and uniform random impact.Should be carefully selected the frequency and amplitude of the forced interferences, depending on the motion of construction. Graphs of the interference at equal amplitudes and approximately equalfrequencies are given in Fig. 5.

The solution of the equation is simulated by system of sum blocks, integrators, multipliers. It is accepted zero initial conditions. Elastic and viscous characteristics of the links are accepted depending on the type of fixing elements.

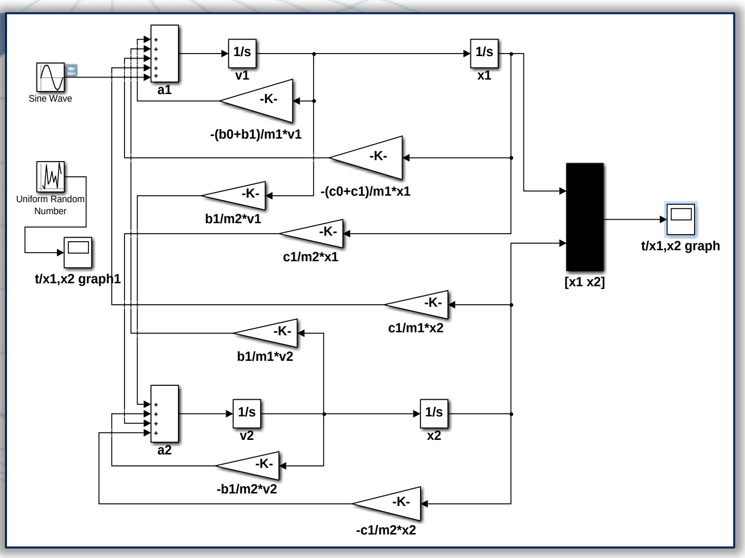

Figure 4. Simulation model of vibrating system

All numerical values are set in linked with the model text file in the area of Matlab. This allows for an easy change of their values.

Dynamic behavior of the bodies is shown on a scope block.

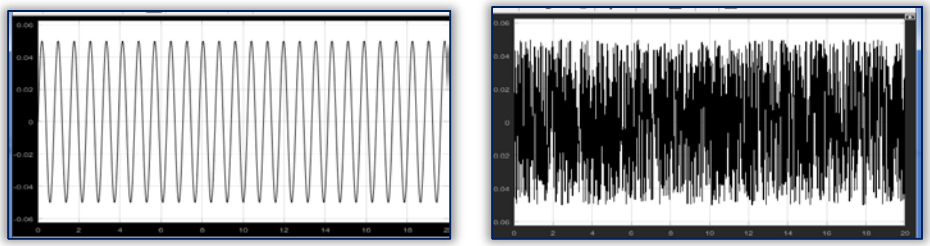

Figure 5. Input signal assine wave and random impact

In Figure 6 are given graphs of the vibrations of the the bodies coused by the above described inpacts. It is accepted some average values for the mass of the bodies. Elastic-viscous charachteristics of the linkwith index 0 are relatively high, suggesting close to hard connection. As regards the second connection - there are accepted once large, once relatively smaller values. As result of the last are reduced vibrations of the second body - measuring equipment.

EXPERIMENTAL STUDY

Experimental study is realized by Stand for modular dynamic testing of construction subject on seismic impact [1,2,4,6] – Fig. 7. The impact on the moving system is realized by horizontal vibrating table. The system for controlling the movement of the table allowsrealization of each of the interference by formulas 1 and 2 shown in Fig. 5. As in the numerical study, the relationship between the container and the moving table is accepted rigid.

In some of the experimental trials, connection between the container and the measurement equipment is accepted rigidwith infinity values of the elastic-viscous characteristics. In the other experiments for the last was accepted elastic-viscous with an average characteristics. With suitable selection of the latter can be reduced amplitudes of the accelerations and displacements of the body modelling the measurement equipment.

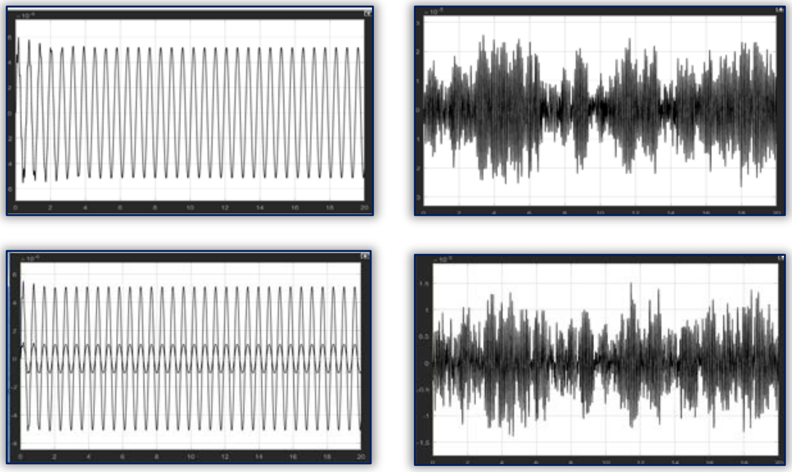

Figure 6. Dynamic behavior of the two bodies

The measurements of the motion of the bodies is performed by specially designed innovative measuring system of light diode lamp and photo resistor.The latter by special Arduino board and program developed in the area of Matlab converts the electrical signal in a digital for visualisation and processing. For the complete experimental study, were used and components from other stands [5] of the Lab for numerical and experimental dynamic modelling.

Figure 7. Photos of experimental study

DISCUSSION

The combined study indicates that in order to obtain optimum kinematic characteristics of the moving equipment, must vary with characteristics of the both elastic-viscous couples. In more stiff connection of first body with the second (container with a measuring equipment) was observed movement of the latter with an amplitude similar to that of the external impact.By reducing the stiffness of that connection is reduced and the amplitude of accelerations and displacements of the body.

In deterministic interferences more precisely can be defined the range and variability of stiffness to obtain the admissible values of kinematic characteristics. During the test should be careful the forced frequency of the interference not to be close to that of the vibrating system, due to the risk of resonance.Especially dangerous is that in experimental research, because the latter can result to unforeseen stresses on the experimental set.

CONCLUSION

Basic numerical and experimental studies were conducted mainly on the influence of the elastic characteristics of the internal and external connections of the links. Subject of the further work is determination of the influence of the dissipative characteristics on the motion of the bodies.

Note: This paper is based on the paper presented at The VIth International Conference Industrial Engineering and Environmental Protection 2016 – IIZS 2016, organized by University of Novi Sad, Technical Faculty "Mihajlo Pupin" Zrenjanin, in Zrenjanin, SERBIA, October 13–14, 2016.

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