DYNAMIC RESPONSE CONTROL FOR A MASS-SPRING-VISCOUS DAMPER SYSTEM BY USE OF AN ADDITIONAL ELECTRO-MECHANICAL IMPEDANCE

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*The paper presents an investigation concerning the possibilities to control the behavior of a dynamic vibration absorber consisting of a mass-spring-viscous damper with parameters **m/k/c**, by integrating in its structure an electro-dynamic actuator and an electrical impedance.*

The principles and the methods by which, through changes of mechanical and/or electric parameters, an effective control of the dynamic response of the system can be achieved are studied and the results are presented.

Keywords: dynamic absorber, electro-dynamic actuator, dynamic control.

1. Introduction

At this moment there are conducted worldwide researches and studies related to the way in which the dynamic response of mechanical or electro-mechanical systems to the vibration or external stimuli can be controlled. Most of them mean or deal with the methods that use, mainly, some electro-mechanical components of additional systems that are integrated into the system to be controlled.

Thus, a typical approach of the dynamic response control of a system is represented by the way, in which the company CEDRAT TECHNOLOGIES [1] made "smart structures" that diminish the effect of induced vibration for an object whose mass must be isolated in terms of external vibration influences.

New methods and principles for the control of dynamic response of mechanical or electro-mechanical complex systems are studied by the company ONERA (Office National d'Etudes et Recherches Aérospatiales) [2].

The present paper continues the previous research in the field of control systems and performance tuning of active and/or semi-active systems for the isolation of vibration effects [4], [5].

The paper presents the theoretical aspects of control possibilities regarding the behavior of a dynamic absorber system consisting of a spring-mass-viscous

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damper with parameter ***m/k/c***, by integrating in its structure an electro-dynamic actuator and an electrical impedance.

2. The basic mass-spring-viscous damper with parameter m/k/c

To carry out the proposed study a mass-spring-viscous damper system, with parameter ***m/k/c***, is considered (Fig. 1), under the action of external forces that make the mass ***m*** to move.

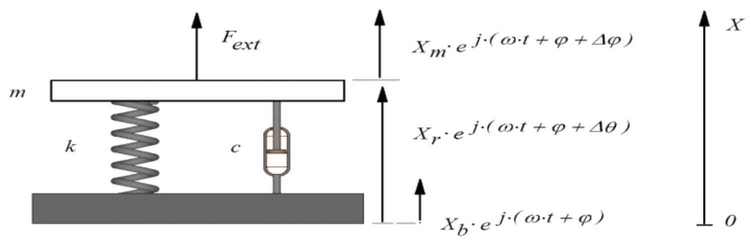

Fig. 1 The schematic diagram of the mass-spring- viscous damper system: ***m*** - mass to be isolated, ***k*** - spring constant, ***c*** - constant of viscous damping, ***Xb*** – moving of base system, ***Xm*** – displacement of mass ***m***, ***Xr*** - relative mass-base displacement..

To control the dynamic response of the system (the response to the action of external forces on the system or the response to base excitation), can use the following methods:

- changing the system parameters (***m/k/c***) by direct action on the mechanical components (method difficult to apply in practice);
- introduction of a mechanical impedance in the system (a dynamic absorber)[3]; it is an easier-to-implement method but does not allow adjustment during operation of the system;
- indirect change of the system parameters (***m/k/c***) by action on the electrical components connected to the terminals of an electrodynamic actuator, mounted in parallel with the viscous damper and spring (way easier to apply in practice, but with limitations) [4], [5];
- an improvement of the dynamic absorber response, the method analyzed in this article.

In this paper is presented the theoretical study performed on the method and the effectiveness of the control of dynamic response of the system (***m / k / c***) by plugging in an additional mechanical impedance achieved only with elements such as those that form the basic system (additional masses , springs and viscous dampers) that make up a dynamic absorber and compared with another control method, which introduces in the system a new dynamic absorber based on an electrodynamic actuator with embedded and external electric circuit, which enables dynamic response control through change of electrical parameters.

The most simple case, at least from a theoretical point of view, is represented by the introduction in the system of an additional impedance represented by the mass $\boldsymbol{m_{supl}}$.

To obtain $\boldsymbol{Vm=0}$, under the action of external forces on the mass $\boldsymbol{m}$, it is necesary to have $\boldsymbol{m_{supl}}=\infty$. This situation can be achieved only by adding additional devices to act as an infinite weight, at least for a particular frecvency or pulsation $\boldsymbol{\omega_0}$, action equivalent to the addition of an additional impedance $\boldsymbol{Z_m(\omega)}$ with $\boldsymbol{Z_m(\omega_0) = \infty}$.

3. The dynamic response control using a complex mechanical impedance

The additional mechanical impedance can be achieved with a simple mechanical system consisting of mass-spring-viscous damper with parameters $\mathbf{m_a/k_a/c_a}$, commonly called dynamic absorber (Fig. 2).

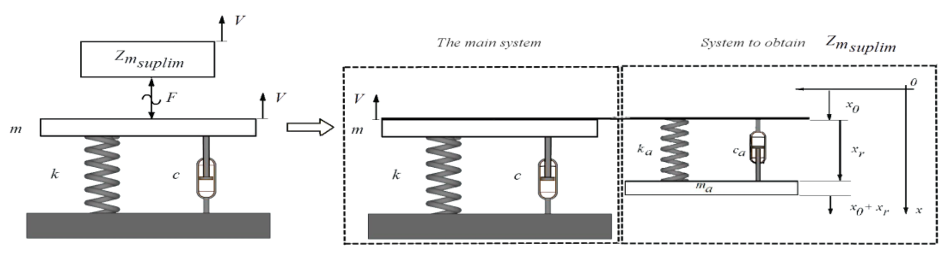

Fig. 2 The control of the dynamic response for a mechanical system with a system based on additional mechanical system generating additional mechanical impedance $\boldsymbol{Z_{msuplim}}$.

Additional system is characterized by mass $\boldsymbol{m_a}$, spring constant $\boldsymbol{k_a}$ and damping constant $\boldsymbol{c_a}$ of the viscous damper.

The additional system can be equated with an "equivalent mass" with a complex value [3] (fig. 3):

$$m_{ech} = m_a \cdot \frac{k_a + j \cdot \omega \cdot c_a}{k_a + j \cdot \omega \cdot c_a - m_a \cdot \omega^2} \tag{1}$$

The following notations are made:

$$c_{a\,c_r} = 2 \cdot \sqrt{k_a \cdot m_a}; \qquad \omega_{na} = \sqrt{\frac{k_a}{m_a}};$$
$$\beta_a = \frac{\omega}{\omega_{na}}; \qquad \xi_a = \frac{c_a}{c_{a\,c_r}} = \frac{c_a}{2 \cdot k_a} \cdot \omega_{na}; \tag{2}$$

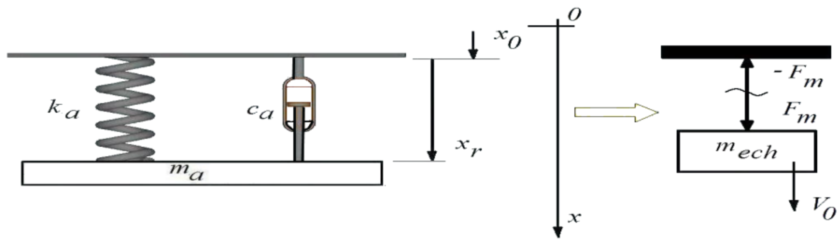

Fig. 3 Equivalence of the system characterized by parameters $\boldsymbol{m_a/k_a/c_a}$ with a "complex mass" $\boldsymbol{m_{ech}}$

If substitutions are made, the following relation is obtained:

$$m_{ech} = m_a \cdot \frac{1 + 2 \cdot \xi_a \cdot \beta_a \cdot j}{\left(1 - \beta_a{}^2\right) + 2 \cdot \xi_a \cdot \beta_a \cdot j} \tag{3}$$

It must be taken into account the fact that:

$$m_{ech} = m_{\text{mod}ul} \cdot e^{j \cdot \theta} = \sqrt{m^2_{ech_{reala}} + m^2_{ech_{imaginara}}} \cdot e^{j \cdot \theta} \tag{4}$$

The graph of the function $F_{\text{mod}ul}(\beta_a) = \frac{m_{ech_{\text{mod}ul}}}{m_a}$, resulting from the simulation made by using the Matlab application is shown in the figure 4.

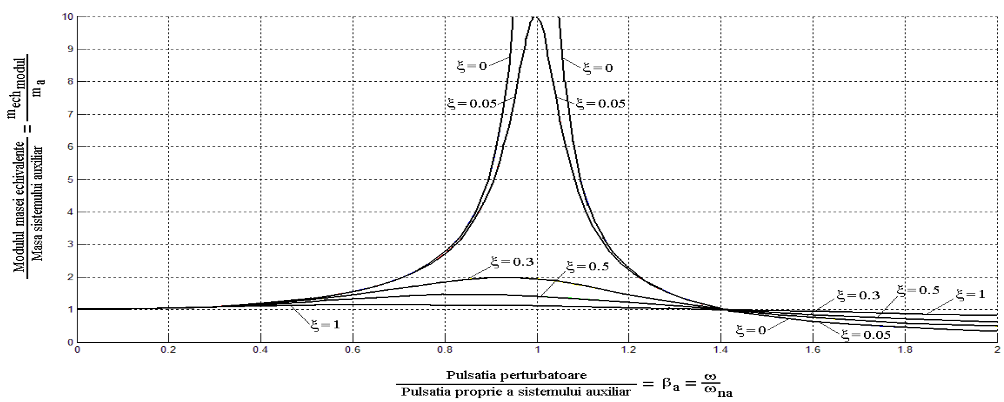

Fig. 4 Graph function that describes the relation between the ratio between the module of the equivalent mass and the additional mass and the ratio ω/ω_{na}.

To obtain the condition of infinite mass, requires null damping in the dynamic absorber system structure: $\boldsymbol{c_a=0}$, ie $\boldsymbol{\zeta_a=0}$, which leads to:

$$m_{ech} = m_a \cdot \frac{1}{1 - \beta_a{}^2} \tag{5}$$

The only solution to get an additional "infinite mass" for a certain critical frequency is to establish a null damping for the structure of the dynamic absorber at the same time with the development of a resonance frequency of the dynamic absorber equal to the critical frequency of dynamic excitation.

Parameter adjustment for the system characterized by the parameters $\boldsymbol{m_a/k_a/c_a}$, in order to ensure optimum working frequency adaptation of the dynamic absorber to the excitement frequency is difficult, both from a theoretical point of view as well as practical, especially if it is desirable that this adjustment is performed during system operation.

Another possibility of adjustment and optimization of the system's operation is represented by the adjustment of system impedance, obtained by the introduction of a electro-dynamic actuator in parallel with the basic spring and viscous damper and an external electrical circuit connected to the terminals of the electro-dynamic actuator.

This circuit can be used to control electro-mechanical parameters of the system (Mecahitech'2012,) [4], [5]. This method is sometimes more difficult to accomplish due to the overall conditions and the necessity of fixing the actuator to the mass ***m*** and also at the base of the system. The attachment of a mechanical absorber to the system is more convenient because it is fixed only on mobile mass ***m***.

The mentioned disadvantage of a mechanical absorber (difficulty adjustment during operation for a variable critical frequency) can be overcome by combining two ideas: the introduction of a mechanical absorber in the system and the use of an electrodynamic actuator for indirect regulation of mechanical parameters of dynamic absorber.

4. Regulating the operation of the system *m/k/c* through the introduction of an electro-dynamic actuator in parallel with the spring and viscous damper

One considered the set-up presented in the following figure, in which the electro-dynamic force was noted with $\boldsymbol{F_{ed}}$.

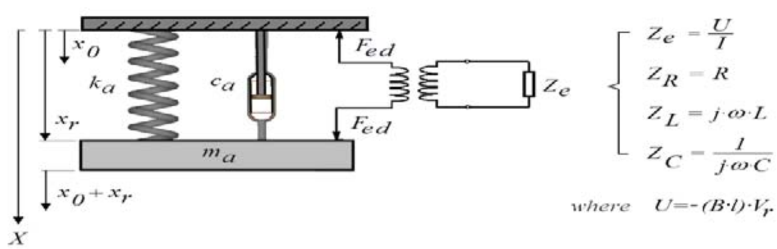

Fig. 5 Introduction of an electro-dynamic actuator in parallel with the spring and viscous damper.

If $\boldsymbol{F}$ is the force that acts on support (reference), the following relation is obtained:

$$F = k_a \cdot x_r \cdot e^{j\cdot\varphi} \cdot e^{j\cdot\omega\cdot t} + j\cdot\omega\cdot c_a \cdot x_r \cdot e^{j\cdot\varphi} \cdot e^{j\cdot\omega\cdot t} - F_{ed} \tag{6}$$

The equation of motion for the mass $\boldsymbol{m_a}$ is in this case:

$$\begin{aligned} -m_a \cdot \left(x_r \cdot e^{j\cdot\varphi} \cdot e^{j\cdot\omega\cdot t} + x_0 \cdot e^{j\cdot\omega\cdot t}\right)\cdot \omega^2 = \\ = -k_a \cdot x_r \cdot e^{j\cdot\varphi} \cdot e^{j\cdot\omega\cdot t} - j\cdot\omega\cdot c_a \cdot x_r \cdot e^{j\cdot\varphi} \cdot e^{j\cdot\omega\cdot t} + F_{ed} \end{aligned} \tag{7}$$

The electro-dynamic force is:

$$F_{ed} = B\cdot l\cdot i = B\cdot l\cdot \frac{U}{Z_e} = -\psi^2 \cdot \frac{V_r}{Z_e} = -\psi^2 \cdot \frac{1}{Z_e}\cdot j\cdot\omega\cdot x_r \cdot e^{j\cdot\varphi} \cdot e^{j\cdot\omega\cdot t} \tag{8}$$

Total force acting on the reference becomes:

$$F = \left[\left(k_a + j\cdot\omega\cdot c_a\right) + \psi^2 \cdot \frac{j\cdot\omega}{Z_e}\right]\cdot x_r \cdot e^{j\cdot\varphi} \cdot e^{j\cdot\omega\cdot t} \tag{9}$$

In the above relations, the term $x_r \cdot e^{j\cdot\varphi} \cdot e^{j\cdot\omega\cdot t} \cdot \left(k_a + j\cdot\omega\cdot c_a\right)$ represents the contribution of the mechanical system and the term $\psi^2 \cdot \frac{j\cdot\omega}{Z_e}\cdot x_r \cdot e^{j\cdot\varphi} \cdot e^{j\cdot\omega\cdot t}$ represents the contribution of electro-mechanical.

Force $\boldsymbol{F}$ will have the expression:

$$F = \frac{\left[\left(k_a + j\cdot\omega\cdot c_a\right) + \psi^2 \cdot \frac{j\cdot\omega}{Z_e}\right]\cdot m_a \cdot \omega^2}{\left[\left(-m_a\cdot\omega^2 + k_a + j\cdot\omega\cdot c_a\right) + \psi^2 \cdot \frac{j\cdot\omega}{Z_e}\right]}\cdot e^{j\cdot\omega\cdot t}\cdot x_0 \tag{10}$$

The equivalent mass $\boldsymbol{m_{ech}}$ of the dynamic absorber and of the electrical system can be expressed using the relationship:

$$m_{ech} = \frac{F}{\omega^2 \cdot x_0 \cdot e^{j\cdot\omega\cdot t}} = -\frac{m_a \cdot \left[\left(k_a + j\cdot\omega\cdot c_a\right) + \psi^2 \cdot \frac{j\cdot\omega}{Z_e}\right]}{-m_a\cdot\omega^2 + k_a + j\cdot\omega\cdot c_a + \psi^2 \cdot \frac{j\cdot\omega}{Z_e}} \tag{11}$$

If the external impedance $\boldsymbol{Z_e}$ is represented by a resistance $\boldsymbol{R}$:

$$Z_e = R \tag{12}$$

then its effect is similar to the change of the damping constant $\boldsymbol{c_a}$ of the viscous damper:

$$c_a^* = c_a + \psi^2 \cdot \frac{1}{R} \tag{13}$$

If the external impedance $\boldsymbol{Z_e}$ is represented by an impedance $\boldsymbol{L}$:

$$Z_e = j \cdot \omega \cdot L \tag{14}$$

then its effect is similar to the change of the elastic spring constant $\boldsymbol{k_a}$:

$$k_a^* = k_a + \psi^2 \cdot \frac{1}{L} \tag{15}$$

If an ***R-L*** parallel circuit is introduced the following relation is obtained:

$$\frac{1}{Z_e} = \frac{1}{R} + \frac{1}{j \cdot \omega \cdot L} \tag{16}$$

situation in which a simultaneously change of the values $\boldsymbol{k_a}$ and $\boldsymbol{c_a}$ occurs.

If the electrical impedance is $Z_e = \infty$ (open terminal) then result:

$$m_{ech} = m_a \cdot \frac{k_a + j \cdot \omega \cdot c_a}{-m_a \cdot \omega^2 + k_a + j \cdot \omega \cdot c_a} \tag{17}$$

so the electrical system has no influence.

The introduction in the circuit of the external impedance $Z_e = \frac{1}{j \cdot \omega \cdot C}$ of a condenser ***C*** has a special effect. The equivalent mass is in this case:

$$m_{ech} = m_a \cdot \frac{k_a + j \cdot \omega \cdot c_a - \psi^2 \cdot \omega^2 \cdot C}{k_a + j \cdot \omega \cdot c_a - m_a \cdot \omega^2 - \psi^2 \cdot \omega^2 \cdot C} \tag{18}$$

and force:

$$\begin{aligned} F = & \frac{k_a + j \cdot \omega \cdot c_a}{k_a + j \cdot \omega \cdot c_a - m_a \cdot \omega^2 - \psi^2 \cdot \omega^2 \cdot C} \cdot m_a - \\ & - \frac{\psi^2 \cdot C}{k_a + j \cdot \omega \cdot c_a - m_a \cdot \omega^2 - \psi^2 \cdot \omega^2 \cdot C} \cdot m_a \end{aligned} \tag{19}$$

The first term corresponds to the introduction of masses $\boldsymbol{m_a}$******* instead of $\boldsymbol{m_a}$:

$$m_a^* = m_a + \psi^2 \cdot C \tag{20}$$

but one must take into account also the second term in the force expression, which does not allow only a change of the additional mass of the dynamic absorber by modifying the value of the capacitor connected across the actuator.

Adjusting the capacitor value can help us to achieve the condition for "infinite mass" (rel 19), leading to impose the following conditions:

$$\begin{aligned} & j \cdot \omega \cdot c_a = 0 \quad \Rightarrow \quad c_a = 0 \\ & k_a - m_a \cdot \omega_0^{\,2} - \psi^2 \cdot \omega_0^{\,2} \cdot C = 0 \quad \Rightarrow C = \frac{m_a \cdot \omega_0^{\,2} - k_a}{\psi^2 \cdot \omega_0^{\,2}} \end{aligned} \tag{21}$$

The above relations indicate the capacity value for the capacitor which provides dynamic absorber adjustment for specific excitation frequency $\boldsymbol{\omega_0}$, without having to adjust mechanical parameters. Adjustment is possible only if the value resulting for C is positive, respectively the critical frequency exceeds the resonance frequency of dynamic absorber.

The real case is that of an electrical resistance and an inductance connected in series, due to coil of electrodynamic actuator, to which it is connected, also in series, an external impedance. The equivalent mass expression becomes:

$$m_{ech} = \frac{F}{\omega^2 \cdot x_0 \cdot e^{j\cdot\omega\cdot t}} = -\frac{m_a \cdot \left[\left(k_a + j\cdot\omega\cdot c_a\right) + \psi^2 \cdot \dfrac{j\cdot\omega}{Z_e + R_b + j\cdot\omega\cdot L_b} \right]}{-m_a\cdot\omega^2 + k_a + j\cdot\omega\cdot c_a + \psi^2 \cdot \dfrac{j\cdot\omega}{Z_e + R_b + j\cdot\omega\cdot L_b}} \tag{22}$$

If an external impedance consisting of a capacitor with the electric capacity ***C*** is considered, the value of the electrical impedance is:

$$Z_e = \frac{1}{j\cdot\omega\cdot C} \tag{23}$$

and so:

$$m_{ech} = \frac{-m_a \cdot \left(k_a + j\cdot\omega\cdot c_a\right)\cdot\left(\dfrac{1}{j\cdot\omega\cdot C} + R_b + j\cdot\omega\cdot L_b\right) - m_a\cdot\psi^2\cdot j\cdot\omega}{\left(-m_a\cdot\omega^2 + k_a + j\cdot\omega\cdot c_a\right)\cdot\left(\dfrac{1}{j\cdot\omega\cdot C} + R_b + j\cdot\omega\cdot L_b\right) + \psi^2\cdot j\cdot\omega} \tag{24}$$

The condition $\boldsymbol{m_{ech}}=\infty$ is fulfilled if only if the denominator of the above relationship is zero:

$$\left(k_a - m_a\cdot\omega^2 + j\cdot\omega\cdot c_a\right)\cdot\left(\frac{1}{j\cdot\omega\cdot C} + R_b + j\cdot\omega\cdot L_b\right) + \psi^2\cdot j\cdot\omega = 0 \tag{25}$$

The above relationship can be fulfilled only if:

$$\begin{cases} \left(k_a - m_a\cdot\omega^2\right)\cdot R_b - c_a\cdot\omega^2\cdot\left(L_b - \dfrac{1}{\omega^2\cdot C}\right) = 0 \\ \left(k_a - m_a\cdot\omega^2\right)\cdot\left(L_b - \dfrac{1}{\omega^2\cdot C}\right) + c_a\cdot R_b + \psi^2 = 0 \end{cases} \tag{26}$$

With the notation:

$$\begin{cases} \Delta m = k_a - m_a\cdot\omega^2 \\ \Delta e = L_b - \dfrac{1}{\omega^2\cdot C} \end{cases} \tag{27}$$

one obtains, by replacing:

$$\begin{cases} R_b \cdot \Delta m = c_a \cdot \Delta e \cdot \omega^2 \\ \Delta m \cdot \Delta e + R_b \cdot c_a + \psi^2 = 0 \end{cases} \qquad (28)$$

From the above relations the following cases can be identified:

Case 1, when ***Δe=0,*** for which:

$$\begin{cases} R_b \cdot \left(k_a - m_a \cdot \omega^2\right) = 0 \\ R_b \cdot c_a + \psi^2 = 0 \end{cases} \qquad (29)$$

If ***R_b*** $\neq 0$, ***the solution is only Δm=0 so*** $\beta_a=1$ ***(dynamic mechanical absorber) and the*** $\psi=0$ *(electrodynamic actuator with the terminals in air)* ***and*** $c_a=0$. *The solution is not convenient because it cancels the effect of electrodynamic actuator and maintains only a mechanical absorber, non-adjustable.*

Case 2, when $c_a=0$ ***and*** $R_b \neq 0$, for which:

$$\begin{cases} R_b \cdot \left(k_a - m_a \cdot \omega^2\right) = 0 \\ \left(k_a - m_a \cdot \omega^2\right) \cdot \left(L_b - \dfrac{1}{\omega^2 \cdot C}\right) + \psi^2 = 0 \end{cases} \qquad (30)$$

From the first equation it follows that $\Delta m=0$ so depreciation $\beta_a=1$, i.e. a purely mechanical adjustment and from the second equation, it yields the condition $\psi^2=0$, equivalent to an electrodynamic actuator with the terminals in air.

As in the previous cases, *the solution is not convenient because it cancels the effect of electrodynamic actuator and maintains only a mechanical absorber, non-adjustable*.

Case 3, when $c_a=0$ and $R_b \approx 0$, for which $\Delta m \cdot \Delta e = -\psi^2$ so $\Delta e = -\dfrac{\psi^2}{\Delta m}$, representing the relationship between the component of the electrical damping command and the mechanical system.

Case 4, when $c_a \neq 0$ and $\Delta e \neq 0$, for which:

$$\begin{cases} \Delta e = L_b - \dfrac{1}{\omega^2 \cdot C} = \dfrac{R_b \cdot \Delta m}{c_a \cdot \omega^2} \\ \Delta m \cdot \dfrac{R_b \cdot \Delta m}{c_a} + \omega^2 \cdot (R_b \cdot c_a + \psi^2) = 0 \end{cases} \qquad (31)$$

Since in the second equation all terms are positive, their sum can not be zero, which shows that this case can not be taken into account.

As a consequence, for the real system with an electrodynamic actuator (with electrical resistance and inductance of coil), just adding an electric capacitor to the terminals provides the condition for the dynamic absorber if the internal resistance of the coil is much reduced and the external capacity is adjusted to satisfy the condition indicated in case 3.

The system can operate in two modes: one mode purely mechanical with the mechanical absorber tuned to the critical frequency and having the external electric circuit open and the second mode with closed external electric circuit and external capacity adjustment (eg by introducing additional capacitors in the circuit, using relays) to adapt the dynamic absorber at critical frequency variation.

Modeling and simulation of the behavior for mechanical system [6] on which is fixed a mechanical absorber which contains an electrodynamic actuator having an external electric circuit connected to the terminals and defined by an electrical impedance can be achieved by:

- equivalent electrical circuits for the systems being studied and the use of dedicated software for the simulation of the electrical circuits (fig. 6);
- modeling of system operation using Matlab Simulink package (fig. 7), starting from the equations:

$$\begin{aligned} &\left(m \cdot s + \frac{k}{s} + c\right) \cdot v_0 = F_{ext} + F_{ed} - k_a \cdot \frac{1}{s} \cdot (v_0 - v_{ma}) - c_a \cdot (v_0 - v_{ma}) \\ &U_{ext} - \psi \cdot (v_0 - v_{ma}) = L_b \cdot s \cdot i + R_b \cdot i + Z_e(s) \cdot i \qquad (32) \\ &m_a \cdot s \cdot v_{ma} = k_a \cdot \frac{1}{s} \cdot (v_0 - v_{ma}) + c_a \cdot (v_0 - v_{ma}) - F_{ed} \end{aligned}$$

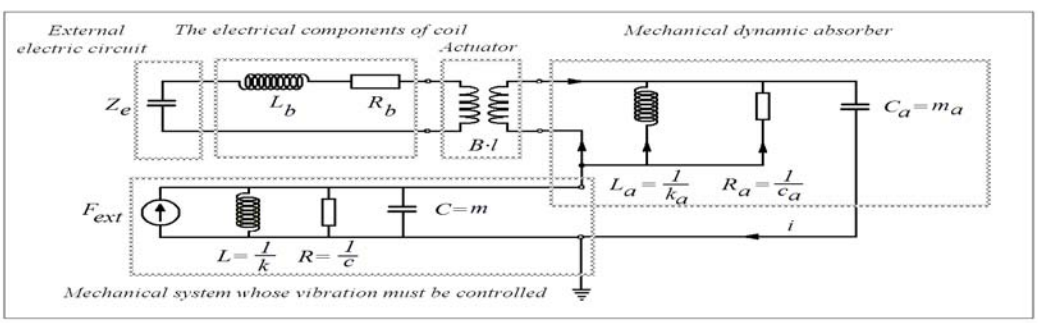

Fig. 6 The equivalent circuits of the systems involved in the control of the dynamic response.

One denotes with $\boldsymbol{v_0}$ – the velocity of mass on with the dynamic absorber is fixed and with $\boldsymbol{v_m}$ – the absolute velocity of dynamic absorber mass.

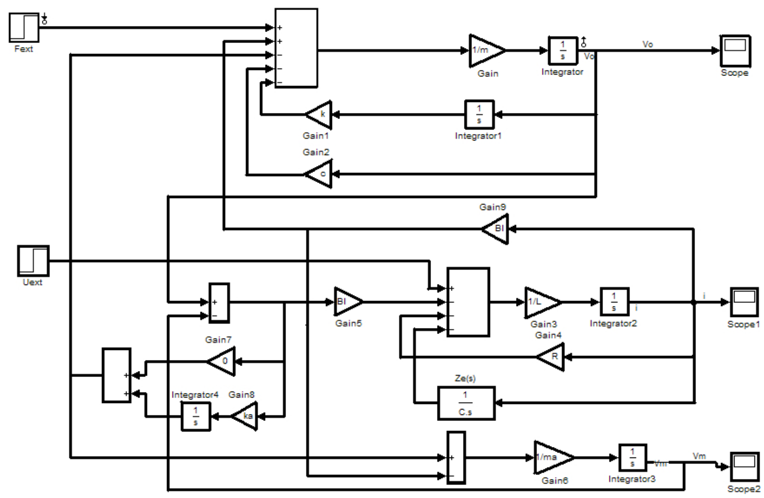

Fig. 7 Simulink simulation scheme for the system, electrodynamic actuator and dynamic absorber.

In fig. 8 the dynamic response function [7] of the system ***m/k/c*** with a dynamic absorber tuned to a pulsation of 10 rad/s is represented (the parameters for the dynamic absorber are $c_a=0$, $m_a=0.1$ ***kg***, $k_a=10$).

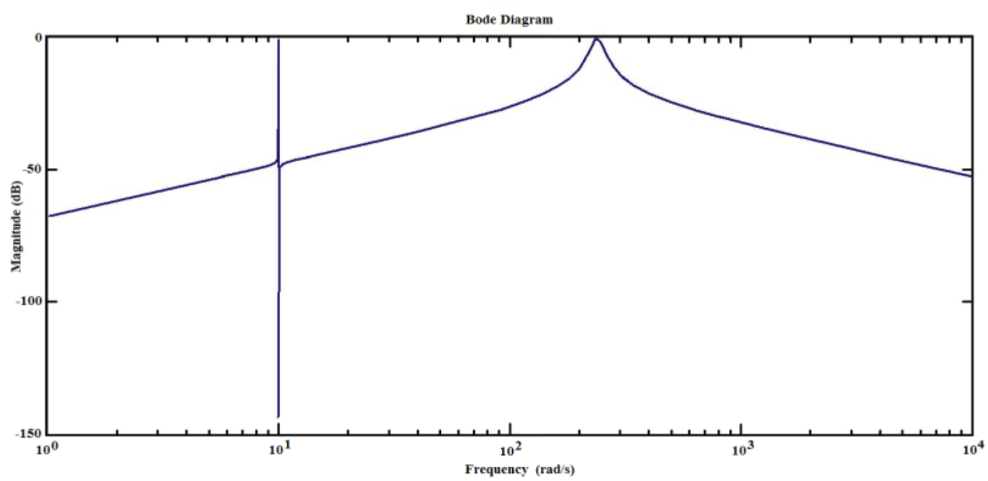

Fig. 8 Bode amplitude diagram for an entry point F_{ext}, an exit point v_o, $\psi = 0$ and external electrical voltage $U_{ext} = 0$.

In Fig. 9 the response of the system is represented, considering the presence of the electrodynamic actuator and a high resistance of coil. The electrical parameters are: $L_b=0.00056$ ***H***, $C=4*10^{-6}$***F***, $R_b=8$ **Ω**. The effect of the electrical circuit is negligible [8]. With the significant reduction of electrical resistance the effect of the electrical circuit, which acts like a new dynamic absorber can be seen (fig.10).

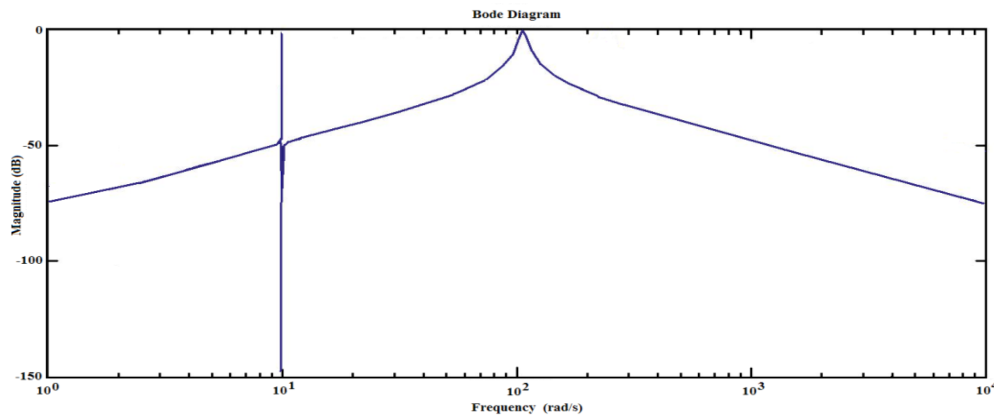

Fig. 9 Bode amplitude diagram for an entry point $\boldsymbol{F_{ext}}$, an exit point $\boldsymbol{v_o}$, $\boldsymbol{\psi=4}$, external electrical voltage $\boldsymbol{U_{ext}=0}$ and R_b=0.5

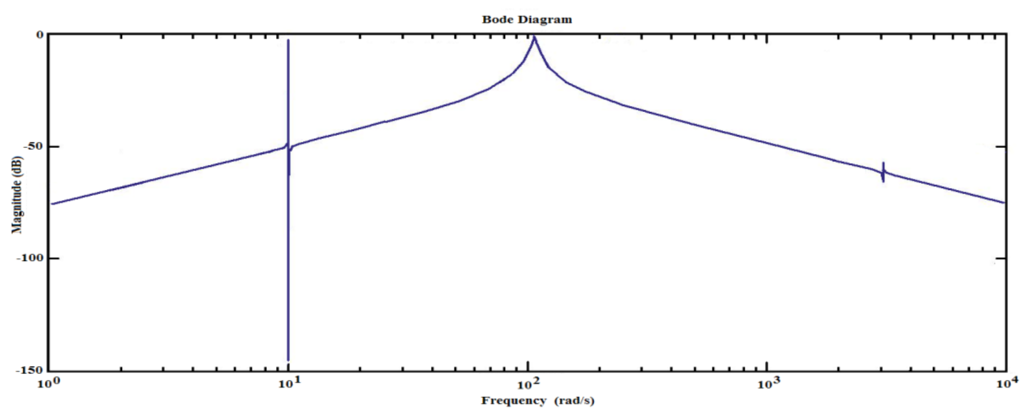

Fig. 10 Bode diagram for the system, dynamic absorber and electrodynamic actuator, with R_b=0.01

5. Conclusions

The use of a dynamic absorber to control the dynamic response of a mechanical system relative to a reference has been known for a long time.

Dynamic absorber is usually considered as an additional mass equivalent with a complex value. It is designed to take the energy of vibration of the reference and to dissipate or store this energy in its mechanical structure.

Usually, the design of dynamic absorber depends on impedance of reference system and the frequencies at which a significant action is desired (which may differ from the resonance frequencies of the structure to which it is attached).

Any change in mechanical impedance of the reference or on the frequency who produces a major excitation and damping of vibration is desired requires the changing of one of the mechanical parameters of the dynamic absorber (mass, stiffness, viscous damping), extremely difficult to made during system operation.

In the article it was presented a more convenient solution by inserting an electrodynamic actuator in the dynamic absorber structure and attaching to the actuator terminals an external electric circuit.

Thus, it is possible to obtain a change of equivalent mechanical parameters of the assembly: mechanic absorber + electrodynamic actuator + electrical circuit by changing the electrical parameters of the circuit, much easier to achieve in terms of construction and possibly to be implemented as an adaptive system, controlled by a microcontroller which can analyze the reference vibration and control the change of one particular parameter value or electric circuit component (with the aid of circuits consisting of networks of electrical components that are to be inserted or removed from the electrical circuit).

The solution has limitations due to the need for electrical resistance to be around zero for the external electric circuit including the coil. Practically it is necessary for "the electrical dynamic absorber" the same operation condition as for mechanical absorber: the cancellation of internal energy dissipation. A better solution may be the introduction of an active system able to introduce electric energy, by creating a reaction connection between parameter $\boldsymbol{v_0}$ and the electrical control parameter $\boldsymbol{U_{ext}}$, considered null in this study. This is the subject to future developments.

R E F E R E N C E S

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