MECHANICAL AND ELECTRICAL SUBSYSTEMS AS IMPLEMENTATION OF ACTIVE REDUCTION OF VIBRATION

Katarzyna Bialas[1]

[1] Silesian University of Technology, Faculty of Mechanical Engineering, Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Konarskiego Street 18A, 44-100 Gliwice, Poland

Corresponding author: Katarzyna Białas, katarzyna.bialas@polsl.pl

Abstract: The primary objective of this work is the presentation of possible physical implementations of active reduction of vibration in vibratory mechanical systems. An issue of crucial importance is also the determination of interaction between the basic system and subsystems responsible for reduction. The work also presents a structural and parametric synthesis which can be defined as the design of systems meeting specific requirements, which, in the case under discussion, are desired frequency values of free vibration. The synthesis presented in the work is a non-classical one; its characteristic being the possibility of the modification of the values of excitation generated by subsystems in time. Elements composing such subsystems may be of various kinds e.g. mechanical, electrical, pneumatic etc. This work presents two of the possibilities i.e. a subsystem consisting of elements in the form of kinematic excitation and a subsystem composed of electrical elements in the form of a coil with moving core and a piezoelectric element.

Key words: analysis, synthesis, active elements, process systems design, reduction of vibrations.

1. INTRODUCTION

The environment around us is increasingly filled with modern machinery and equipment; this being due to civilisation development and aimed at increasing our living standards. The appearance of new mechanisms is characterised by growing functionalism, yet it is not indifferent to surroundings. The forms of such an impact are various and many with some being harmful for humans or devices. Quite often the negative effects of machinery and equipment operation take shape of vibration or noise. Many scientists representing numerous research and development centres are involved in tests aimed to reduce the aforesaid adverse effects [Buchacz & Świder, 2001].

The research related to side effects are primarily focused on:

- determination of the influence of equipment and machinery on the environment with special attention given to impact on humans,
- determination of the origin of side effects,
- development of a method allowing total or, if impossible, partial reduction of negative impact on humans and the environment.

Constructors and designers are also concerned with another research issue which includes:

- elimination of vibration of new equipment and machinery,
- adaptation of already existing equipment and machinery to reduce the negative impact on the environment.

The reduction or elimination of undesired vibration can be achieved by applying various methods. The most commonly applied methods are:

- passive,
- semi-active,
- active.

Passive methods of vibration reduction consist in applying passive elements i.e. elements whose parameter values are not changeable in time. The application of these methods enables either the dispersion or the temporary storage of energy and requires the use of additional structural elements acting as vibration isolators e.g. rubber and metal elements. Passive methods do not require any additional sources generating energy from the outside. Passive elements include the following dampers:

- viscoelastic
- viscous,
- dynamic.

Passive methods do not bring desirable results in case of necessity to reduce low-frequency vibration or vibration characterised by a wide frequency band. [Engel & Kowal, 1995, Michalowski, 1994,].

Active methods require energy supplied from outside sources, usually in the form of excitation generated by these sources. The value of excitation is adjusted to the current state of the system. The parameters of active elements can change in time. The active vibration methods require the use of mechanical, pneumatic, hydraulic, electric and electromechanical devices. Active methods make it possible to overcome limitations typical of passive methods. [Guida et al., 2010, Kendall, 1969].

The combination of both of the methods described above is a semi-active one i.e. a method in which passive elements are used, yet with their parameter values changeable in time [Soong & Dargush, 1999]. The most commonly applied sami-active dampers are:

- semi-active hydraulic dampers,
- semi-active viscous dampers,
- semi-active electro-rheological dampers,
- semi-active magneto-rheological dampers,
- semi-active friction dampers,
- semi-active dampers changing structural rigidity,
- semi-active fluid dampers.

2. THE SYNTHESIS OF MECHANICAL SYSTEMS

The synthesis presented in this work is viewed as a task reverse to the analysis of vibratory mechanical systems (fig.1). Carrying out such a reverse task makes it possible to obtain a system structure and parameters characterised by required properties. For this reason, the foregoing is referred to as a structural and parametric synthesis. Such an non-classical approach may be used while designing new equipment and machinery meeting specific requirements related to the frequency of free vibration of a given system. The application of this method is not only limited to new devices but may include already existing machinery or its components allowing their modification and adaptation to new requirements [Bellert & Woźniacki, 1968, Buchacz, 2005, Buchacz, 2009, Buchacz & Płaczek, 2010, Buchacz & Świder, 2001, Buchacz & Żółkiewski, 2007, Sękala, 2011].

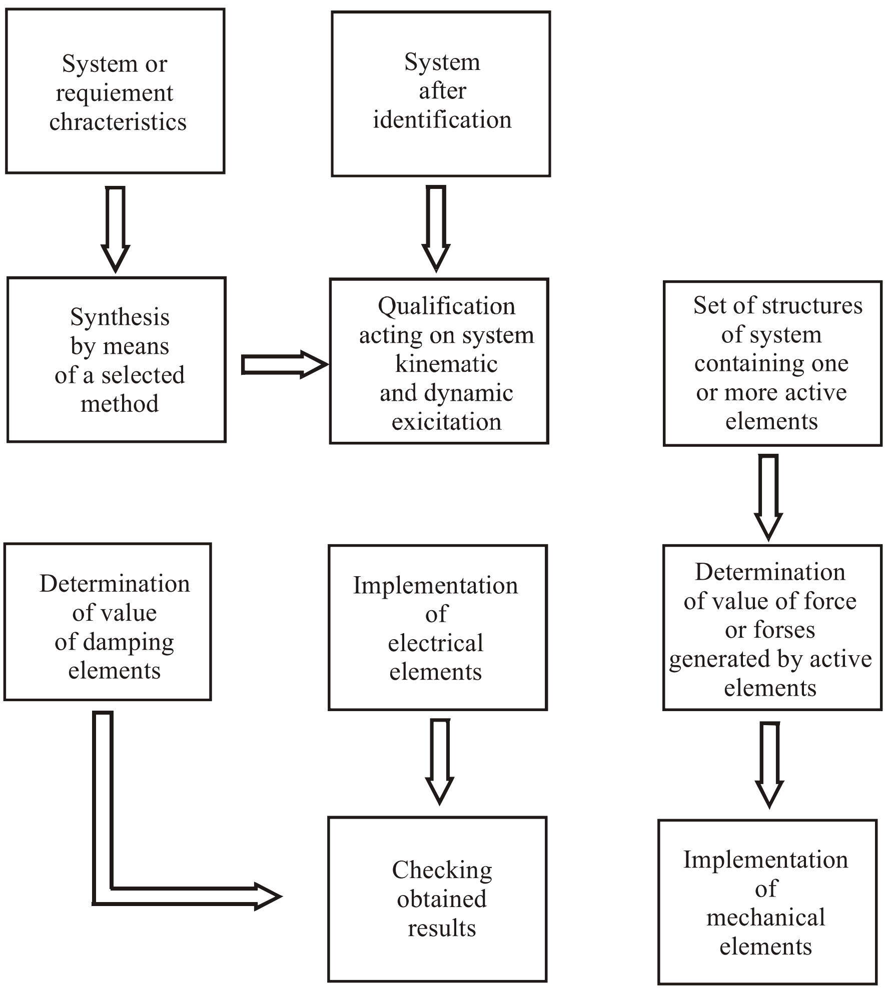

Fig.1. Synthesis of mechanical systems

The synthesis of mechanical systems discussed in this work and illustrated in Figure 1 constitutes a non-classical approach to the design of mechanical vibratory systems. The first step consists in specifying the requirements for a future system and carrying out a passive synthesis i.e. a synthesis by means of which only the basic (inert and elastic) elements of the system will be obtained. Next, it is necessary specify the type and value of excitation, both dynamic and kinematic, acting on the system as well as select the manner (passive or active) of vibration reduction. In case of selecting the passive method, one should decide whether passive elements are to be proportional to elastic or inert elements and determine their values. The selection of the active method entails the necessity to determine the values of active elements i.e. the values of excitation generated by these elements. Afterwards, one should choose the type of elements to be applied (mechanical or electrical ones). Finally, it is necessary to verify obtained results in order to select the best possible solution.

In order to create a characteristic function it is necessary to determine the values of individual resonance and anti-resonance frequencies. Functions obtained thus may take the form of slowness (1,2) or mobility (3,4) [Buchacz & Świder, 2001]. In order to obtain a ramified system it is necessary to decompose a function in the form of slowness into partial fractions (5)[Buchacz, 2005, Buchacz, 2009, Buchacz & Świder, 2001].

The slowness parameters for systems with odd number of components that are subjected to restrains:

$$U(s) = H\frac{d_l s^l + d_{l-1}s^{l-2} + \ldots + d_0}{c_k s^k + c_{k-1}s^{k-2} + \ldots + c_1 s} \qquad (1)$$

where:
k – magnitude of the numerator,
l – magnitude of the denominator,
H – any positive real number.

Slowness function that describes semi-defined systems with even number of components:

$$U(s) = H\frac{d_l s^l + d_{l-1}s^{l-2} + \ldots + d_1 s}{c_k s^k + c_{k-1}s^{k-2} + \ldots + c_0} \qquad (2)$$

The mobility parameters for systems with even number of components that are subjected to restrains:

$$V(s) = H\frac{c_k s^k + c_{k-1}s^{k-2} + \ldots + c_1 s}{d_l s^l + d_{l-1}s^{l-2} + \ldots + d_0} \qquad (3)$$

The mobility function that describes semi-defined systems with odd number of components:

$$V(s) = H\frac{c_k s^k + c_{k-1}s^{k-2} + \ldots + c_0}{d_l s^l + d_{l-1}s^{l-2} + \ldots + d_1 s} \qquad (4)$$

$$U(s)\frac{1}{H} = \frac{c_1}{s} + m_1 s + \frac{1}{\frac{s}{c_2} + \frac{1}{m_2 s}} + \ldots + \frac{1}{\frac{s}{c_n} + \frac{1}{m_n s}} \qquad (5)$$

By decomposing into partial fractions one obtains the structure and parameters of inert and elastic elements of a mechanical system (fig.2). The next step of synthesis involves the determination of external impact on the basic system i.e. the determination of the kind of excitation and its value (fig.3).

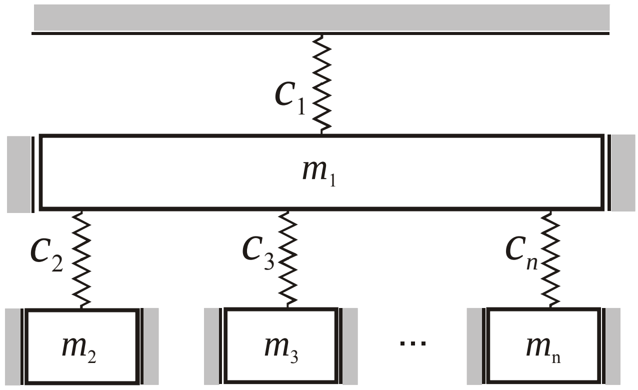

Fig.2. The example model of a restrained system obtained after decomposition of a characteristic function expressed in the form of slowness into a partial fractions.

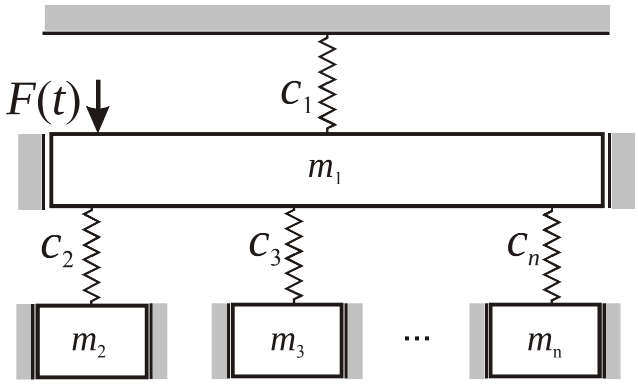

Fig.3. The example model of a restrained system obtained after decomposition of a characteristic function expressed in the form of slowness into a partial fractions with excitations.

In case of the decomposition of a characteristic function in the form slowness into a continued fraction (6), it is possible to obtain a cascade system (fig.4). Figure 4 presents one of the possibilities i.e. a one-sidedly restraint system. By means of the method under discussion one can also obtain a two-sidedly restraint system or a system without restraints.

$$U(s) = \frac{c_1}{s} + m_1 s + \cfrac{1}{\cfrac{s}{c_2} + \cfrac{1}{m_2 s + \ldots + \cfrac{1}{\cfrac{s}{c_n} + \cfrac{1}{m_n s}}}} \qquad (6)$$

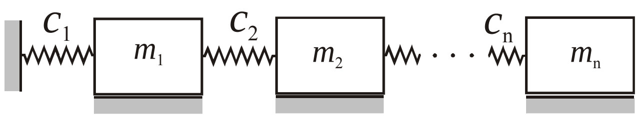

Fig.4. The example model of a restrained system obtained after decomposition of a characteristic function expressed in the form of slowness into a partial fractions.

2.1 Passive reduction of vibration

In order to reduce undesired vibration in a system it is possible to apply passive or active elements.

Passive elements may be in the form of viscous dampers proportional to inert or elastic elements. Models of systems incorporating passive elements are presented in Figures 5 and 6.

The application of the passive reduction of vibration does not offer the possibility of modifying the values of passive elements in time. In case of system with changing excitation values, the aforesaid limitation renders the prevention of undesired vibration impossible. The application of passive viscous dampers does not provide desirable results in case of low-frequency vibration either. The latter poses a very significant hazard to the health of people present in the environment where such vibration occurs as well as proves detrimental to equipment and machinery.

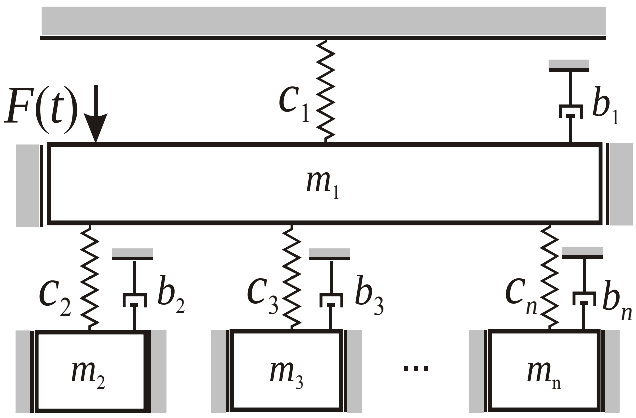

Fig.5. The model for a discrete mechanical system with passive components proportional to inertial components

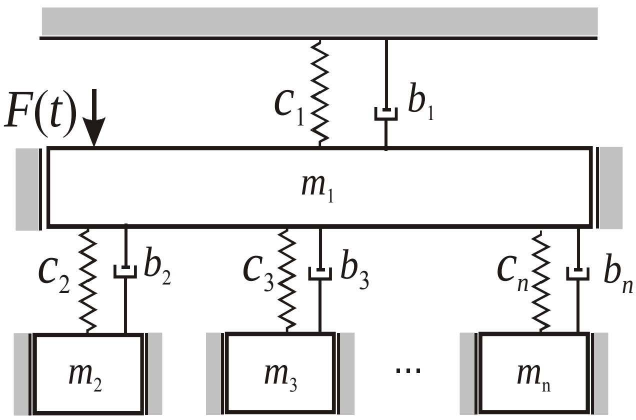

Fig.6. The model for a discrete mechanical system with passive components proportional to elastic components

2.2 Active reduction of vibration

The application of passive elements does not always make it possible to obtain desired results.

In such cases, one may apply active elements (fig.7). The reduction of vibration of individual inert elements caused by excitation generated from the outside is implemented by means of excitation generated from active subsystems. By solving a system of equations written in the form of a matrix (6) one receives the values of active elements.

$$G = D \cdot A - F \quad (6)$$

where:

G – matrix of excitations generated by active elements,

D – matrix of dynamic stiffness,

A – matrix of amplitudes (approaching zero),

F – matrix of dynamic excitations.

An issue of significant importance is the physical implementation of active elements. It is possible to apply various types of elements i.e. mechanical, electrical, pneumatic etc. Another important problem is the impact of these elements on the basic system. In case of mechanical elements a possible solution is the excitation of kinematic excitations (Fig. 8) are characterised by the possibility of changing their parameters in time. The only parameters which can change their values are shifts y_i, with elastic elements remaining stable at the same time. In order to determine the values of the said shifts, one should use dependence (7) [Białas, 2010].

$$y_i = \frac{K_i}{c_{ii}} \quad (7)$$

where:

K_i – values of kinematic excitations, equivalent to the values of G_i,

y_i – displacement that occurs in the specific kinematic equation,

c_{ii} – values of the elastic components that occurs in the specific kinematic equation.

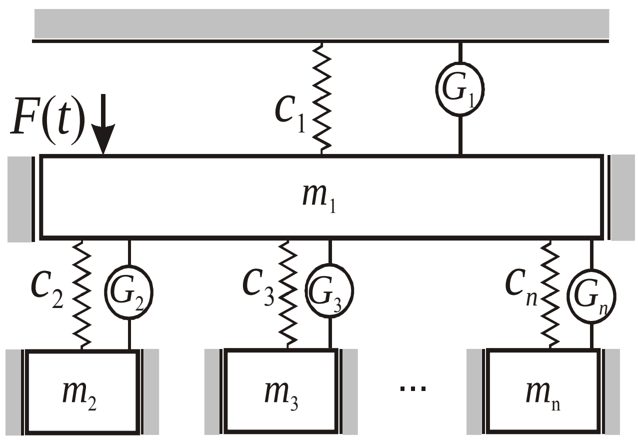

Fig.7. The model of a discrete mechanical system with active components

Figure 8 presents a model of a system with active elements in the form of kinematic excitations.

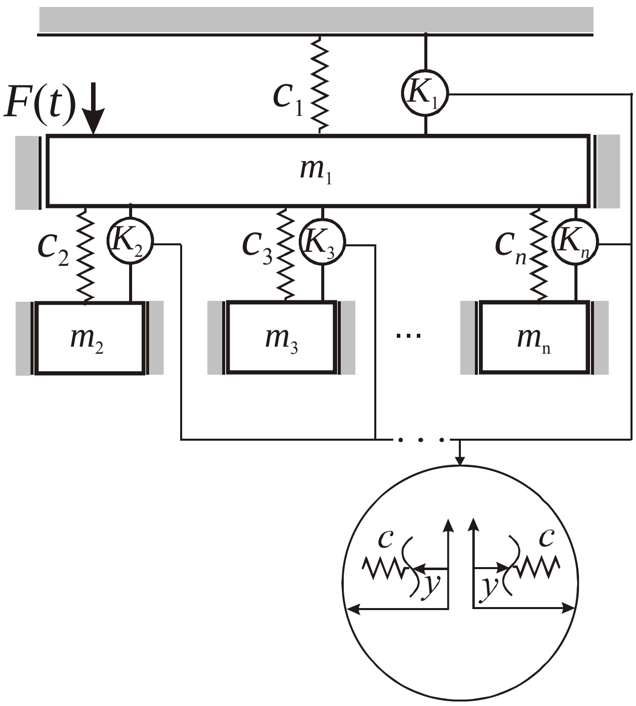

Fig.8. A model of the system with kinematic excitations

Another possible solution of the physical implementation of active elements is the application of electric elements e.g. the use of a coil with moving core. The value of the force in the magnetic field is expressed by the following formula: (8) [Onwubolu, 2005]:

$$F = BIL \tag{8}$$

where:
F = force acting on the conductor,
B = magnetic flux density,
I = current in the conductor,
L = length of the conductor.

Electrodynamic force acts in the direction perpendicular to the plane formed by a current-carrying wire and magnetic field induction lines. The sense of electrodynamic force is determined using the left-hand rule (or right-handed screw rule). Electrodynamic force is the force with which the electromagnetic field acts on a current-carrying wire placed in a given field; the force is directly proportional to the value of current flowing in the wire and the length of the latter.
Figure 9 presents a model of the system with electric elements as excitations generated by active elements
Another possibility in case of the application of electric elements is the use of piezoelectric elements (fig.10).
A piezoelectric oscillator is a mechanically vibrating element in a piezoelectric generator. The piezoelectric oscillator is a solid usually taking a proper shape and cut out of piezoelectric material in an appropriate manner. The purpose of the solid is electrical excitation causing mechanically non-damped vibration.

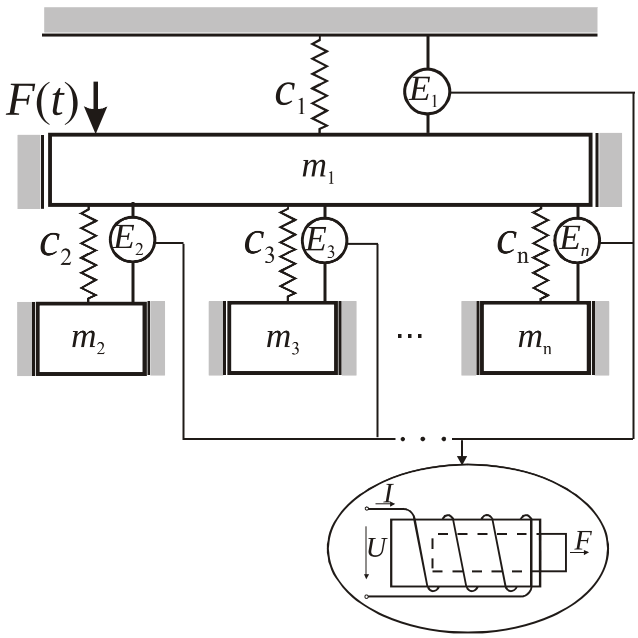

Fig.9. A model of the system with electric elements – coil with moving core

The most commonly applied piezoelectric material is crystalline quartz in the form of a circular or square plate. The plate is placed in a holder between electrodes, by means of which it is electrically coupled with an exciting system. The properties of piezoelectric material enable the generation of vibration.
Depending on the frequency range, quartz oscillators can be divided into:
- higher frequency oscillators, in which frequency is defined by the smallest size of the oscillator,
- lower frequency oscillators, in which frequency is defined by a greater oscillator size.
The free vibration frequency of a plate depends on its basic dimensions.
The piezoelectric effect consists in the occurrence of mechanical stresses caused by electric charges. In turn, the inverse piezoelectric effect consists in the change of crystal dimensions caused by the application of an electric field [Buchacz & Wróbel, 2007, Groszkowski, 1958].
Various types of vibration generated in the piezoelectric oscillator depend on the shape, cutting fashion and manner of excitation and are divided into:
- stretching and compressing vibration,
- shear vibration,
- bending vibration,
- torsional vibration.
The phenomenon of conversion of mechanical energy into electric one, occurring in piezoelectric materials,

makes it possible to apply the latter in many technological fields e.g. in the reduction or control of mechanical vibration.

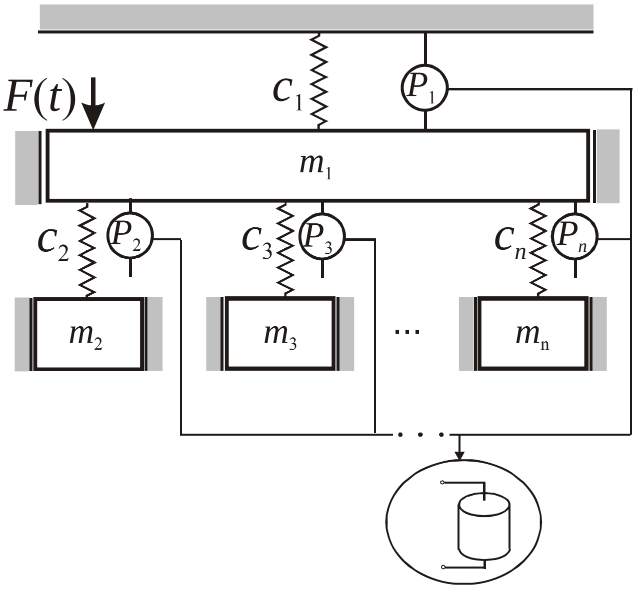

Fig.10. A model of the system with electric elements – piezoelectric elements

3. CONCLUSIONS

The primary purpose of this study is to present the method of synthesis of mechanical ramified systems. The synthesis is double-staged i.e. at the first stage one receives the structure and parameters of elastic and inert elements of ramified system characterised by given values of free vibration frequency, whereas the second stage consists in selecting appropriate vibration damping. The work presents systems with passive and active elements, their physical implementation as well as shows the systems, in which active elements are implemented through mechanical and electric elements. Further research will be concerned with the determination of mutual relations between the basic and added systems.

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