Reduction of vibration by using mechatronical subsystem

K Białaś and A Buchacz

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

E-mail: katarzyna.bialas@polsl.pl

Abstract. The primary aim introduced in this paper is synthesis of mechatronical system understand as planning of this type of systems. Mechatronical system is consisted of fundamental mechanical system and subsystem reducing vibration including electric elements. Fundamental system is received applying reverse task of dynamic (synthesis) and it’s including inertial and elastic elements. The subsystem includes electric elements by means moving-coil transducer. The synthesis can also be used to change the already existing systems. Due to the method, introduced in this work, may be performed as early as whilst the designing of future functions. Using this way of designing is support for designers of mechanical systems with active reducing of vibrations.

1. Introduction

During designing a physical object it is needed to take into Investigation many aspects which can influence its process at a later stage. Using the correct modelling of a physical object facilitates the respective optimisation of its project as early as at the design step. At the starting of a design procedure the construction engineer may obtain or take the parameters and texture of the system meeting expected necessities with reference to dynamic characteristics or, in the event of an already existing system – design a system eliminating unexpected phenomena.

There are many procedures of decreasing pulsations. We can split them into passive, semi-active and active approaches. The major dissimilarity between this way of reducing vibration is application passive or active elements to accomplish them. In passive reduction of vibration are used passive elements and their parameters cannot change in time. In this way of reducing vibration energy is disperse or store for some time.

In semi-active way of reducing vibration are used passive elements too. Change between passive and semi-active method is that components in semi-active method can be chance in time. In active way of reducing vibration are used active elements which can change their parameters in time and energy is equalize by outside supplemental sources. Active elements can be realized by using mechanical, pneumatic, hydraulic, electromagnetic or electro-dynamic elements [1-4].

Shown in this work non-classical approach of designing of mechatronic systems is based on synthesis of these systems. The synthesis is inverse task of dynamics and result of it is receive texture and parameters of system. The task is inverse to analysis because we can obtain system which comply with prerequisite concern the values of poles and zeros or frequency of system. This method of design it is possible to use in existing system and modified its. In case of synthesis of mechatronic system we divide this procedure on two major stages. The first stage is linking with fundamental mechanical
passive system build only from inertial and elastic elements. In the second stage we choose way of reducing unwanted vibration and obtain structure and parameters of this subsystem.

The issue presented on this paper concerns introducing reverse task of mechatronic system with electric components as realization of active components to reducing of vibrations. Electric elements are implemented through the moving-coil transducer [1-9].

2. Research problem and method

In an attempt to obtain a system containing active elements, it is necessary to carry out the synthesis of the characteristic function or the identification of the passive system. Thereafter, depending on the texture and parameters of this system and enforcements acting on this system, the structure of the system with active elements and the values of forces generated by these elements are chosen.

To receive structure and parameters of passive fundamental mechanical system which achieve the requirements to deal with spectrum of frequency it is possible to use one of the methods of synthesis. The characteristic function of system may be define by means mobility of slowness (equation (1)-(4)), which can be shown by means of rational functions of the following forms [1,10,11].

- slowness of semidefinite systems:

\[
U(s) = H \frac{d_1 s^l + d_{l-1} s^{l-2} + \ldots + d_0}{c_k s^k + c_{k-1} s^{k-2} + \ldots + c_0}
\]  

(1)

- slowness of restrained systems:

\[
U(s) = H \frac{d_1 s^l + d_{l-1} s^{l-2} + \ldots + d_0}{c_k s^k + c_{k-1} s^{k-2} + \ldots + c_1 s}
\]  

(2)

where: \( l \) – odd degree of numerator, \( k \) – degree of denominator, \( k-l = 1 \), \( H \) – any positive real number;

- mobility of semidefinite systems

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

(3)

- mobility of restrained systems

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

(4)

where \( k \) – odd degree of numerator, \( l \) – degree of denominator, \( k-l = 1 \), \( H \) – any positive real number.

There are two main types of synthesis of passive mechanical systems. One of them is decomposition of a characteristic function into a continued fraction. This characteristic function can be in the form of mobility or slowness (equation (5)). We obtain systems of the cascade structure (semidefinite or restrained) [1, 10, 11].

\[
U(s) = \frac{c_1}{s} + m_1 s + \frac{1}{s} + \frac{1}{s} + \frac{1}{s} + \frac{1}{s}
\]  

(5)

The next method of synthesis of passive mechanical systems is decomposition of a characteristic function in the form of slowness into partial fractions (equation (6)). As a result of this type of
synthesis (decomposition into partial fractions) we obtain systems of the branched structure (semidefinite or restrained) \([1, 10, 11]\).

\[
V(s) \frac{1}{H} = \frac{s}{c_1} + \frac{1}{m_1 s + \frac{1}{c_2} + \frac{1}{m_2 s} + \cdots + \frac{1}{c_n} + \frac{1}{m_n s}}
\]

(6)

After first step of synthesis of mechatronical system one takes structure and parameters of mechanical system – only parameters of inertial and elastic elements. In the second step one determinates external excitations acting on basic system and select elements reducing vibrations. One of the opportunities is active elements. Polar graph of system obtain as result of synthesis with active elements is present in figure 1.

**Figure 1.** Polar graph of system after synthesis with active elements.

Next step is connected with choosing structure with active element or elements and calculate values of this elements. By solving the system of equations presented in the matrix form (equation (7)), one obtains the values of forces generated by active elements \(F_{e1}, F_{e2}, \ldots, F_{en}\).

\[
\begin{bmatrix}
K_{1,1} &=& \frac{\partial D(\omega)}{\partial[(1)_1]} \\
K_{1,2} &=& -\text{Sim}(K_{1,1}; K_{1,2}) \\
K_{2,1} &=& -\text{Sim}(K_{2,1}; K_{2,2}) \\
K_{2,2} &=& \frac{\partial D(\omega)}{\partial[(1)_1]} \\
K_{n,1} &=& -\text{Sim}(K_{n-1,1}; K_{n,2}) \\
K_{n,2} &=& \text{Sim}(K_{n-1,2}; K_{n,1}) \\
&& \vdots \\
K_{n,n} &=& \frac{\partial D(\omega)}{\partial[(1)_1][2]_{n-1}}
\end{bmatrix}
\begin{bmatrix}
A_1 \\
A_2 \\
\vdots \\
A_n
\end{bmatrix}
= \begin{bmatrix}
F_1 \\
F_2 \\
\vdots \\
F_n
\end{bmatrix}
\]

(7)

where

- \(D(\omega)\) – characteristic equation,
- \(\frac{\partial D(\omega)}{\partial[1]}\) – derivative of structural number in relation to the edge \([1]\),
- \(\text{Sim}\left(\frac{\partial D(\omega)}{\partial[1]}; \frac{\partial D(\omega)}{\partial[2]}\right)\) – function of simultaneity of structural number, the inverse image of which contains two oriented edges \([1]\) and \([2]\),
- \(F_1, F_2, \ldots, F_n\) – excitations,
- \(F_{e1}, F_{e2}, \ldots, F_{en}\) – excitations generated by active elements.

Possible solution of the physical implementation of active elements is the application of electric elements e.g. the use of a moving-coil transducer (figure 2) \([12-15]\).
To obtain the constitutive equations of moving-coil transducer is possible to use Faraday’s law and Lorentz force law. In compliance with Faraday’s law the voltage increment “de” (equation (8)) elementary length “dl” in the direction of the current flow, inducer by the motion of the coil is following:

\[ de = v \times B dl \]  (8)

where: \( v \) – velocity of the coil, \( B \) – magnetic flux density

The complete force of the field acting on an elementary length of the conductor is obtained using equation (equation (9)):

\[ df = idl \times B \]  (9)

where \( f \) – electromagnetic force, \( i \) – current in the conductor

\[ de = vBrd\phi \]  (10)

Using an elementary length ( \( dl = rd\phi \) ) the voltage increment from equation (equation (8)) is following (equation (10)):

\[ e = 2\pi nrBv = Tv \]  (11)

where \( T = 2\pi nrB \) – transducer constant

The voltage in the moving-coil transducer in direction of the current is present in equation (11).

\[ f = i2\pi nrB = Ti \]  (12)

The complete power provided to the moving-coil transducer is equal to the sum of the electric energy and the mechanical energy (equation (11), (12)).

Accordingly at any time, there is a balance between electrical energy absorbed by the device and the mechanical energy delivered (and conversely). The moving-coil transducer cannot store energy, and is as a perfect electromechanical converter [16-18].

3. Conclusions
Presented in this work synthesis (reverse task) of mechatronical systems with the active reduction of vibration implemented with electric elements constitute a new approach to the problem of designing such systems. In order to design this system it is necessary to synthesize or identify a passive system and next, depending on the structure of the passive system and on excitations affecting it, select a structure containing active elements from the sequence of structures. In this work is only presents possibility of using electric elements as active reduction of unwanted vibrations. A very important problem is to check the influences between the basic system and the subsystem. This problem will be presented in next works.
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