The possibility of physical implementation of active vibration reduction

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Abstract. This work presents non-classical method of design of mechanic systems with subsystem reducing vibrations. The purpose of this paper is also introduces synthesis of mechanic system with reducing vibrations understand as design of this type of systems. This work presents method of reduction unwanted vibration by using mechanical elements, electrical elements, magnetorheological damper ect. The use of such a method enables the analysis and synthesis of mechanical systems irrespective of the type and number of the elements of such a system. The purpose of this paper is also introduces synthesis of mechanical system which is the reverse task of dynamics. The result of synthesis is obtaining system meeting the defined requirements. The system was consisted from mechanical elements and sub-system realized by many types of elements. This subsystem is an active or semiactive subsystem which enables overcoming limitations which occur if passive elements are used. The majority of vibration occurring in devices and machines is harmful and has a disadvantageous effect on their condition. Harmful impact of vibration is caused by the occurrence of increased stresses and the loss of energy, which results in faster wear machinery. Introduced in this work approach adopted makes it possible to undertake actions aiming at the elimination of phenomena resulting in the unwanted operation of machinery or generation of hazardous situations in the machinery environment. Thank to the approach, can be conducted as early as during the designing of future functions of the system as well as during the construction of the system.

1. Introduction
Vibrations are among the most frequent physical phenomena observed in everyday life. Typically, vibrations have an adverse effect on their environment. The negative effects include the impact on plant, machinery and structure operation and life. Humans also experience the effect of vibrations. Exposure to a vibration environment can be a cause of multiple diseases. For this reason, many research institutes are involved in studies on vibration damping and isolation. Designers take the vibration potential and vibration damping options into account in building and designing new buildings or structures. Another task for designers and structural engineers is to adapt existing plant and machinery to the conditions in which they operate. Vibration reduction can be used in the case of existing systems, or by predicting the behaviour of the system, it is possible to design systems with vibration reduction. The paper presents two non-classical methods of designing systems with regard to the requirements imposed on them.

The non-classical approach to circuit design is also called structural-parametric synthesis. After obtaining systems that meet the desired requirements, active vibration reduction can be applied.
Four theoretical examples of the implementation of active subsystems made of various types of elements are presented [1-9].

2. Non-classical method of design of mechanical system

Synthesis, conceived as the design of vibrating mechanical systems, consists of a development of system structure and parameters depending on the desired frequency spectrum. System properties can be recorded with the use of dynamic characteristics transformed into dynamic response or rigidity and, following transformation, into mobility (1,2) or response (2,3). Two main methods of vibrating mechanical system synthesis are known: distribution of characteristic function by continued fraction and distribution of characteristic function by partial fractions.

Mobility of semi-specified systems:

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

(1)

where:

- \( k \) – even order of numerator, \( l \) – order of denominator, \( k - l = 1 \), \( H \) – any positive real number.

Mobility of restrained systems:

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

(2)

where:

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

Slowness of semi-specified systems:

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

(3)

where:

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

Slowness of restrained systems:

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

(4)

where:

- \( l \) – even order of numerator, \( k \) – order of denominator, \( l - k = 1 \), \( H \) – any positive real number.

In order to obtain the structure and parameters of inert and elastic elements of a dynamic system one applies two basic methods [1]:

- decomposition of a characteristic function into a continued fraction (5),
- decomposition of a characteristic function into simple fractions (6).

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

(5)

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

(6)
where:
\( c \) – elastic elements, \( m \) – inertial elements.

3. **Active reduction of vibration – physical realization**
Physical realizations of active systems can consist of various elements. These may include mechanical, electric, hydraulic, pneumatic components, etc. Example arrangements involving the particular types of components are shown on the figures 1 to 4. An active system made of mechanical components can have the form of kinematic excitation (figure 1). In the case of kinematic excitation, the elements capable of changing their values are displacements \( y_i \), while elastic elements \( c_i \) remain unchanged [2].

![Figure 1. A model of the system with active elements – kinematic excitation.](image1)

Another possible arrangement for a physical realization of active components is the use of electric items such as a solenoid. When sinusoidal voltage is applied to the solenoid, the polarity and strength of the magnetic field produced by the solenoid will change, and axial movement of the core follows (figure 2) [2-4].

![Figure 2. A model of the system with electric elements – moving-coil transducer.](image2)

The implementation of active vibration damping through piezoelectric components is presented on the drawing. A piezoelectric oscillator is a solid body, typically in the proper shape, cut out of piezoelectric material in the appropriate manner.

The most commonly used piezoelectric materials include crystalline quartz, shaped as a circular or square plate. The plate is positioned between electrodes. Due to the properties of the piezoelectric materials, they are capable of producing vibrations (figure 3).
Two piezoelectric effects are known. The first one of these is related to the presence of mechanical tension occurring in response to electric charges. An inverse piezoelectric effect consists of a change of crystal dimensions in response to the applied electric field.

The mechanical energy into electrical energy conversion and the electrical energy into mechanical energy conversion that occurs in piezoelectric materials has opened an extensive range of options for using such materials in multiple fields of engineering [9-10].

![Figure 3](image1.png)

**Figure 3.** A model of the system with active elements – piezoelectric.

Magnetorheological dampers are used as the solution in realization of active components. A system incorporating magnetorheological dampers as active components is shown on the figure 4 [11].

![Figure 4](image2.png)

**Figure 4.** A model of the system with active elements – magnetorheological dampers.

Magnetorheological dampers are frequently used in such important applications as the construction industry and the automotive industry.

The first devices working with the use of magnetorheological fluid dampers were the dampers used in large drum-type washing machines. The function of magnetorheological dampers was the damping of undesired vibration occurring during the work of these washing machines. Construction is another industry area where magnetorheological dampers are used. They are commonly applied here to protect structures against seismic action. Within the construction industry, magnetorheological dampers are also used in bridge structures to prevent displacement. Dampers of this type are used in suspension bridges to prevent rope displacement. The automotive industry is among those sectors in which magnetorheological dampers play an important role. Magnetorheological fluid was first used in the driver seat construction in 1996. Specifically, it was the arrangement implemented in a truck driver’s seat. Drivers of these vehicles are exposed to physiological effects of vibrations, related to the prevalence of many diseases. As a result of further development and research of magnetorheological fluid, it was used in passenger car suspension structure springs. The first solutions of this type appeared on the market under the MagneRide brand, developed by Delphi and Lord.

Before the magnetorheological fluid solutions, solenoid valves were used in shock absorbers. Work was also started on modifying car suspensions through the use of solutions based on
magnetorheological fluid properties and control options. In 2002, mass production of a passenger car with a suspension fitted with magnetorheological dampers was launched in the Cadillac Seville. This opened the process of replacing the old structural suspension solutions with new ones, particularly popular in high profile models. This is due to the relatively high prices of magnetorheological liquid as the primary medium in these solutions. After 2002, other car maker brands started to implement these solutions, including Audi, Chevrolet Corvet, Cadillac Roadster.

Where magnetorheological dampers are used, it is important to choose and adjust them precisely to specific suspensions mounted in specific car makes and models. There are many factors affecting the final versions of these dampers, such as the car size and weight, technology, and the production process. Control of such dampers is based on solenoids, electric power or permanent magnets. Magnetorheological fluids are recognized among smart materials, and their rheological properties are sensitive to the present magnetic field.

Multiple technology solutions can be distinguished for magnetorheological damper fluids. A shock absorber very often consists of a piston, cylinder, and magnetorheological fluid. A permanent magnet is positioned in a wall seat, consisting of two similar rings in a symmetrical arrangement. Through the permanent magnet, a magnetic field is generated, affecting the magnetorheological fluid and changing the rheological properties, which leads to shock absorption (figure 5) [11-14].

![Figure 5. Magnetorheological damper.](image)

Magnetorheological fluid is composed of two basic ingredients, i.e. the medium and ferromagnetic particles, with such additional items as surfactants. Table 1 presents the example parameters of magnetorheological fluid.

| Parameter                        | Magnetorheological fluid |
|----------------------------------|--------------------------|
| Viscosity without field          | 0.2–0.3 Pa·s             |
| Yield point                      | 50–100 kPa               |
| Maximum current                  | 50–100 kPa               |
| Density                          | 3–4 g/cm³                |
| Response time                    | <10 ms                   |
| Typical power ratings            | 2–25 V, 1–2 A            |
| Field limitations                | Saturation               |
| Operating temperature            | 50 do 150 °C             |

Based on a Bounce Wen model of a magnetorheological damper, the force generated by such a damper can be determined (7).

$$F_z = f_0 + c\dot{x} + k_0x + ax$$

where:

- $f_0$ – battery impact
- $c\dot{x}$ – viscous resistance of fluid flow through an opening
4. Conclusions
The paper presents a non-traditional design engineering method for vibrating mechanical systems. The author describes certain active vibration reduction methods. The paper presents the options for active components realization. Examples of such realizations are the applications of mechanical, electrical, piezoelectric and magnetorheological elements. In order to verify the operation of an active system, it is important to analyze the basic system, the active subsystems, the sensors and the mutual effects among all these components.

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