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Piezoelectric accelerometer in reduction of vibrations in mechanical systems

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Abstract. The aim of this study is to visualize the dynamic vibrating basic system, active element and sensors transmitting the current state of the system. The paper presents the use of piezoelectric accelerometers as vibration sensors used in active vibration reduction. In active vibration reduction, apart from actuators, there are also necessary elements with which it will be possible to continuously test and measure vibrations. It is necessary that the active element generates sufficient force to reduce unwanted vibrations. The selection of active elements reducing vibrations and sensors transmitting the current state of the basic system is presented. Due to such a comprehensive approach, it is possible to obtain a model of the system that will have the desired properties at the design stage. It will also be possible to select an appropriate subsystem using which it will be possible to eliminate the harmful effect of vibrations on the basic system.

1. Introduction

A phenomenon that often occurs in everyday life is the phenomenon of vibration. Very often the impact of vibration is harmful and negatively affects the environment in which it occurs. The vibrations are often a side effect of the basic operation of the devices. The effect of these actions is the wear and tear of machines and equipment, it can also affect their malfunction. For this reason, the consultants have a goal to make new machines and devices achieve lower operating costs and to increase their efficiency. The harmful effect of vibrations is also felt by man. The human body reacts particularly badly to vibrations with a low frequency range. All these causes make many scientific and research centers deal with the phenomenon of vibration. It is necessary to analyze the phenomenon of vibrations and develop methods to combat them. An important problem is also to determine the causes of vibrations and to track their course over time. More and more often, the use of various types of vibration elimination is already at the design stage. Many methods of vibration reduction are known and used. There are different divisions of vibration reduction methods. One of the divisions is the division into passive, semi-active and active methods. Active methods use elements whose parameters can be variable over time and depend on the current state of the basic system. Therefore, an important issue is the measurement of vibrations which is associated with the design of appropriate systems for this service. The example presented here is made up of mechanical and electric elements. By using the electric subsystem, it is possible to change the power generated by this subsystem [1-10].

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2. Research problem and method

Vibration sensors are devices that are used to measure certain quantities. Measured values are displacement, velocity or acceleration. Vibration measurement can be carried out in two different ways. The record of vibrations in relation to the set reference system is called absolute measurement. The relative measurement consists in introducing an additional element to the system and measuring its vibrations in relation to the tested object. In sensors, this element is called the seismic mass

To the class of sensors for measuring absolute vibrations, the most common sensors include piezoelectric accelerometers and electrodynamic sensors with a seismic mass. The relative vibrations are made using contactless sensors.

For vibration measurements in the absolute methods most commonly used non-contact proximity sensors:

- proximity and electromagnetic proximity switches,
- Eddy current proximity sensors,
- proximity sensor capacitive.

However, when measuring using relative methods, accelerometers are the most popular [11]:

- piezoelectric,
- electrodynamic.

Most of the proximity sensors can be used to measure vibrations of elements only with ferromagnetic properties.

One of the most commonly used vibration transducers is the piezoelectric accelerometer. The operation of the piezoelectric accelerometer is based on the phenomenon of electric charge generation on the walls of piezoelectric materials under the influence of deformation forces.

During the movement, the mechanical forces caused by the inertia of the seismic mass act on the piezoelectric element. As a result, an electric charge is generated. Piezoelectric materials generate a charge proportional to the value of the force that affects them [10,11].

The most important element of the piezoelectric sensor is the piezoelectric material plate. The piezoelectric element in the sensor is placed in such a way that during vibration is subjected to the mass reaction force. This force is proportional to acceleration and defined by Newton's second law.

In the case of a piezoelectric accelerometer, two construction solutions are most commonly used:

- converter with which the mass exerts compression force on the piezoelectric element.
- a transducer in which the mass exerts a shearing force on the piezoelectric element sensor element.

At a constant seismic mass, the force exerted on the piezoelectric element is proportional to the acceleration value. In the case of usable frequencies of the sensor, we obtain a simple proportional dependence of the generated charge (voltage) on acceleration. This dependence is referred to as the sensitivity of the sensor (1,2).

Charge sensitivity:

$$S_q = \frac{q}{a} \tag{1}$$

Voltage sensitivity:

$$S_u = \frac{u}{a} \tag{2}$$

where q – charge; *u* – voltage; *a* – accelerate

In figure 1 has been presented simulates the action of a piezoelectric sensor in the *Matlab* program.

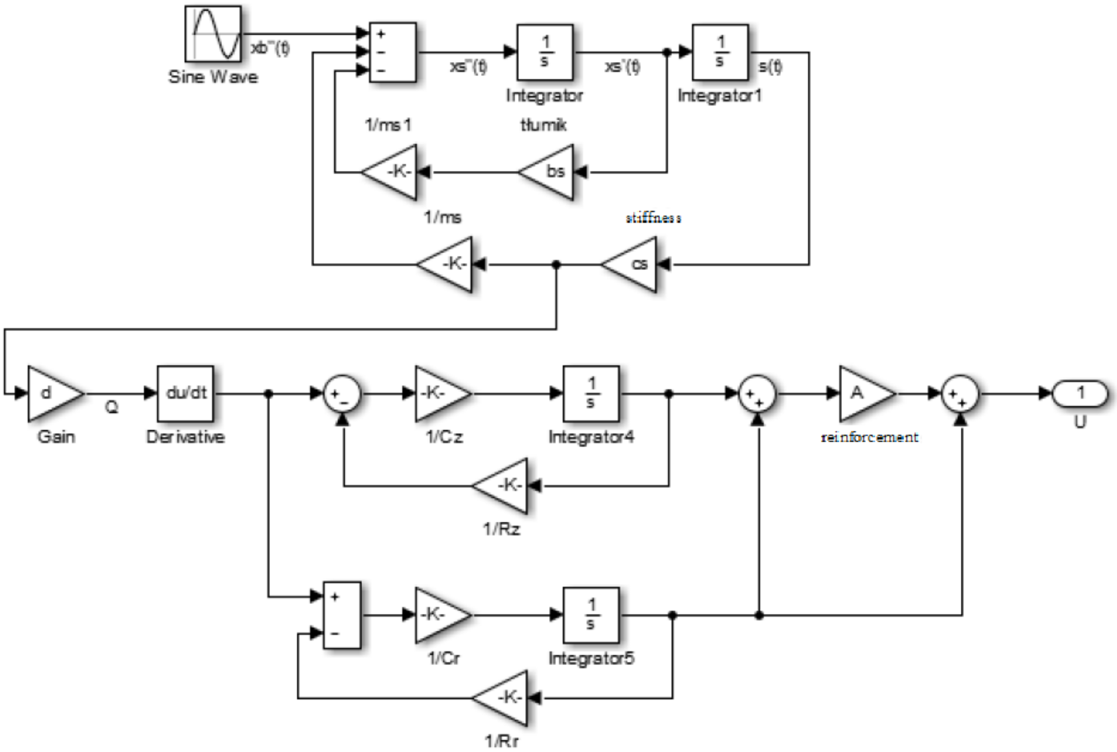

Figure 1. A program that simulates the action of a piezoelectric sensor.

The discreet vibrating mechanical system considered in the work (figure 2) consists of two inertial elements and two elastic elements. An external excitation in the form of harmonic force F (F = 15sinωt kN) operates on the system under consideration. Force acts on the first inertial element.

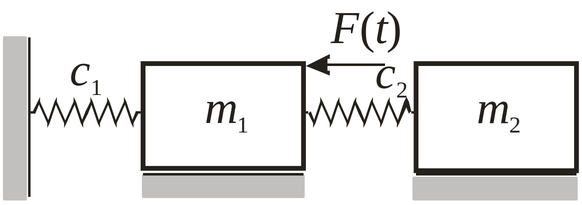

Figure 2. The system under consideration.

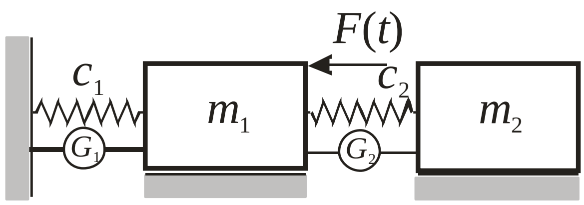

Figure 3. The system with active elements.

Tabel 1. The values of passive elements.

No.	element	value
1.	m_1	9 kg
2.	m_2	11 kg
3.	c_1	400 N/m
4.	c_2	500 N/m

Reduction of undesirable vibrations can be accomplished using passive or active elements. The work was limited to the use of active elements reducing vibrations (figure 3). In the case of passive elements viscose dampers can be used. To determine the values of forces generated by active elements, it is necessary to solve the system of equations (3) in the matrix form [2-4].

$$G = D \cdot A - F \tag{3}$$

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.

Tabel 2. The values of active elements.

No.	Frequency	The value of amplitude of force generated by active element [k*N*]
1.	ω = 3,5 *rad/s*	G_1=15,3
2.		G_2=1,1
3.	ω = 7,5 *rad/s*	G_1=16,5
4.		G_2=0,3

The program simulating the vibrating system with active elements reducing vibration is shown in figure 4.

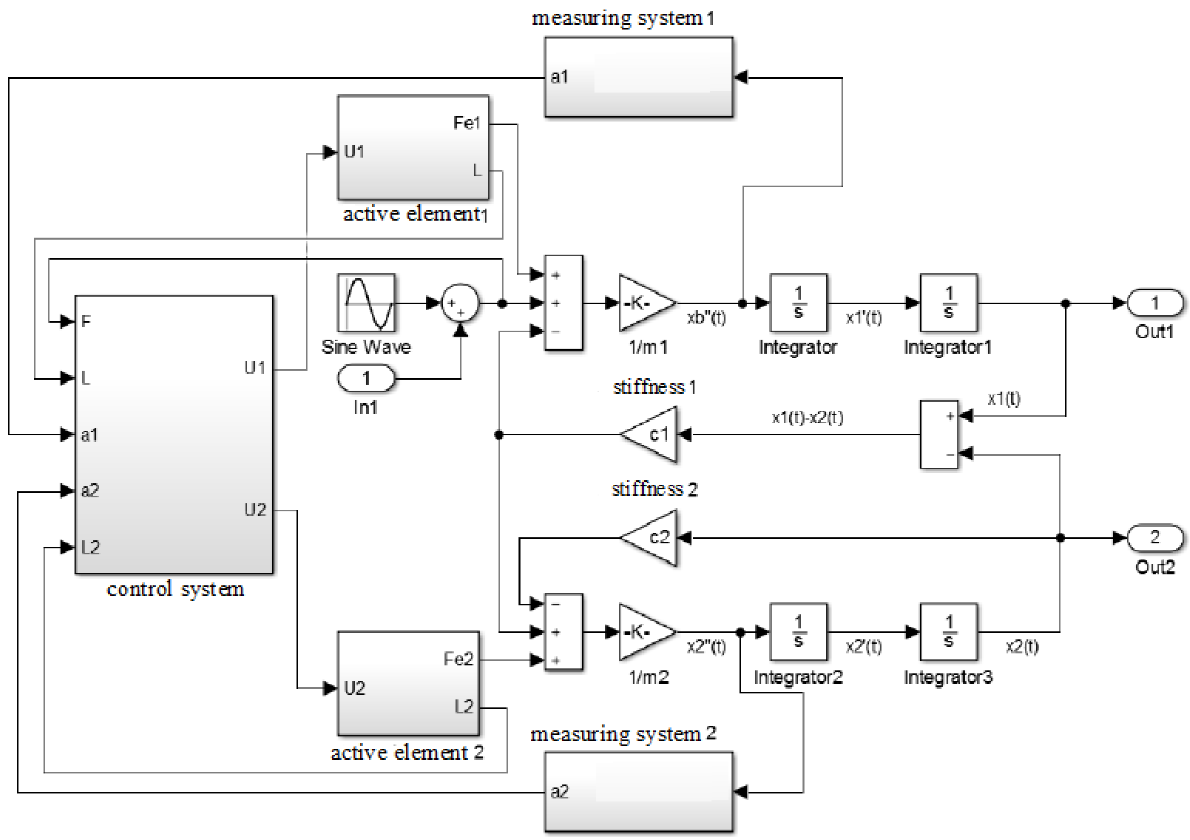

Figure 4. The program simulating the vibrating system.

An analysis of the system concerned. Diagrams of amplitude-frequency characteristics of the system without damping and a system with active vibration reduction were drawn up (figure 5).

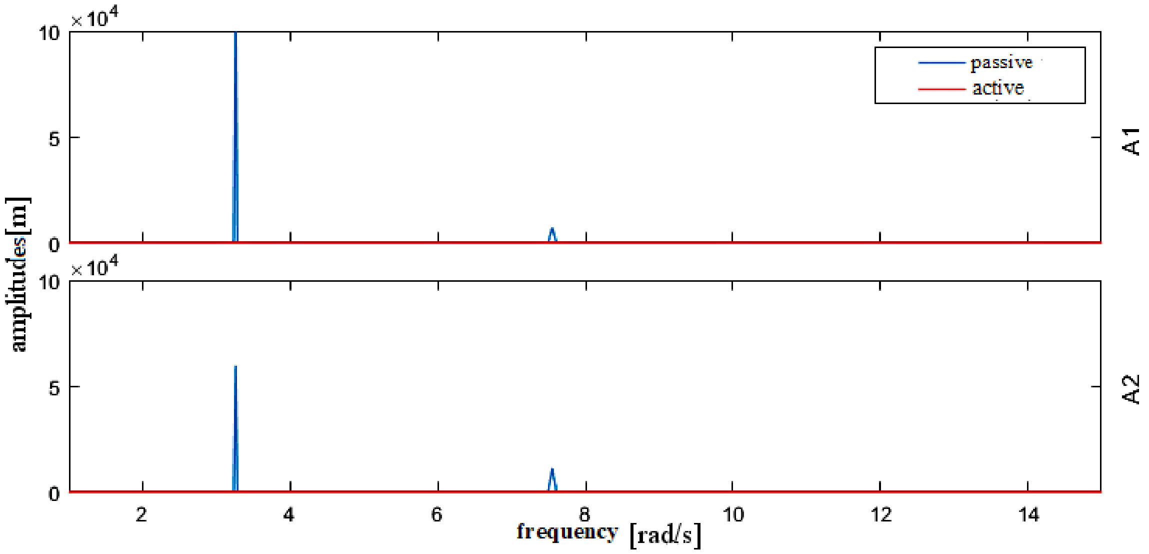

Figure 5. Diagrams of amplitude-frequency characteristics.

3. Conclusions

The paper presents the analysis of systems with active vibration reduction and vibration sensors that are designed to track the current state of the system. The presented graphs show that the system with vibration reduction eliminates undesirable vibrations. However, in the case of a system without reduction, you can see clear peaks in the graphs of amplitude-frequency characteristics. The considerations presented in the article are an introduction of using sensors in active vibration reduction

4. References

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