Estimation of the position error of the magnetorheological elastomers active vibration control platform for precision vacuum equipment

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Abstract. Most of the modern vacuum nanotechnological and research equipment is associated with the vibration control systems. Recently, systems based on composite materials, such as magnetorheological elastomers, are becoming more widely used. Such materials make possible to combine the functions of active, semi-active and passive vibration control in one device. This paper presents a research on the position error of the vibration control platform based on magnetorheological elastomers. This error occurs due to the inevitable unevenness of the top panel of the platform caused by the special properties of the elastomeric actuator. It leads to deviation of the platform from the horizontal plane position. The research on the measurement error was made by the contour estimations method and the correlation coefficients of the actuators movements were used.

1. Introduction
For ultra-precision technological processes (nanolithography, scanning probe microscopy, precision metalworking, alignment of fiber optic systems) it is necessary to provide vibration control at disturbance frequencies in a wide frequency range from 0.5 to 200 Hz with vibration displacement amplitudes up to 200 μm. The most effective vibration protection method is vibration isolation which can be divided into passive, semi-active and active isolation.

Magnetorheological (MR) and electrorheological (ER) fluids and elastomers form a type of smart materials that can change its’ properties under the influence of external magnetic and electric fields, respectively. These materials used in precise positioning and vibration control systems make it possible to decrease the positioning error and response time of such positioning systems and the vibration control transfer coefficient of vibration control systems [1, 3].

2. Research object, platform for active vibration control
The object of this research is the vibration control platform based on MR elastomers (figure 1). Magnetorheological elastomers (MRE) are composite materials, compounds based on a non-magnetic matrix of elastomer (mixture of rubbers, silicone) with soft magnetic fillers, particles of micron size,. The particles tend to align themselves into a chain structure so the MRE changes its’ elastic-viscosity-plasticity characteristics, when an external magnetic field is applied. The MRE deformation will depend on the magnitude of the external magnetic field. The nonmagnetic matrix returns the particles to their nominal position due to its’ elastic properties, when the external magnetic field disappears.
The purpose of the investigated platform is to reduce the oscillations of the object caused by external vibration and shock disturbances [3]. It can work in all three modes of vibration control: active, semi-active and passive.

Passive vibration control is provided by the quasi-zero stiffness suspension system with (QZSS) [2]. QZSS is a combination of loads, levers and spring elements designed to reduce the load of platform and its’ actuators (MR dampers) created by the mass of the isolated object. Elements of the system support the movable platform plate at four points symmetrically from its’ center.

Active and semi-active vibration control is provided by four MR dampers located symmetrically from the platform center. An electromagnetic coil controls the damper actuation [3].

![Figure 1. Active vibration control platform based on MRE.](image)

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The four MR actuators are fixed on the platform base. Each MR damper has a MRE disk membrane and one electromagnetic coil in the armored core [3]. Each actuator can be controlled independently by an automated control system which creates a signal transformed into the current in the coil.

3. Experimental research
The MREs mounted on MR dampers can have different characteristics even within the one technological lot. It happens because the distribution of metal particles in the elastic matrix is difficult to control during the manufacturing process. This leads to deviation of the platform movable plate from the horizontal plane. Thus, the purpose of the study in this work is to research the positioning error of the platform caused by these differences.

The measurements were carried out on a four-channel displacement measuring system capaNCDT 6200 (Micro Epsilon, Germany). The system has four capacitive position sensors and one controller. The system can measure platform displacement with a resolution of up to 10 nm and a data acquisition rate of 3.9 kHz. The sensors are installed onto supports above the connection points of the MR dampers and the platform moving plate with a distance of about 0.2 mm to the platform movable plate (figure 2).

![Figure 2. Experimental bench.](image)

As a result of the research, the maximum deviation of the platform moving plate from the horizontal plane is 110 μm, which is unacceptable for the nanotechnological purpose. The control signal needs to be adjusted for each damper according to the experimental curves (figure 3).
4. Experimental results processing
The estimation of measurement error was carried out by the contour estimations method [4]. The required number of parallel experiments of the position of the actuator in each experiment was determined, when experimental measurement results were processed. A number of parallel experiments was 30 with a measurement results standard deviation of 0.1 μm.

Verification of the distribution of the experimental results by the Pearsons’ test showed its’ compliance with the normal distribution law. The contour estimations method showed that the maximum random measurement error does not exceed 0.5 μm. This means the experimental results have the sufficiently high accuracy of the measurements and show the reliability of the obtained results of active vibration control platform actuators displacements.

The uniform distribution law was chosen as the worst possible form of experimental displacement results distribution.

5. Conclusion
The experimental measurements of the MRE platform displacement as a function of the control electric current showed that the deviation of the platform moving plate movements from the nominal value (0 A current) was about 110 μm with a maximum control current 0.5 A.

The reasons of deviation are the different MRE properties of each actuator due to its’ manufacturing technology.

The systematic measurement error is up to 0.4 μm and random errors is up to 2 μm. The errors were detected and significantly reduced. Thus, the experimental results allowed to achieve high accuracy of the measurements. It confirms the high reliability of the results.

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