334. Application of Piezoactive Material/Rheological Fluid Composite Structures in Engineering

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Abstract. Active materials are rapidly expanding their variety as well as applications due to their promising high–tech potential. Composite structures of active materials enable researchers to develop mechatronic systems and devices with inherent intelligence features and increased level of integration. A composite structure consisting of piezoactive material and electrorheological fluid is proposed, and its possibilities in developing self-adjusting and adaptive systems are discussed.

Keywords: adaptive damping, composite structure, active material.

Notation

\( S \) – strain;
\( s^E \) – compliance when the electric field is not applied;
\( T \) – stress;
\( d \) – piezoelectric coupling constant;
\( E \) – electric field strength;
\( D \) – charge–density displacement;
\( \epsilon^t \) – permittivity at constant stress. Superscript \( t \) stands for the matrix transpose;
\( \sigma \) – stress in the electrorheological fluid;
\( E \) – electric field strength;
\( \eta \) – viscosity;
\( u \) – displacement of fluid particle;
\( y \) – particle coordinate;
\( t \) – time;
\( \chi(t) \) – shear strain in the coating surface which is proportional to the mass displacement;
\( F(t) \) – excitation force;
\( A \) – coating cross section;
\( l \) – coating surface length.

Introduction

Over the past centuries the materials meeting specific needs for strength, durability, weight, flexibility, etc. were developed. With the advent of active materials, the components able to modify themselves in these dimensions came into reality. They are copying the intelligent forms of the living world and thus share inherent intelligence which allows them to respond to the changes in the environment. In the simplest case these materials respond directly to stimuli without any signal processing. More sophisticated systems contain their own sensors, actuators and computational capabilities in order to modify their behaviour responding to the changing environment. Such smart systems based on active materials are currently used for a growing range of commercial applications in structural engineering, biomedical, optical techniques, aerospace and other applications.

A lot of various active materials are more or less widely used. Piezoactive materials, rheological fluids and shape memory materials have become classical in this area. Others, like magnetostrictive, electroplastic, electro-optic, electroacoustic, pyrosensitive materials, are expanding wide scale applications. Active material composite structures have the most promising high–tech potential for shock and oscillation suppression systems [1,2]. The application possibilities of an active material structure consisting of a piezoactive material and rheological fluid are discussed in the paper, which is an overview of the ongoing research [3-6].

Piezoactive material/rheological fluid composite structure and its applications

Piezoactive materials (PAM) applications are based on the piezoeffect, which is described as follows:
Due to the possibilities to develop devices featuring rapid response, practically unlimited resolution, large force generation, broad operating frequency range, high stability and low power consumption, PAM is widely used for sensing as well as for actuating (Fig. 1). Examples of PAM applications for actuation are ultrasonic motors, micromanipulators, laser tuning devices and other instrumentation. Sensing properties of PAM are exploited in accelerometers and oscillation suppression systems based on the same effect.

Shear stress in electrorheological fluid (ERF) depends on the voltage applied:

$$\sigma = aE^2 + \eta \frac{\partial u}{\partial t} ;$$

Thus the fluid viscosity becomes the function of the voltage (see Fig. 1). There are two possibilities to change ERF viscosity: to make use (a) of voltage $U$ alteration at the gap $h$ between electrodes being $h=\text{const}$ and (b) to make use of gap $h$ alteration at voltage between electrodes being $U = \text{const}$. In the first case the electric field strength (and ERF viscosity as well) become directly proportional to the voltage and in the second case – inversely proportional to the gap magnitude.

**Fig. 1.** ERF and PAM, and their composite structure properties
transducers $PT$ [3]. Depending on the position of piezoelectric transducer in relation to mass $m$ and additional mass $m_a$, electrical charge $U$ is related to the position $U(x)$, velocity $U'(x)$ or acceleration $U''(x)$ of the moving mass $m$. Thus the damping characteristics of system can be independently controlled by any kinematic parameter of mass motion.

The proposed composite structure has a lot of various useful applications. The system shown in Figure 2, $a$ can be directly applied as an adaptive shock absorber as well as for self-adjusting force actuating in the exercising machines [4]. It is also suitable for adaptive damping system which is schematically shown in Figure 2, $b$ [5,6]. The system consists of $PAM$ coating on the structural element and the layer of $ERF$ contacting with it. When oscillations in the structural element are excited, the electric charge proportional to their magnitude occurs in the electrodes due to the direct piezoeffect in the $PAM$ and causes the electric field whose strength is:

$$E = \frac{1}{d} \left[ \frac{1}{1} x(t) - s \cdot \frac{F(t)}{A} \right].$$

(3)

The $ERF$ viscosity changes in the area of $ERF$ contact with electrodes in accordance with the applied voltage and thus damping becomes adaptive. The presented system exhibits both passive and active damping features. However, classical passive dampers can only be tuned best for a relatively small frequency range, whereas an adaptive damping system shown in Figure 2, $b$ is characterized by a wide frequency range.

Using multi-layer structures and films of $PZT$ and $ERF$ it is possible to realize adaptive damping of the continuous systems (rod, shaft, plate, frame, etc).

The sectioned electrodes allow us to organize the adaptive response in relation to the magnitude of strain in the structure [3]. The example is shown in Figure 3, where piezoelectric layer is fixed to the vibrating structure. One of the electrodes of the piezoelectric layer is sectioned and is in contact with $ERF$. $U_x(t)$ is the distribution of electric charge on the sectioned electrodes; $\sigma_{xy}$ - are stresses in the active layer. It is easy to notice that damping and flow resistance will be directly related to the maximum value of the stresses in the structure without applying an external electrical field.

**Fig. 2.** Control possibilities of the $ERF$ - $PAM$ composite structure ($a$) and its application for adaptive damping ($b$)

**Fig. 3.** Adaptive damping system ($a$) and its dynamic behavior ($b$): $1$ - vibrating structure; $2$ - $PAM$ layer; $3$ - a - continuous electrode; $4$ - sectioned electrode; $5$ - continuous electrode in the contact with the $ERF$ layer
Summary

The composite structure consisting of piezoactive material and electrorheological fluid was proposed and its application possibilities for self-adjustable damping systems were analyzed. The possibilities to develop systems with response to different kinematic parameters of a moving body and strain distribution have been discussed.

References


