

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;

ε^T – permittivity at constant stress. Superscript t stands for the matrix transpose;

σ – stress in the electrorheological fluid;

E – electric field strength;

η – viscosity;

u – displacement of fluid particle;

y – particle coordinate;

t – time;

$x(t)$ – PAM shear strain in the coating surface which is proportional to the mass m 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:

$$S = s^E T + d^T E, \tag{1}$$

$$D = dT + \varepsilon^T E;$$

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

$$\sigma = \alpha E^2 + \eta \frac{\partial u}{\partial y \partial t}; \tag{2}$$

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.

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=const* and (b) to make use of gap *h* alteration at voltage between electrodes being *U = const*. In the first case the electric field strength (and *ERF* viscosity as well) become directly proportional the voltage and in the second case – inversely proportional to the gap magnitude.

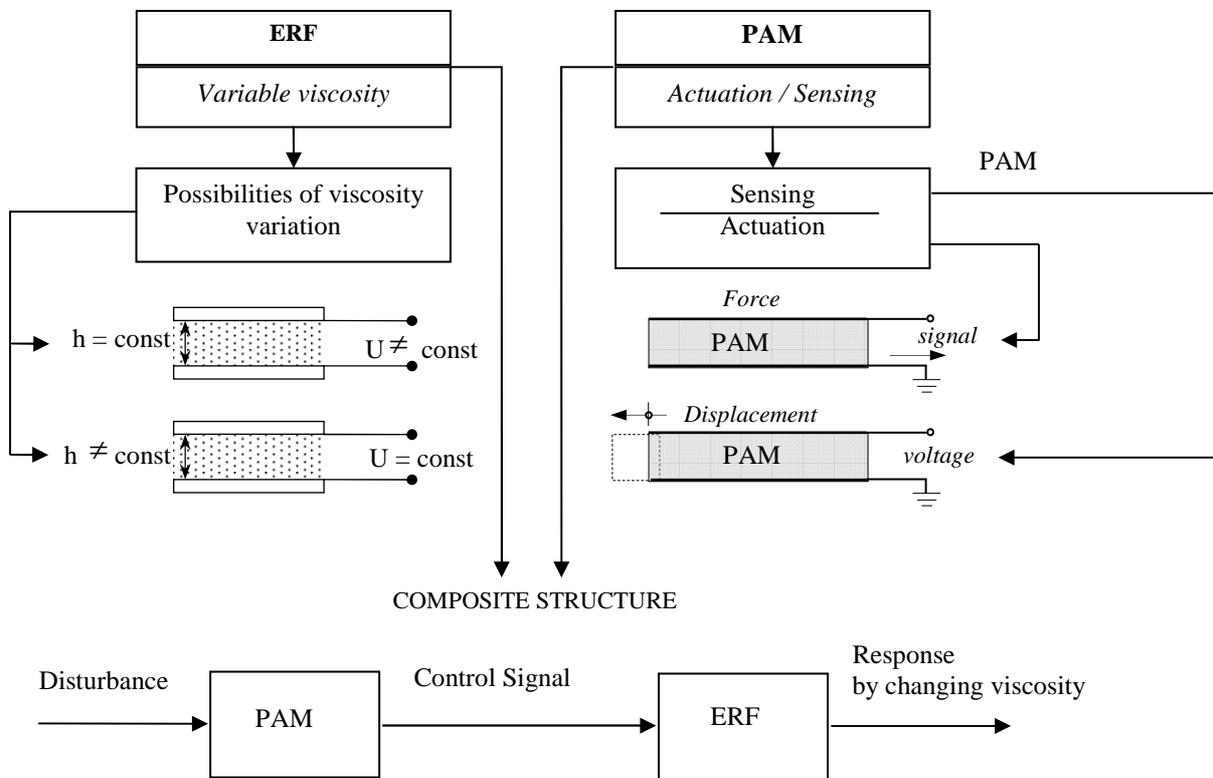


Fig. 1. ERF and PAM, and their composite structure properties

Low zero-field viscosity, high *ER* effect, wide range of control and high shear stability of *ERF* are of great importance and lead to its successful applications for vibration suppression as well as design of simple, quiet and rapid-response interfaces between electronic controls and mechanical systems. Well known applications are for shock absorbers in vehicles, dampers for seats, machinery, centrifuges, prostheses, etc.

Composite structures consisting of *ERF* and *PAM* promise possibilities to develop systems with inherent

intelligence of higher level because they allow combination of sensing, control and variable parameter elements into structures which exhibit self-adjustment and adaptability properties. The possibilities of such structure to respond to disturbance in accordance with various kinematic parameters are shown in the Figure 2, a. Mass *m* is translating in the *ERF*, whose flow along the contact with mass is affected by the viscosity and shear rate of shear stress of *ERF*, which is strongly related to electrical charges *U*, taken from the electrodes of piezoelectric

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(ẋ)* or acceleration *U(ẍ)* of the moving mass *m*. Thus the damping characteristics of

system can be independently controlled by any kinematic parameter of mass motion.

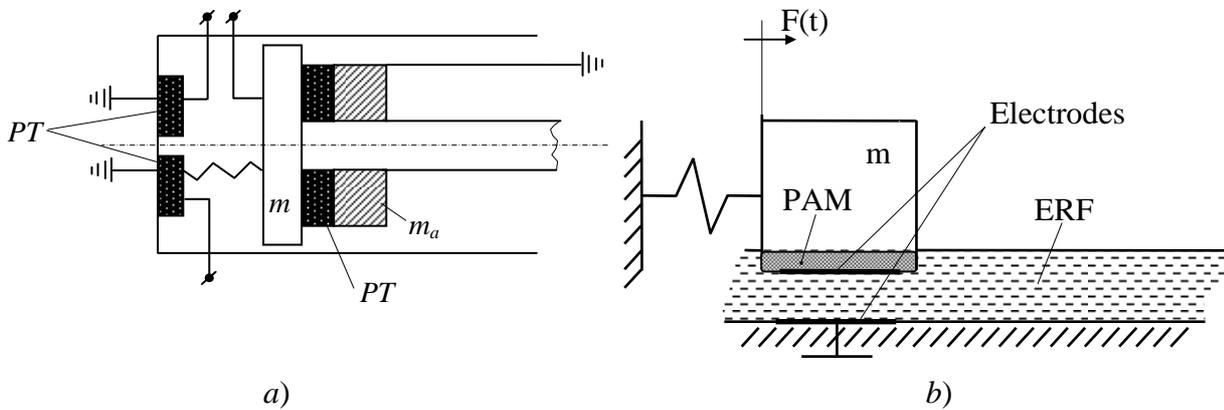


Fig. 2. Control possibilities of the *ERF - PAM* composite structure (a) and its application for adaptive damping (b)

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:

$$E = \frac{1}{d} \left[\frac{1}{l} x(t) - s^E \frac{F(t)}{A} \right]; \quad (3)$$

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; *σ_{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.

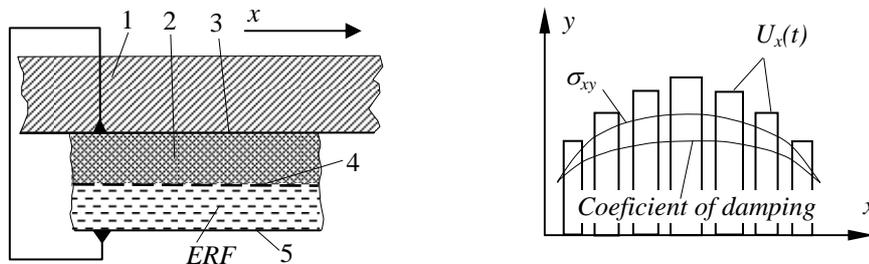


Fig. 3. Adaptive damping system (a) and its dynamic behavior (b): 1 - vibrating structure; 2 - *PAM* layer; 3 a - continuous electrode; 4 - sectioned electrode; 5 - continuous electrode in the contact with the *ERF* layer

Summary

The composite structure consisting of piezoelectric 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.

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