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Research Paper

Improved thermal characteristics of a novel magnetostrictive jet dispenser using water-cooling approach

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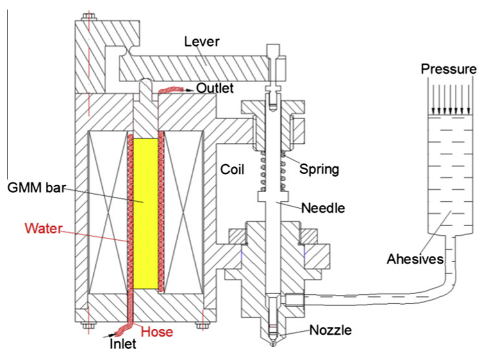
HIGHLIGHTS

- A novel magnetostrictive jet dispenser with water-cooling system is proposed.
- The temperature increasement will lower 13.6 °C.
- The cooling system will improve the jetting uniformity in long time work.

GRAPHICAL ABSTRACT



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ABSTRACT

Temperature increasement of giant magnetostrictive jet dispenser may affect the dot consistency during long time work. In order to tackle the issue, a novel structure with water-cooling system is proposed. The thermal models considering thermal contact resistance based on the mechanisms of heat generating, heat transferring and heat dissipating were established. The experimental platform for temperature testing was set up, and experiments were carried out. The agreement between simulation and test results proves that the simulation models are reliable. The simulation results of the novel structure show that temperature of the magnetostrictive bar is lower and steadier compared with the original one. It proves that the water-cooling system is effective to improve the thermal characteristics and uniformity of the magnetostrictive jet dispenser.

1. Introduction

Jet dispensing technology is widely applied in modern industry, such as microelectronic packaging, LED (Light-emitting diode) packaging, automotive industry, optoelectronic packaging [1–6]. Dispenser is the key device of dispensing machine. With the development of the industry, higher efficiency and uniformity dispenser is required [7–12]. Many experts devoted their energies to jet dispensers and obtained great achievements [13–22]. Many contact based dispensers were instead of jet dispenser for high efficiency. To improve the uniformity and performance of jet dispenser, a temperature control device is usually designed accompanying with the dispenser. The temperature control device is used to preheat adhesives and keep adhesives at constant temperature. Besides the characteristics of adhesives, precision of the actuator of jet dispenser can also affect the uniformity of the jet dispenser.

Magnetostrictive jet dispenser is one of these achievements, which is feature of high frequency [23]. The structure of the existing magnetostrictive jet dispenser is presented in Fig. 1. When the pulse current activates the coil, the alternating magnetic field can

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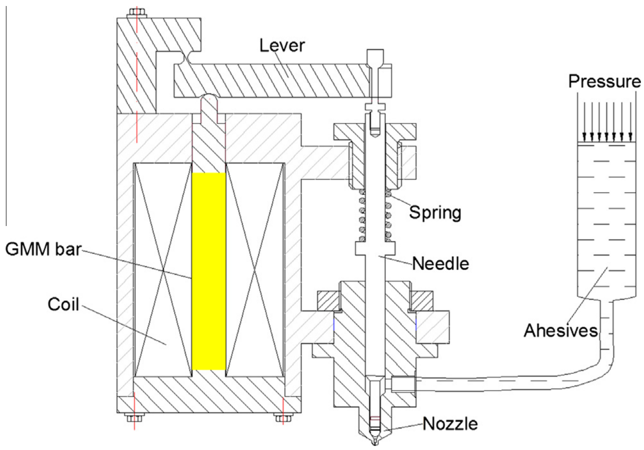

Fig. 1. Structure of the original giant magnetostrictive jet dispenser.

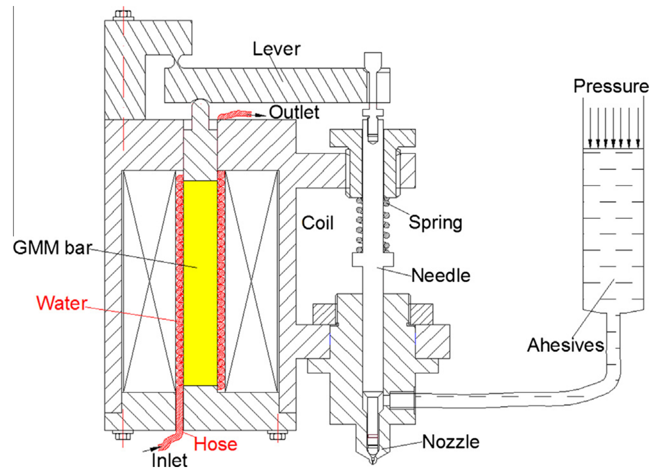

Fig. 2. Structure of the novel giant magnetostrictive jet dispenser.

be obtained. The GMM bar in the alternating magnetic field will vibrate periodically. Then the lever and the needle will move up and down with the GMM bar. When the needle moves down with the pressure of the spring, adhesives will be jet out from nozzle. The coil of the magnetostrictive jet dispenser generates heat, when it works. The magnetostrictive bar in the coil will elongate with temperature increasing. Then, the distance between the needle and the nozzle will vary and the expansion rate of GMM bar will vary with temperature changing. It may affect the uniformity of the jet dispenser during long time range.

The uniformity of existing magnetostrictive jet dispenser in short time range is very high [24]. However, due to the thermal expansion of the GMM bar, the uniformity of existing magnetostrictive jet dispenser in long time range is not high enough.

Therefore, this study was undertaken to examine a new method that jet dispenser can achieve high uniformity through improve the precision of actuator. According to this idea, a novel magnetostrictive jet dispenser with water-cooling system to control temperature increasing of giant magnetostrictive material (GMM) bar is firstly proposed to further improve the uniformity of jet dispenser. And the thermal models and simulations of the giant magnetostrictive jet dispenser are also discussed. The water-cooling system makes the temperature variation small, which can also be used in other GMM or electro-magnetic application.

2. The novel magnetostrictive jet dispenser, thermal models and experimental set up

2.1. The novel magnetostrictive jet dispenser

The structure of the novel giant magnetostrictive jet dispenser with water-cooling system is presented in Fig. 2. The work principle is similar as the original jet dispenser. In the novel giant magnetostrictive jet dispenser, a hose is wound on the GMM bar, in which water flows in order to limit the temperature increasement of the GMM bar. A pump makes the water in hose cycle, and the flow rate can be controlled by the pump. Compared with the original one, the GMM bar of the new jet dispenser is surrounded by water hose. Most heat inner the coil is taken away by cooling water. It makes the temperature of the GMM bar steady relatively.

2.2. Thermal models of magnetostrictive jet dispenser

The thermal model of magnetostrictive jet dispenser consists of the heat generate model, heat transfer model, thermal convection model and thermal radiation model. The jet dispenser system follows energy conservation law,

$$\frac{\partial q_i}{\partial x_i} + p - \rho c \frac{\partial T}{\partial t} = 0 \tag{1}$$

where T is temperature, t is time, x_i is coordinate components, q_i is component of heat flux vector, ρ is density, c is specific heat and p is heat generation power of the jet dispenser system.

When heat transfers, it follows Fourier's Law which is as follow,

$$Q = -kA\frac{dT}{dx} \tag{2}$$

where Q is heat transferring through an interface, A is area of the interface, k is thermal conductivity and x is coordinate.

Heat generated by the magnetostrictive jet dispenser is determined by energy loss. All heat source of the GMM based jet dispenser belongs to the second kind thermal boundary condition. Energy loss of electro-magnetic system normally consists of copper loss and iron loss. Loss caused by resistant of coil is copper loss, which can be calculated as follow,

$$Q_{Cu} = n \cdot \int_0^T I(t)^2 R d(t) \tag{3}$$

where Q_{Cu} is copper loss, n is number of the cycles, T is period of the driving pulse current, $I(t)$ is current, R is resistance of the coil. The coil of the giant magnetostrictive jet dispenser is activated by pulse current. The current waveform can be obtained by an oscilloscope, which is shown in Fig. 3. According to the work principle of the novel giant magnetostrictive jet dispenser, the copper loss of the coil during each cycle is the same.

There is a GMM bar in the coil of the novel magnetostrictive jet dispenser. Iron loss consists of hysteresis loss and eddy current loss of GMM bar. When ferromagnetic material is in magnetization process, the total magnetization lags behind the magnetic field strength. This phenomenon is hysteresis, which is caused by friction among inner magnetic domains and crystal structure anisotropy. The hysteresis loss can be calculated through hysteresis loop. The characteristics of selected GMM were tested by Jiao-Guang Rare Earth Material Co., Ltd., and the hysteresis loop is shown in Fig. 4. Energy density of the hysteresis loss during one cycle can be expressed as follow,

$$w_h = \oint HdB = S. \tag{4}$$

Power of hysteresis can be calculated by following equation,

$$p_h = w_h \cdot f \tag{5}$$