Journal of Magnetism and Magnetic Materials 252 (2002) 344–346

Journal of magnetism and magnetic materials

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Fluid transportation mechanisms by a coupled system of elastic membranes and magnetic fluids

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Abstract

The basic properties of the fluid transportation mechanism that is produced by the coupled waves propagating along a thin elastic membrane covering a magnetic fluid layer in a shallow and long rectangular vessel are investigated. It is shown that the progressive magnetic field induced by the rectangular pulses generates sinusoidal vibration of the displacement of elastic membrane and makes the system work more efficiently than the magnetic field induced by the pulse-width-modulation method.

Keywords: Magnetic fluid; Coupled vibration; Coupled wave; Fluid transportation; Progressive magnetic field

1. Introduction

The transportation mechanisms of fluids and/or solid films proposed in our previous papers [1–3] are produced by the coupled waves that propagate along a thin elastic membrane covering a magnetic fluid layer in a shallow and long rectangular vessel. In this paper, a fluid transportation system is made and the basic properties of this mechanism that is worked by progressive magnetic field are shown. Rectangular pulses are used to generate the progressive magnetic field while the magnetic field was applied by using the digital electronic pulse-width-modulation (PWM) circuit in the previous experiments [1–3]. The magnetic fluid can return to the upstream region by passing through two bypaths from the downstream region to reduce the pressure of downstream region of the magnetic fluid layer and suppress the pulsations of the membrane. The effect of these bypaths is also mentioned.

2. Experimental

A schematic diagram of the experimental apparatus is illustrated in Fig. 1. The fluid transportation mechanism is constructed from a water channel, two thin elastic membranes, two magnetic fluid layers and 32 electromagnets. The cross section of the water channel is 50 mm width and 6 mm height. The total volume of water in the channel is about 960 cm^2. The magnetic fluid layer, the main channel size is 50 mm width, 6 mm height and 510 mm length, is filled with water-based magnetic fluid (TAIHO, W-40). To reduce the pressure of the downstream region of the magnetic fluid layers under applied progressive magnetic field, the magnetic fluid can return to the upstream region from the downstream by passing through the bypaths as shown in Fig. 1. The elastic plane membranes covering the magnetic fluid layers are made of silicon rubber of 1 mm thickness and the tensile strength is 77 MPa. To apply magnetic field, the 16 electromagnets are arranged on the both sides linearly along the axis of the channel. The magnetic field is applied in the form of rectangular pulse waves propagating along a train of electromagnets to excite wavy motions of the elastic membranes. The flow can be observed and the flow velocity is measured by a video tape recorder at the acrylic pipe region. The displacement of the elastic membrane just under the eighth magnet from upstream is measured by the optical displacement-measuring instrument (YA-MAN, Optfollow Model-1000). Dynamical responses are investigated under several conditions of the applied field. Frequency,

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PII: S0304-8853(02)00631-5

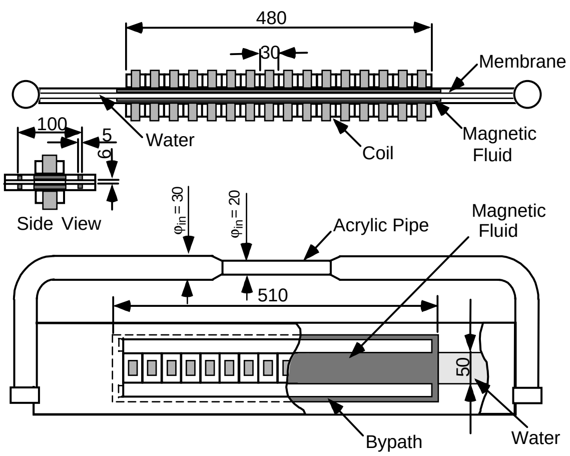

Fig. 1. A schematic diagram of the experimental apparatus of the fluid transportation mechanism.

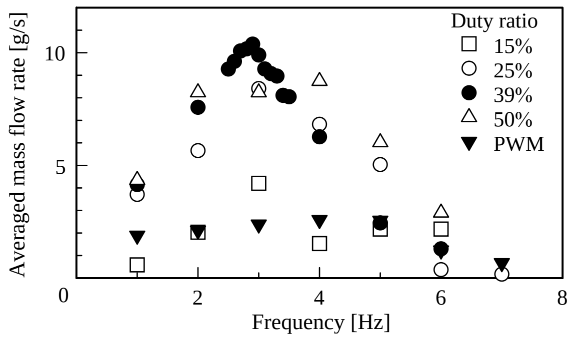

Fig. 2. Averaged mass flow rate changing due to the frequency and the duty ratio. The duty ratio is 39% in the case of PWM. The applied electric current is 5 A.

duty ratio and input method of magnetic field are changed. The duty ratio is defined by the time ratio of applying magnetic field. The electricity supplied to the electromagnets is 5 A.

3. Results and discussion

Fig. 2 demonstrates the averaged mass flow rate changing due to the frequency of applied magnetic field. The mass flow rates are calculated by $\rho Av/2$, where ρ is the density of water, A is the cross-sectional area of the acrylic pipe and v is the averaged velocity measured at the center of the acrylic pipe. Fig. 2 also shows the effect of the duty ratio on the averaged mass flow rate. From this figure, it is clear that the mass flow rate has a peak value at the frequency of 3 Hz under all duty ratios except 50%. The mass flow rate takes maximum value at the frequency of 2.9 Hz and the duty ratio of 39% under our experimental arrangement. The flow rate produced by using the PWM method is also illustrated in Fig. 2 and it shows that the flow rates under the magnetic field of rectangular pulses are larger than those under the applied magnetic field produced by the PWM method. It means that using the series of simple rectangular pulses are more effective on this mechanism than the PWM method. The displacement of the elastic membrane at the center of the driven system is shown in Fig. 3. From Fig. 3(a), the applied rectangular pulses make the membrane vibrate sinusoidally at the peak frequency of the flow rate. From Figs. 3 and 4, at the frequency of 4 and 5 Hz the amplitudes of displacement are larger than that at the peak frequency, while the peak frequency of the maximum flow rate is 3 Hz. The same result can be found from the PWM case. From Fig. 3(b), the amplitude of displacement of the membrane takes larger value at the frequency of 3 or 4 Hz than that of the peak frequency produced by the rectangular pulses, however, the flow rate is about 25% of the maximum value. This indicates that tidy sinusoidal vibration of low frequency near the natural frequency of this coupled system is important to produce efficient transportation. In cases of the rectangular pulses with frequencies of 4 and 5 Hz, nonlinearity can be seen in the displacement of

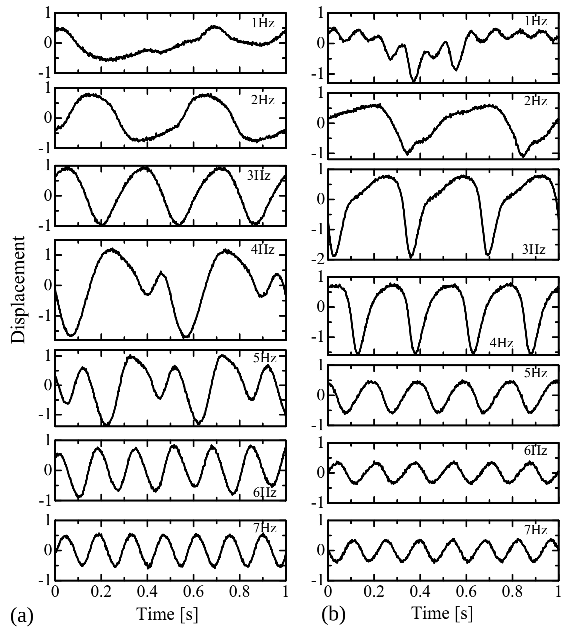

Fig. 3. Displacement of the elastic membrane at the central point of the fluid transportation mechanism. The displacement is normalized by the maximum value (1.67 mm) under the rectangular pulse of frequency 3 Hz. The mechanism is driven by (a) the rectangular pulse and (b) PWM method. The duty ratio of PWM cases is 39%. In both cases, the duty ratio is 39%. The applied electric current is 5 A.

the membranes. The reason why such nonlinearity appears is not clear. In cases of higher frequencies like 5, 6 and 7 Hz, the displacement also changes sinusoidally, however, the flow rates are small compared with the maximum value. It is considered that the carried fluid cannot follow the wavy motions of the membrane because of its inertial effect.

On the other hand, from visual observation of the flow and the membranes, the carried fluid and membranes pulsate at low input frequencies of 0.5 and 1 Hz without the bypaths of the magnetic fluid layers. The observation of the flows and displacement of the membranes under our arrangement leads to the result that the bypaths suppress pulsation of the membrane effectively and produce smooth flow of carried water at low frequencies, 0.5 or 1 Hz.

4. Concluding remarks

The fluid transportation mechanism that is produced by the coupled waves of elastic membranes and magnetic fluids is worked by the progressive magnetic field generated by the simple rectangular pulses. The averaged mass flow rate has peak value at the frequency when the membrane vibrates sinusoidally. This peak frequency does not depend on the duty ratio. To improve flow condition at low frequencies, the bypath of the magnetic fluid layer is useful.

Acknowledgements

This research was partly supported by the Grant-in-Aid for Scientific Research of the Japanese Ministry of Education, Culture, Sports, Science and Technology.

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