Basic Load Characteristics of Magnetostrictive Amorphous Wire Micro-Motor

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***Abstract*—Basic load-characteristics of magnetostrictive amorphous wire micro-motor were measured applying load by sticking a weight on the rotating wire. It was found that the weight of 0.45 g was applicable to the rotating amorphous wire and this weight value gives rise to angular momentum larger by about 2200 times than that of rotating amorphous wire alone.**

***Index Terms*—Amorphous wire, large gyromagnetic effect, magneto-elastic resonance, magnetostriction, micro-motor.**

I. INTRODUCTION

HIGH-SPEED mechanical rotation of magnetostrictive amorphous wire around its wire axis in an ac longitudinal field was reported as a large gyromagnetic effect [1]. So far, an origin of this effect has been attributed to the predominant magneto-elastic effect of amorphous materials [2], [3]. We reported it originates from the magnetostrictive vibration [3]. Because of its simple structure, the micro-motor of amorphous wire is very attractive for micromachine and/or microsensor application. One of potential applications is a gyroscope. To apply to that, it is necessary to increase angular momentum. In the present investigation, we measured the basic load-characteristics of the micro-motor.

II. EXPERIMENTAL

A short piece of amorphous $Co_{50}Fe_{50}$-(Si, B) wire with 37 mm long and 0.3 mm diameter was used for a motor. The saturation magnetostriction of the wire is 15×10^{-6}. The wire was put in a solenoid with 15 mm long as shown in Fig. 1. In the solenoid, the wire was inserted through 0.5 mm diameter holes in PET (poly ethylene terephthalate) film and put on a glass plate on one wire end. The rotation of the wire was observed around the magneto-elastic resonance frequency depending on wire length [3]. Therefore, excitation frequency of a drive field was set around the resonance frequency. Rotational speed was measured by optical method as illustrated in Fig. 1. The wire was put in between a LED (light-emitting diode) and a PD (photo diode). The mechanical configuration of the used wire is not straight strictly. So, the wire rotation blocks the illumination from the LED and generates pulse signal in the PD whose frequency is proportional to the rotation speed of the wire. A load to the motor was applied by putting a weight (clay) with glue on the wire. A weight up to 0.5 g was glued changing position as shown in Fig. 2. A high-speed video camera with rate of 600 frame/s was used to analyze dynamic motion of the rotating wire.

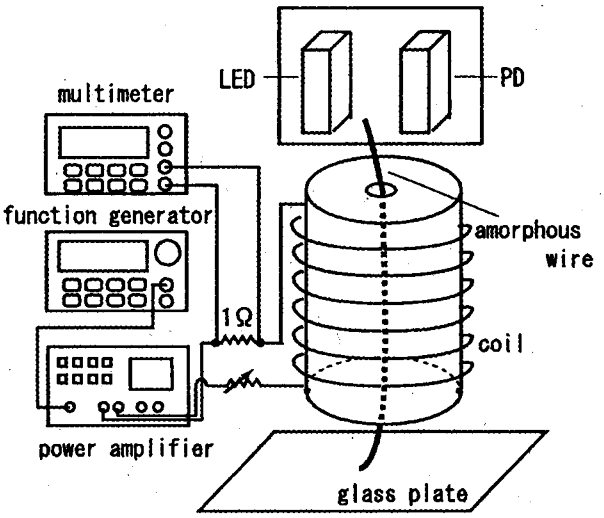
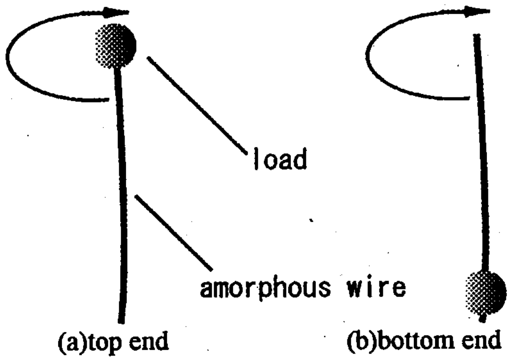


Fig. 1. Experimental set-up for the study.



(a)top end (b)bottom end

Fig. 2. Glued position of the weight.

III. RESULTS AND DISCUSSION

Fig. 3 shows a rotational speed as a function of drive field frequency for wires with and without load (50 mg) in ac drive field of 200 A/m and a dc bias field of 1200 A/m. Amplitude of a dc bias field was chosen such that the maximum rotational speed was obtained [3]. The wire without load can rotate in a frequency range of 63 to 65.4 kHz and exhibit two-peaks characteristic as shown by closed circle in Fig. 3. When a weight position is near the top end, two-peaks characteristic did not change except rotational speed, which goes down to about one-half. However the characteristic was influenced markedly as weight

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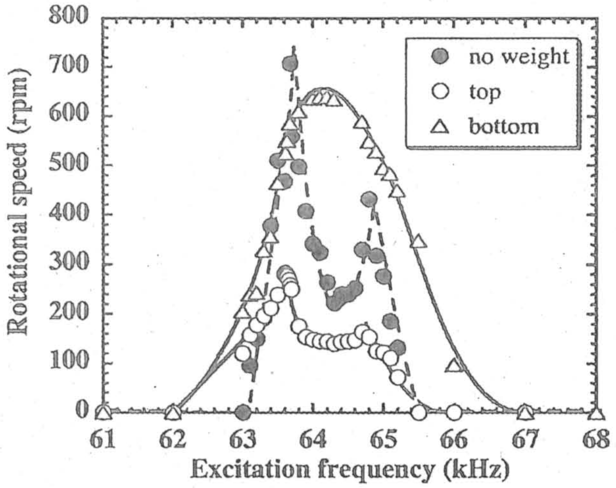


Fig. 3. A rotational speed as a function of drive field frequency for wires with and without load.

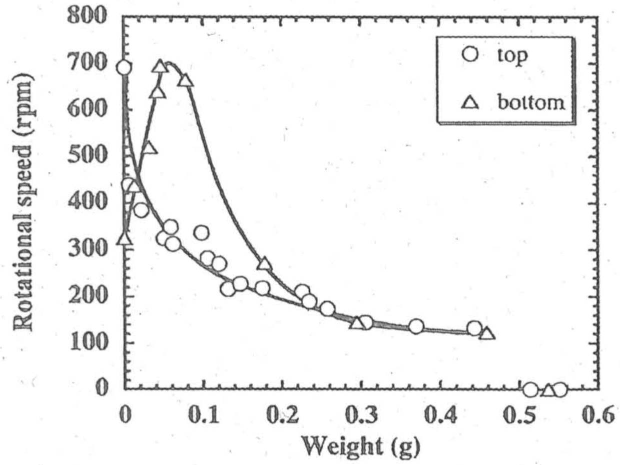
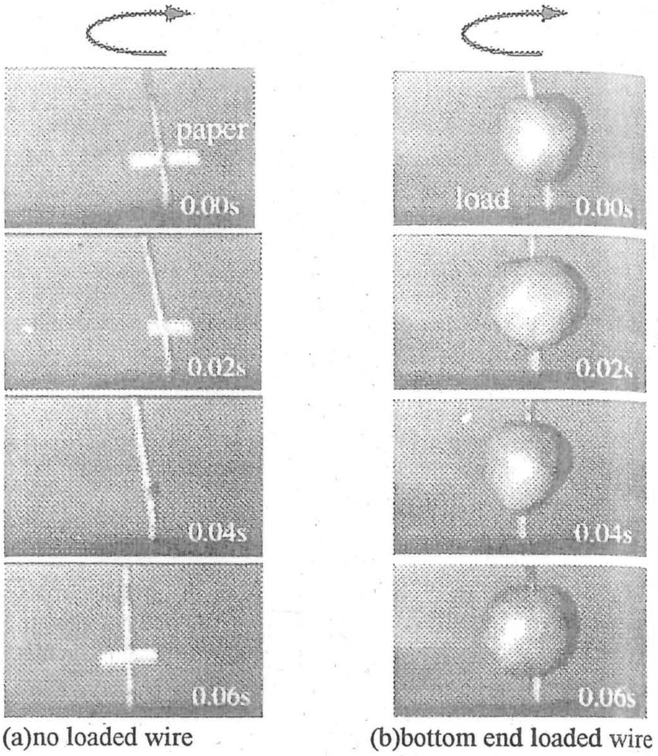


Fig. 4. The rotational speed as a function of weight for the top and bottom end loaded wires.

position shifts toward the bottom end of the wire. The wire with load at the bottom end shows parabolic characteristic with a peak value around $f = 64.3$ kHz. Thus, the wire with load at top and bottom ends exhibits the maximum rotational speeds at 63.7 kHz and 64.3 kHz, respectively. So we chose these drive frequency and measured the rotational speed varying value of weight.

Fig. 4 shows the rotational speed as a function of weight for the wires loaded at the top and bottom end when an ac field of 200 A/m and dc bias field of 1200 A/m were applied. When the weight is increased at the top end of wire, rotational speed deceases exponentially. The maximum applicable weight is 0.45 g, which is about 25 times as large as the weight of rotating amorphous wire. On the other hand, the rotational speed of the wire loaded at the bottom end increases first and takes a peak value at $W = 50$ mg and then decreases rapidly with increasing weight up to 0.45 g, beyond which the wire rotation stops. It is seen that the value of maximum applicable weight does not depend much on the position of the weight. Thus, the frequency and weight dependences of the rotational speed are affected strongly by the position of weight along the wire. This is especially true when the wire is loaded by weight at the bottom end. As seen in Fig. 4, loading of weight of 50 mg increases the rotational speed.



(a)no loaded wire (b)bottom end loaded wire

Fig. 5. A wire motion on the glass plate with and without the load.

To study this effect, dynamic configuration of the wire rotation was observed by a high-speed camera. Fig. 5 shows the pictures near the bottom end of rotating wires without and with the load of weight. Four picture frames were taken in 0.06 second. An ac drive field of 200 A/m at 64.3 kHz and a dc bias field of 1200 A/m were applied simultaneously. The wires without and with the load rotate about 1/3 and 7/10 revolution in 0.06 second, respectively. These rotational speed corresponds to 320 rpm with $W = 0$ g and 700 rpm with $W = 50$ mg, respectively. A piece of small paper was stuck on the unloaded wire for reference. It is clearly seen that bottom end of unloaded wire moves a few mm on a glass plate during 1/3 revolution. While the end of loaded wire does not move much during a revolution. It seems that the difference comes from the difference in position of the center of gravity of the rotating wire and weight. It is considered that the rotation of the wire is driven by magneto-elastic vibration through the contact of the wire with glass and PET (see Fig. 1). Sticking the weight near the bottom end of wire will shift the center of gravity near the contacting point with glass and would stabilize the rotation of wire as observed in Fig. 5(b). This may increase the efficiency of driving force transfer through the contact of wire with glass and increase rotational speed of bottom end loaded wire as seen in Figs. 3 and 4.

In a gyrocompass, mechanical torque is proportional to time derivative of angular momentum. So, the angular momentum of the rotating amorphous wire was estimated based on the measured rotational speed in Fig. 4. The angular momentum of rotating body is defined as [4],

$$L = I\omega \tag{1}$$

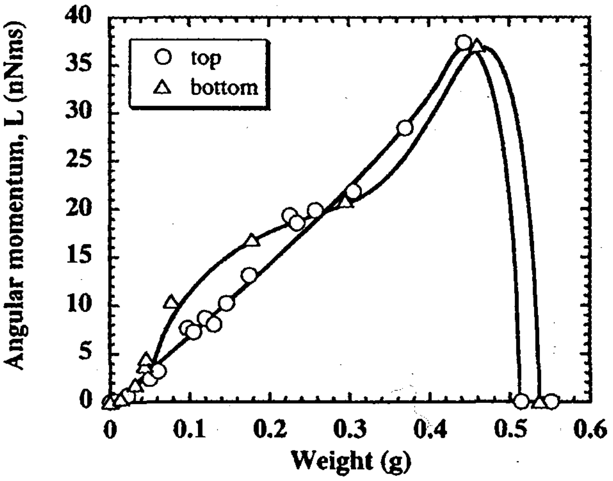


Fig. 6. The angular momentum of the rotating wire with the top and the bottom end load.

where I is the momentum of inertia and w is angular velocity. The I depends on the shape of objects. We assume sphere and cylinder for the shape of weight and wire, respectively. Then, (1) is rewritten as,

$$L = (2/5)MR^2\omega + (1/2)mr^2\omega \qquad (2)$$

where M, m are mass and R, r are radii, respectively, of the weight and amorphous wire. The calculated angular momentum L is shown in Fig. 6 for the wires with the weight at top end and bottom end. The L which is mostly independent of the weight position increases with increasing weight and takes the maximum value of about 37 nNms at $W = 0.45$ g. The angular momentum of the wire without weight is 17 pNms. Therefore, increase in the angular momentum by about 2200 times could be attained by placing the weight on the wire.

The mechanical rotation of amorphous wire originates from the magneto-elastic resonance [1]–[3]. In general, it is difficult to make resonating substance do work because the quality factor: Q is decreased markedly by the external force. As shown in Figs. 3 and 4, light load is applicable to the rotating wire. So the kinetic energy was evaluated for the wire loaded by weight at the wire ends. The kinetic energy of rotating body is defined as

$$E = (1/2)I\omega^2. \qquad (3)$$

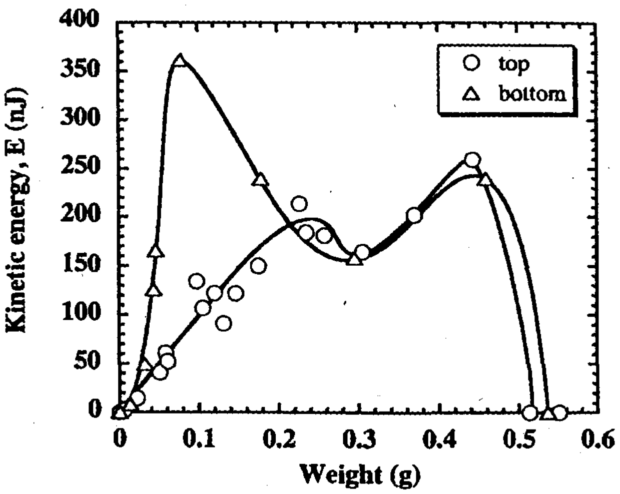


Fig. 7. The kinetic energy of the rotating wires with the top and the bottom end load.

Fig. 7 shows the kinetic energy: E of the rotating wires loaded by weight at the top and bottom end. The wire rotating at 660 rpm with the weight (0.1 g) at bottom end exhibits the maximum E of 360 nJ. While, the E of the wire rotating at 700 rpm without the load is 0.6 nJ. The kinetic energy with energy of the rotating wire driven by the magneto-elastic resonance can be increased markedly by choosing the loading position properly.

IV. CONCLUSIONS

Fundamental load-characteristics of amorphous wire micromotor were measured by sticking the weight on the wire. The maximum weight applicable to the wire rotating at 120 rpm was 0.45 g. Increase in the angular momentum by about 2200 times could be attained by sticking the weight on the wire end.

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