Magnetic Twisting Ball Display Method Using Resin Ball with Magnetic Coating Layer
-A Candidate Method for Electronic Paper-

Masakatsu Okawa, Makoto Omodani*,** and Kenji Kono****
*Course of Optics and Photonics, Department of Applied Science, Tokai University
**Tokai University Future Science & Technology Joint Research Center
***Hitachi Maxell, Ltd.
Kanagawa, Japan*

Abstract

Targeting the creation of magnetic twisting ball displays, we confirm the performance of a technology that partially coats white resin balls with a magnetic layer to form the contrasting black hemispheres. Control experiments verify that such balls can be magnetically driven and that power off steady state displays is possible by suspending the balls in a thixotropic fluid of appropriate viscosity. An experimental display sheet is prepared using the balls and thixotropic suspension fluid; rewriting and image holding performances are confirmed using a 3 by 5 driving unit with 15 electromagnets. The relations between driving pulse width and the display characteristics elucidate the minimum pulse width required for image switching.

1. Introduction

The amount of digital information continues to increase due to the rapid adoption of the Internet. Electronic Paper looks to be an ideal way of allowing this increasing amount of digital information to be read comfortably. This study addresses a magnetic twisting ball display system, which is a promising candidate for Electronic Paper. This paper focuses on the basic characteristics of ball rotation and fixation. A segment type display panel is then tested.

2. Principle

The principle of the magnetic twisting ball display is shown in Fig. 1. It is generally easier to drive balls magnetically than electrically, because of the ease of preparing magnetic dipoles on the balls.

We suggested a resin-based magnetic coating as the black hemisphere of the ball.[4] Conventional metal oxide balls tend to have the demerit of slow response due to their considerable inertia.

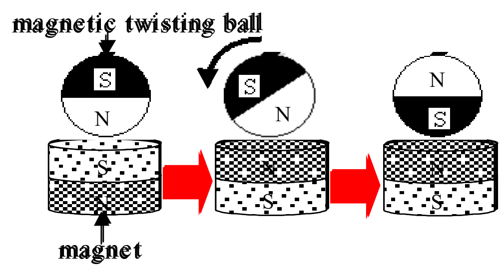

Figure 1. Principle of rotation of a magnetic twisting ball

3. Experiment

3.1 Ball Rotation and Fixation Using Thixotropic Fluid

We tested ball rotation with an applied magnetic field, and ball fixation without magnetic field. A thixotropic fluid was used to realize both ball rotation and ball fixation. The viscosity of this fluid increase with shearing speed.

Experimental Methods

Figure 2 shows the apparatus used to observe the rotation behavior of the balls. Hundreds of balls were suspended in thixotropic fluid filled in a cylindrical test cell. Experimental conditions are listed in Table 1. A solenoid coil was set under the cell to drive the balls. The minimum value of magnetic flux density required for ball rotation was measured. The minimum values were not the same for all balls in the cell. We measured sets of two values: values for the fastest ball and that for the slowest ball. Time taken to complete ball rotation was also measured. Ball behavior was video taped using a digital microscope set above the cell. Six thixotropic fluids were created by adding different levels of silica to the same fluid stock. Measured viscosity values of the fluids tested are shown in Fig. 3. Thixotropic characteristics of tested fluids are indicated as viscosity values at two different viscometer rotation speeds: 6rpm, and

60rpm. Ball fixation was tested by cutting the driving magnetic field when the black hemisphere, the heavier hemisphere, was facing upward. Ball fixation was judged using the criteria that ball re-rotation should not occur within 10 seconds after the magnetic field was cut.

Table 1. Contents of Test Items

Item	Contents
Fluid	Silica distributed hydrocarbon (Isoper-M)
Ball	Acrylic (20 to 200 μm)
Cell	Diameter: 40 mm, Height: 5 mm
Coil	Solenoid coil of 100 turns of 0.35 mm φ enamel coated wire, Diameter: 6 mm, Height: 10 mm

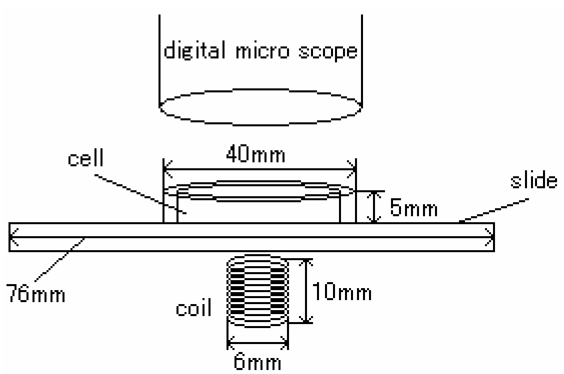

Figure 2. Experimental apparatus for measuring ball behavior

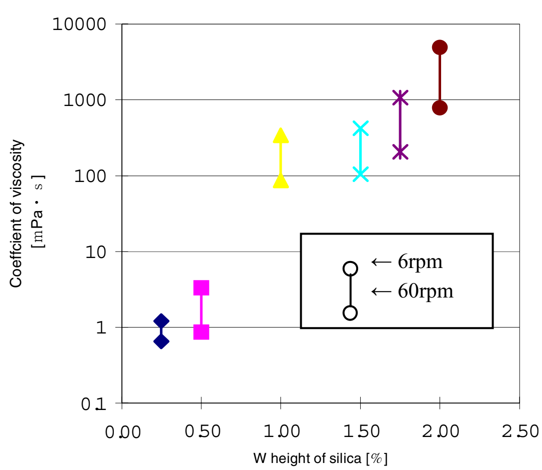

Figure 3. Measured viscosity of thixotropic fluid

Measured Results

Figure 4 shows measured ball rotation time required for bi-stable rotation in each thixotropic liquid. It is shown that the differences in rotation times decrease as the magnetic field increases. Figure 5 shows the measured minimum magnetic field strengths required for ball rotation. Results on ball fixation are also shown in Fig. 5: two liquids with higher viscosity (weight of silica: 1.75% and 2.0%) showed fixation without magnetic field. The realization of both ball rotation and fixation was achieved with the two highest viscosity thixotropic fluids. This means that a display can be created that offers image conservation without power consumption.

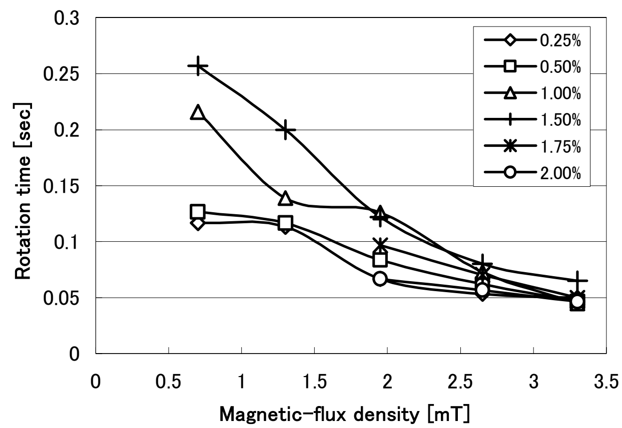

Figure 4. Response characteristics of display balls

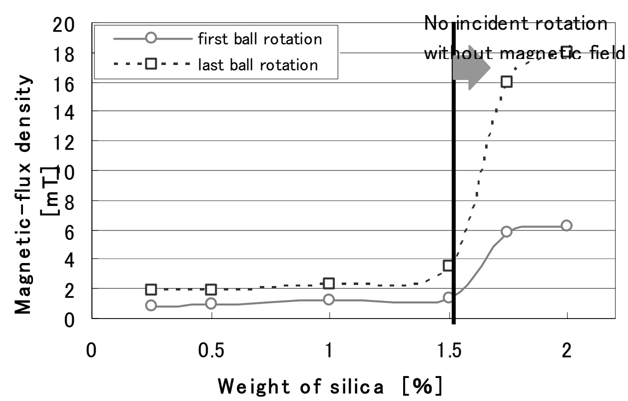

Figure 5. Minimum magnetic flux density necessary for balls rotation

3.2 Rewriting Tests on Prototype Display

Experimental Method

An experimental display unit with 15 segments was prepared. The balls used were special in that the black area was smaller than the white area: ball materials and size were the same as those of the first experiment. These balls were intended to realize better white reproduction at the cost of slightly worse black reproduction. Figures 6 and 7 show the experimental display unit and the arrangement of the coils. We prepared 15 sets of driving coils, which was constructed with 30 turns of enameled wire (diameter: 0.35 mm) and iron core (diameter: 2 mm). A thixotropic liquid, viscosity [570 mPa・s (6 rpm) , 71mPa・s (60 rpm)], was used. A display area of 3 cm × 3 cm was prepared by using two sheet (thickness: 188 µm) of PET film. Directions of magnetic fields formed by each coil unit were controlled by switches wired to each coil.

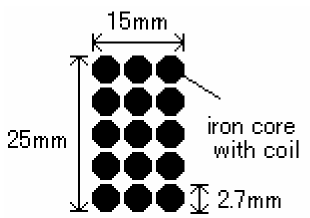

Figure 6 Arrangement of driving coils

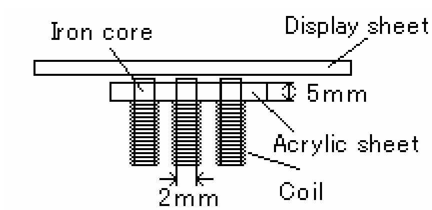

Figure 7. Experimental display unit of 15 segments

Experimental Result

Figure 8 shows typical images (numerals "2" and "8"): enlarged portions are shown in Fig. 9. No image degradation was observed in one week period.

Figure 8. Results of writing test

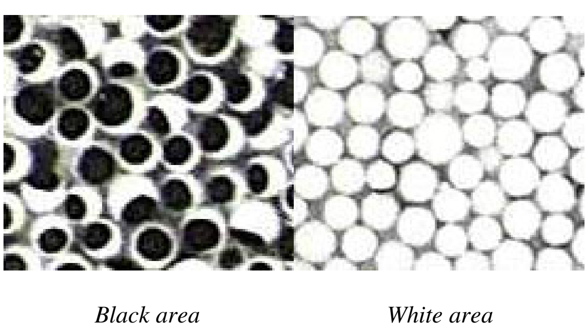

Figure 9. Enlarged portions of a displayed image

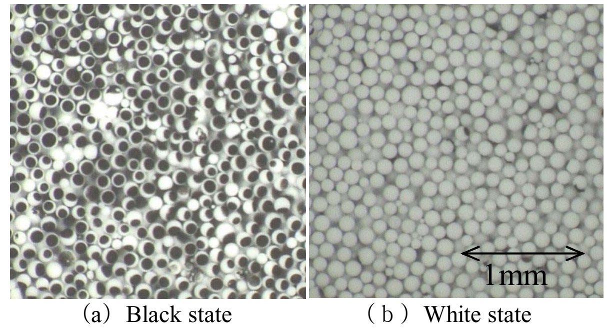

Figure 10. Appearance of display sheet (T = 500 ms)

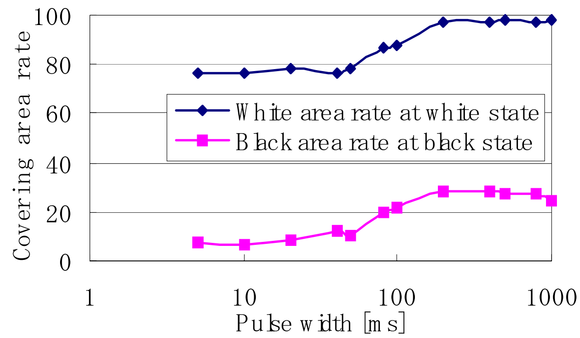

Figure 11. Rates of covering area

3.3 Evaluation on Required Driving Pulse Width

Power consumption of this display system depends on the pulse width required for ball rotation. The relation between driving pulse width and ball rotation behavior was evaluated by experiments.[5]

Experimental Method

The display sheet was the one used in the previous experiment. Image refreshing between full black and full white was tested. Driving magnetic field was applied using a 100 turns of coil wound around an iron core of diameter 20 mm. Pulse widths ranging from 5 to 1000 msec were tested at a driving current of 1.2 ampere applied to the coil circuit. Covering rates of white area and black area were measured in the display area.

Measured Result

Figure 11 shows covering rates for the various driving pulse widths. Maximum black and white coverage is possible if the pulse width exceeds 200 msec.

4. Discussion

Our basic study has confirmed that our magnetic twisting ball display technology can yield bi-stable display characteristics. However, it should be added that the weak point of our prototype display unit is the defocusing of the magnetic field.

Further effort is needed to improve the resolution, power consumption, and display system integration.

5. Conclusions

1. By using a thixotropic suspension liquid with suitable viscosity, it is possible to create magnetic twisting ball displays that offer both ball rotation and image retention.
2. An experimental display unit with 15 segments was prepared and shown to offer rewriting and power-free retention of numerals.
3. Relations between driving pulse width and display characteristics were measured; the minimum pulse width required for image switching was elucidated.

References

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Biography

Masakatsu Okawa was born in 1980. He received his B.S. degree in 2003 from Tokai University. He is expected to receive his M.S. degree from graduate school of Tokai University in 2005. He is now engaged in a study of magnetic twisting ball display.