Experimental Study on the Magnetic Force Acting on the Toner Using an Enlarged Model in Magnetography

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Abstract

This paper describes an experimental simulation on the magnetic force acting on the magnetic toner in magnetography with longitudinal recording. The author has presented some calculative simulations on the magnetic force acting on the toner from the magnetic latent image of the recording medium. Since it is difficult to measure the real magnetic force, a simulative experiment was carried out using an enlarged model. The results of the experiment and the calculations were compared. In the experimental apparatus, some of the rectangular permanent magnetic bars were arranged in line and they were likened to the recording medium. A steel ball was likened to a magnetic toner. An enlarged model of about 1000 times was made. The attractive force between the magnetic bars (recording medium) and the steel ball (toner) were measured by a balance. As a result it was found that the attractive force between the recording medium and the toner is very strong at the transition regions of the recording medium and weak at the intermediate region between the adjoining transition regions. However, the attractive force between the toners next to each other is fairly strong at the intermediate regions between the transition regions of the recording medium. As a result, the toner bridge is formed between the adjoining transition regions to form solid black.

Introduction

It is one of the most important subjects to know the magnetic force acting on the magnetic toner from the magnetic latent image. The author has presented some calculative simulations on the magnetic force acting on the toner from the magnetic latent image of the recording medium in magnetography with longitudinal recording.[1-5] Since it is difficult to measure the real magnetic force, a simulative experiment is carried out using an enlarged model. The results of the experiment and the calculations are compared to make sure that the calculative simulations are proper.

Method of Study

Figure 1 shows a schematic diagram of the experimental apparatus. This is for measuring magnetic force acting on an isolated magnetic toner. Some of the rectangular permanent magnetic bars are arranged in line and they are likened to the recording medium with latent image. A steel ball is likened to a magnetic toner. The magnetic bars are arranged with the same magnetic poles next to each other. Transition regions are generated at the region of the magnetic poles. Magnetic flux rises from a transition region of the north pole of the magnetic bar into the air and returns to the transition region of the south pole of the magnetic bar. A steel ball which is positioned in the air is magnetized and it is attracted to the magnetic bars. The magnetic bars are arranged on a three dimensional stage and the position of the steel ball to the magnetic bars is adjusted. The attractive force between the magnetic bars (recording medium) and the steel ball (toner) are measured by a balance.

A fishing line is penetrated through the hole of the steel ball. The steel ball is hanged from one end of the balance and a weight is hanged at the other side. If the weight is lighter than the attracting force between the steel ball and the magnetic bar, the steel ball remains on the magnetic bar. If the weight is heavier than the attracting force between the steel ball and the magnetic bar, the steel ball is separated from the magnetic bar. At the moment when the steel ball is separated from the magnetic bar by adding a small weight, the current whole weight is employed as the attracting force between the steel ball and the magnetic bar.

The dimension of the magnetic bar, the steel ball and the weight is as follows.

magnetic bar: 50*10*10mm(L*H*D)
Fe-Al-Ni-Co alloy
steel ball: 9.5mmϕ, with a hole, 3.18gf
without a hole, 3.48gf
weight: 100mgf -200gf

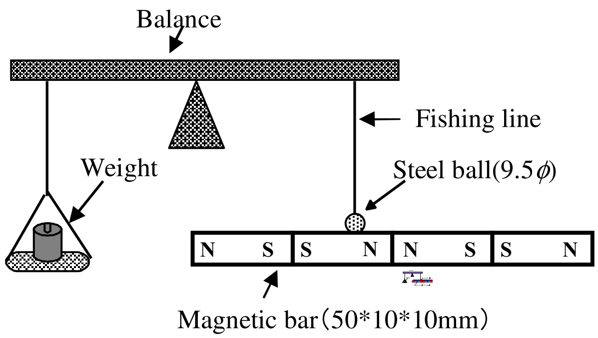

Figure 1. Arrangement of the experimental apparatus

If the toner size is assumed to be 10μmϕ, the steel ball with 9.8ϕ becomes about 1000 time enlarged model. Since the distance between the adjoining magnetic poles of the magnetic bars is 50mm, a half dot size becomes 50 mm and one dot size becomes 100mm. 100mm in 1000 time enlarged model corresponds to 100μm in real size. Therefore one dot size is 100μm and the pixel density becomes 254dpi. The pixel density of 254dpi is employed in the following calculations.

Figure 2 shows a schematic diagram of the second experimental apparatus. This is for measuring magnetic force acting on adjacent magnetic toners. A lot of steel balls cover the surface of the magnetic bars. As shown in Fig. 3, when the measuring ball with fishing line begins to be separated from the magnetic bar, the adjoining balls also tend to go with the measuring ball, because the adjoining balls are attracted each other. In order to lift only the measuring ball, a ball holder is arranged to hold the adjoining balls as shown in Fig. 4. As a result, only the measuring ball can be separated.

Figure 5 shows the measured distribution of the magnetic force acting on an isolated ball in the experiment apparatus shown in Fig. 1. The force at the region near the magnetic poles of the magnetic bar is very strong, while the force at the intermediate region between the adjoining magnetic poles is very weak. Figure 6 shows the calculated distribution of the magnetic force acting on an isolated magnetic particle.

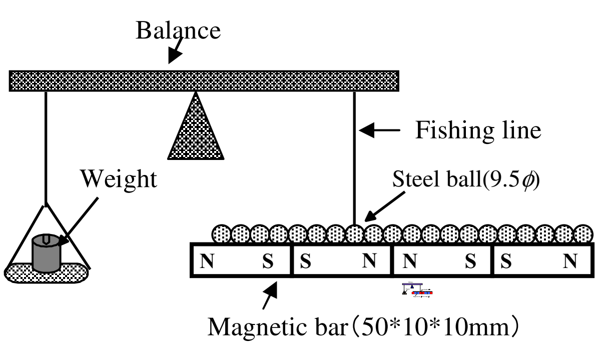

Figure 2. Arrangement of the experimental apparatus (2)

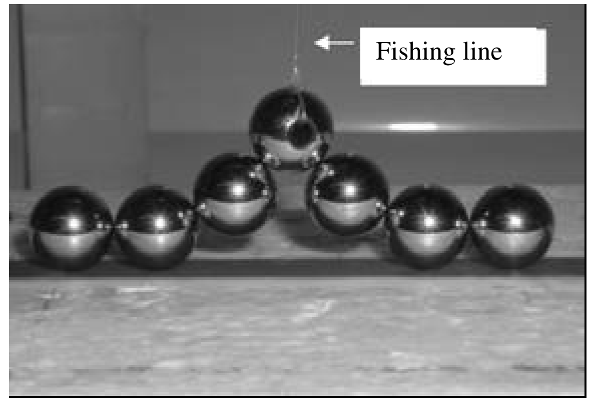

Figure 3. Photograph showing the adjoining balls are lifted together

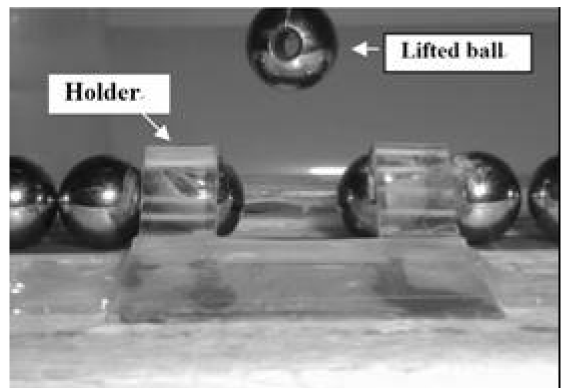

Figure 4. Photograph showing only one ball is lifted separately

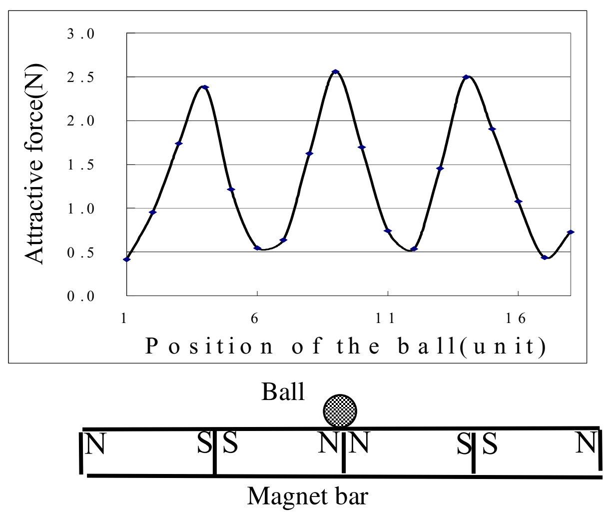

Figure 5. Distribution of the Magnetic force acting on an isolated ball (experiment)

The calculation was carried out using the following equation which has been described in my previously published paper.[1]

The magnetic force acting on a magnetic particle at a point is calculated as follows:

$$F = \chi H \times dH/dr \quad (1)$$

where F: magnetic force acting on the magnetic particle per unit volume, H: synthesized magnetic field at the point of the magnetic particle, r: location of the magnetic particle, χ: effective susceptibility of the particle including demagnetization factor.

In Fig. 6, Z_s means the distance from the surface of the recording medium and Z_s=5μm corresponds to the center point of the toners of the first layer since toner size is 10μm.

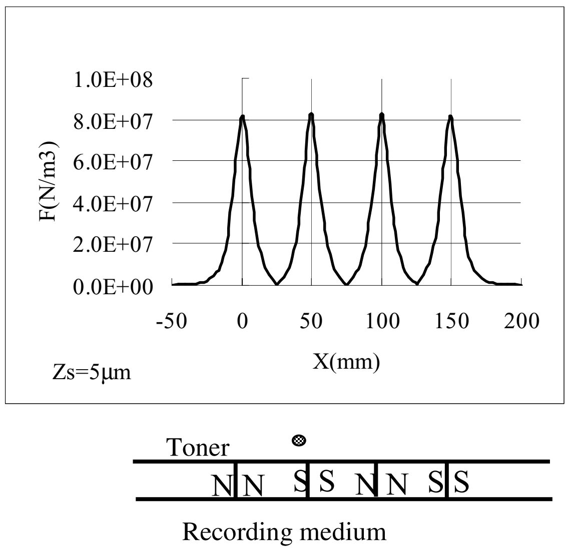

Figure 6 Distribution of the Magnetic force acting on an isolated toner (calculation)

The shapes of the both graphs resemble well. In the calculated result the magnetic force at the intermediate point is zero. It means that the magnetic particle at the intermediate point is attracted from both adjoining poles by equal strength with opposite direction and the total force becomes zero. The measured result did not show zero. That is because it was difficult to position the magnetic ball right in the middle point between the adjoining magnetic poles. Therefore measuring error is occurred.

Figure 7 shows the measured distribution of the magnetic force acting on a ball in the adjoining balls by the experiment apparatus shown in Fig. 2. The force at the region near the magnetic poles of the magnetic bar is very strong, and the force at the intermediate region between the adjacent magnetic poles is also fairly strong. The latter is different from the case shown in Fig. 5.

Figure 8 shows the calculated distribution of the magnetic force acting on a magnetic toner in the adjoining toners. The calculation was carried out using the following equation (2) which has been described in my previously published paper.[2] It was calculated as an attracting force in the ring shaped magnetic circuit which is comprised of a permanent magnet part (recording medium) and a magnetically soft material part (toner layer).

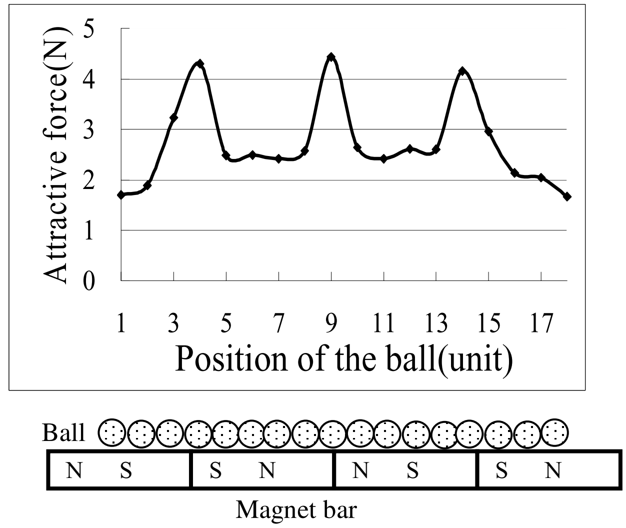

Figure 7 Distribution of the Magnetic force acting on a ball in the adjoining balls (experiment)

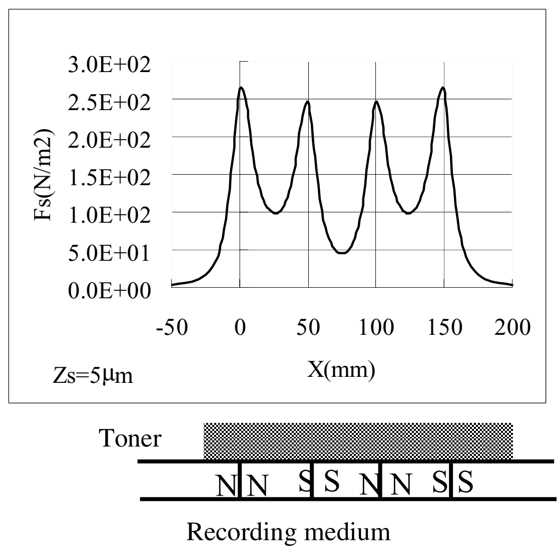

Figure 8 Distribution of the Magnetic force acting on a toner in the adjoining toners (calculation)

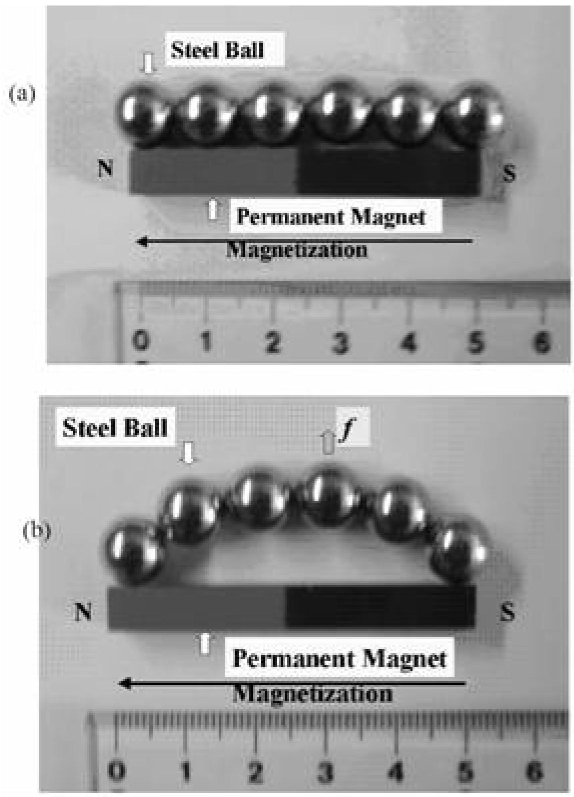

Figure 9. Photographs of an enlarged model showing the toner bridge is formed between the adjoining magnetic poles of the recording medium

Magnetic force per unit section area, *Fs*, in the magnetic circuit is expressed as follows.

$$Fs=B^2/2\times(1/\mu_0-1/\mu) \quad (2)$$

where B: magnetic flux density of the toner layer, μ_0: permeability of vacuum, μ: permeability of the toner layer

The shapes of the both graphs resemble well.

Figure 9 shows photographs which indicate the way of attraction of the magnetic bars and the magnetic balls in an enlarged model. It shows a magnetic bar and some steel balls.

As shown in Fig. 9 (a), a bridge of steel balls is formed in the region between the opposite magnetic poles at the opposite ends of the permanent magnetic bars. It seems at a glance that each ball is attracted to the permanent magnetic bar. However, as shown in Fig. 9 (b), if a small force is added to the balls to separate the balls from the magnetic bar, the balls at the end of the magnetic bar will not be separated from the bar, while the balls at the intermediate region are separated easily from the permanent magnet. However, they are not separated from the adjoining balls. As shown in Fig. 10, the toners are magnetized by magnetic flux which rises from the north pole of the recording medium and returns to the south pole of the recording medium through the toner bridge. The magnetic charges appear at the surface of the toners by magnetization. The toners next to each other are attracted themselves because they have opposite poles respectively at the contact areas.

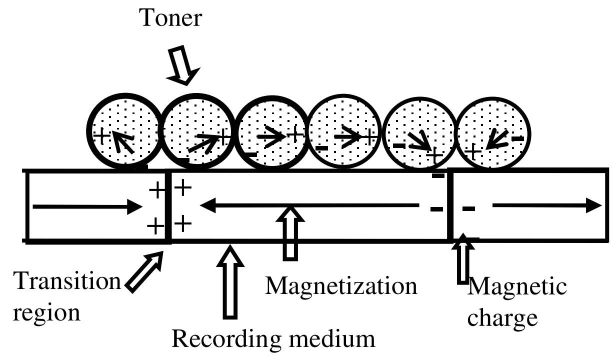

Figure 10. Toner attraction model showing the toner bridge is formed between the adjoining magnetic poles of the recording medium

In summary, attractive force between a toner and the magnetic recording medium is very strong only near the transition region of the recording medium and becomes weak rapidly as the position is away from the transition region, while a fairly strong attractive force works between the toners next to each other at the intermediate area between the adjoining transition regions of the recording medium. As a result the toner bridge is formed between the adjacent transition regions and solid black can be obtained with desired size.

Conclusion

A simulative experiment for measuring the magnetic force acting on magnetic toner was carried out using an enlarged model. Rectangular permanent magnetic bars were likened to the recording medium. A steel ball was likened to a magnetic toner. An enlarged model of about 1000 times was made. The following results are obtained:

(1) Attractive force between the recording medium and the toner is very strong at the transition regions of the recording medium and weak at the intermediate region between the adjoining transition regions.
(2) Attractive force between the toners next to each other is fairly strong at the intermediate regions between the transition regions of the recording medium.
(3) As a result, the toner bridge is formed between the adjoining transition regions of the recording medium to form solid black.

Since the results of the experiment resemble those of the calculations well in the shape of the graphs, it is ascertained that the calculative simulation the author has presented heretofore is proper.

References

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Biography

Norio Kokaji received the B.E. and Ph.D. degrees from Tohoku University, Japan in 1965 and 1991, respectively. He joined Hitachi Koki Co., Ltd. and Iwatsu Electric Co., Ltd., in 1965 and 1969, respectively. Since 1997 he has been a professor of Meisei University. His work has primarily focused on R&D of printing technology, especially magnetography. His works include almost the whole areas of magnetography using longitudinal recording. Recently his interest is also in R&D of magnetic display as an electronic paper. E-mail:kokaji@ee.meisei-u.ac.jp