Analysis of the Magnetic Force Acting on the Magnetic Toners from the Adjoining Magnetic Transition Regions in Magnetography

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Abstract

This paper describes the magnetic force acting on the magnetic toners from the magnetic latent images of the adjoining magnetic transition regions with longitudinal recording. It is found that large magnetic force emerges around each center of the transition regions, whereas magnetic force becomes zero in the middle region between the adjoining transition regions. According this result, it seems that magnetic toners might be attracted only the near region of the center of the transition regions and no toner in the middle region between the adjoining transition regions. Experimentally, however, the toners cover the latter region also. Here, a new model is introduced. In the model, a closed magnetic circuit is formed comprising magnetic toners and the recording medium. The toners are attracted each other due to magnetic induction to form toner bridge between the adjoining transition regions. It is found that the magnetic attracting force in the toner bridge is about 300 times larger than the gravitational force.

Introduction

It is one of the most important issue to know the magnetic force acting on magnetic toner from the magnetic latent image. The magnetic force from an isolated magnetic transition region of the recording medium was already discussed.[1,2] This paper describes the magnetic force generated from the adjoining magnetic transition regions with longitudinal recording. A new model of a magnetic circuit comprising toners and the recording medium is introduced.

Method of Analysis

Fig. 1 shows the coordinate system. For the purpose of simplification, it is assumed that the recording medium is magnetized only in the x-direction and that the dimension in the y-direction is sufficiently larger than the thickness of the recording medium. The y-direction is extended from the surface of the paper to the back of the paper.

The equations of magnetization function, magnetic field and magnetic force are the same as employed in my previously reported paper.[2] Arctangent function is employed as the magnetization function of the transition region.

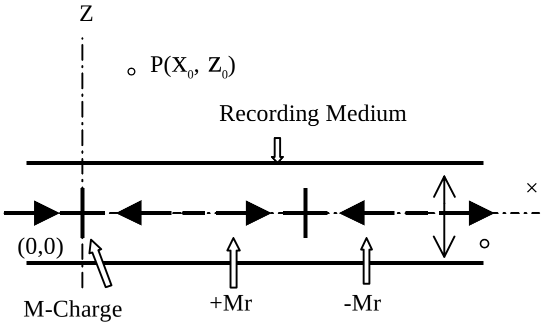

Figure 1. Coordinate system

The magnetic field generated from each transition region is expressed by the following equations.

$$H_x(x,z) = M_r/\pi\mu_0 \times [tan^{-1}\{(z+\delta/2+a)/x\} - tan^{-1}\{(z-\delta/2+a)/x\}] \quad (1)$$

$$H_z(x,z) = M_r/2\pi\mu_0 \times \ln[\,\{x^2+(z+\delta/2+a)^2\}/\{x^2+(z-\delta/2+a)^2\}] \quad (2)$$

Or the following approximate equations(2)can be also used.

$$H_x(x,z) = M_r\delta/\pi\mu_0 \times x/r^2 \quad (3)$$

$$H_z(x,z) = M_r\delta/\pi\mu_0 \times (z+a)/r^2 \quad (4)$$

Where, M_r: residual magnetization in the recording medium, μ_0: permeability of vacuum, r : distance from the assuming charge center $(0,-a)$ to the point P(x_0,z_0), a: transition constant.

Each magnetic field which emerges from each transition region are superposed to form the resultant magnetic field at the point, P(x_0,z_0). Then the magnetic force acting on a magnetic particle at the point, P(x_0,z_0), is calculated as follows:

$$F = m \times dH/dr = \chi H \times dH/dr \quad (5)$$

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, m: magnetic moment which is induced in the magnetic particle and $m=\chi H$, χ: effective susceptibility of the particle including demagnetization factor.

When there are adjoining transition regions, demagnetizing magnetic field, H_d, is generated. The direction of the demagnetizing magnetic field H_d is opposite to that of the magnetization M_r. As a result, the magnetization of the recording medium is reduced. The reduced magnetization M_r' is employed in the above equations in stead of M_r.

Calculations are effected using the above equations and table 1. The values of table 1 are the typical values employed in the magnetic printer with longitudinal recording.[2,3]

Table 1. Values of the parameters used for calculation of the magnetic force

Recording medium	Co-Ni-P
Thickness	$\delta=1\mu m$
Residual magnetization	$M_r=0.8Wb/m^2$
Demagnetized magnetization	$M_r'=0.55Wb/m^2$
Coercive force	$H_c=32kA/m$
Toner	
Susceptibility	$\chi=1.58\times10^{-6}H/m$
Relative permeability	$\mu_s=2$
Pixel density	400dpi

The Result of the Calculations and Studies

The result of the calculations are shown in Fig.2-6. In these figures *z* of $10\mu m$ is employed. The average diameter of the toner is about $10\mu m$ and this value of *z* is about center of the toner layer with the thickness of about $20\mu m$. And the distance between the adjoining transition regions is $30\mu m$. The center of the positive magnetic charge is assumed at $x=0\mu m$ and that of the negative magnetic charge is at $x=30\mu m$. The middle point between the adjoining transition regions is at $x=15\mu m$.

According to Fig. 2-4, the x-component of the magnetic field H_x becomes stronger inside of the adjoining transition regions than that of outside, because each magnetic field H_x from each magnetic charge has the same direction in this region, whereas it has the opposite direction in the outside.

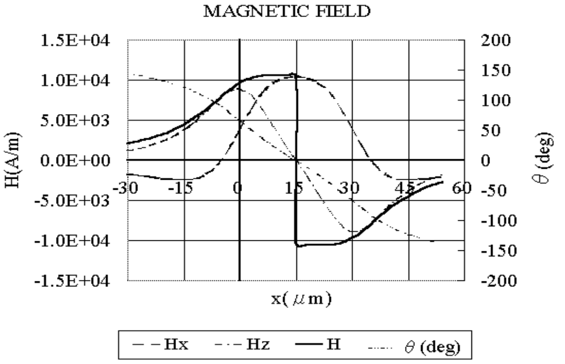

Figure 2. Magnetic field distribution

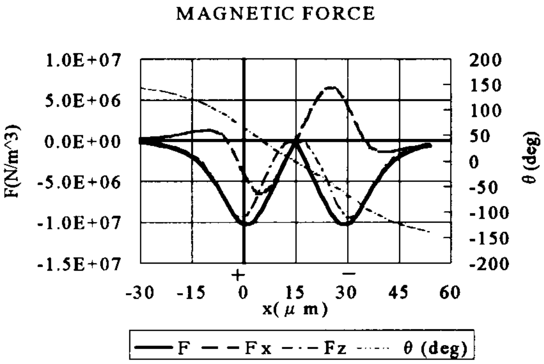

Figure 3. Magnetic force distribution

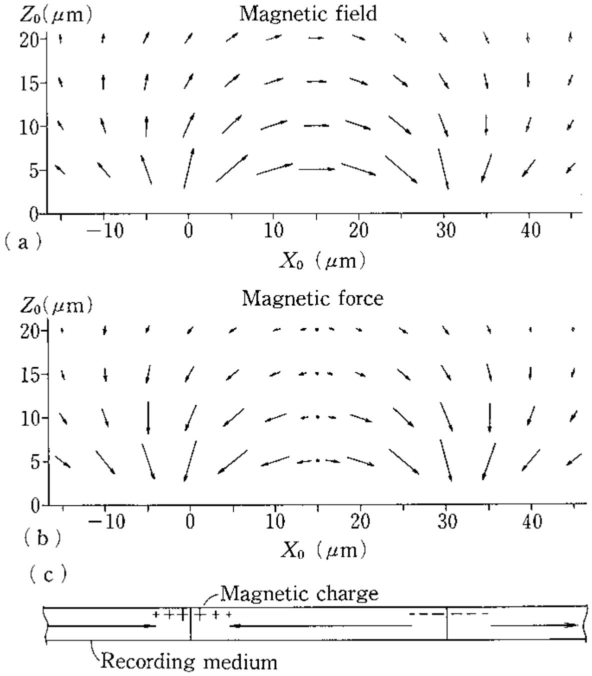

Figure 4. Vector expression of the magnetic field and the magnetic force distributions

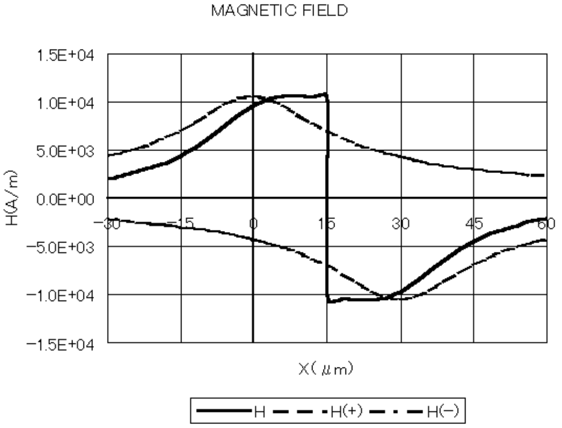

Figure 5. Magnetic fields from the isolated transition region and the adjoining transition regions

As shown in Fig. 5, while the synthesized magnetic field *H* becomes stronger inside of the adjoining magnetic charges than those of isolated magnetic charge, the magnetic field *H* becomes weaker outside of the adjoining magnetic charges than those of isolated magnetic charge.

According to Fig. 3, 4(b) and 6, all of the magnetic force F_x, F_z, and *F* become weaker than those of isolated magnetic charge in the whole region. Each magnetic charge attracts a magnetic particle to its own region. As a result, the magnetic force becomes zero at the middle point $x=15\mu m$, because each magnetic force is balanced at the middle point.

It seems that the magnetic toners are attracted only the near regions of the center of the transition regions. Because the magnetic force *F* is strong only at the near regions of the center of the transition regions and becomes zero at the middle point between the adjoining transition regions. Experimentally, however, the magnetic toners cover the whole region between the adjoining transition regions.

It is considered as follows. Magnetic charges are induced in the toners by the magnetic field between the adjoining transition regions. As shown in Fig.7(a), for example, negative magnetic charge is induced at an end of the first toner at $x=0\mu m$ and positive magnetic charge is induced at another end of the toner in turn. Then negative magnetic charge is induced at one end of the next toner and positive magnetic charge is induced at another end of the second toner. One end of a toner and another end of the next toner are attracted each other due to their opposite polarity one after another and finally a toner bridge is formed between the adjoining transition regions.

A closed magnetic loop is formed by the recording medium and the toner layers. This resembles a magnetic circuit which comprises a permanent magnet and a magnetically soft bar as shown in Fig.7(b). The recording medium corresponds to the permanent magnet and the toner layers corresponds to the magnetically soft bar.

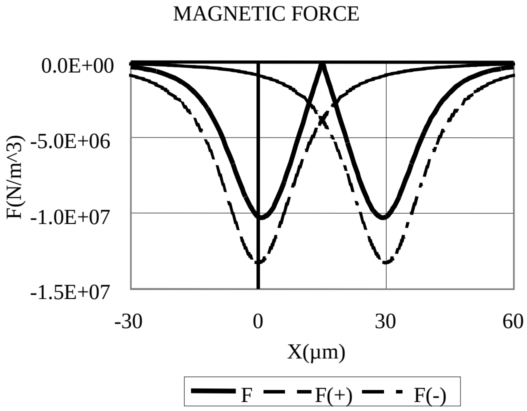

Figure 6. Magnetic forces from the isolated transition region and the adjoining transition regions

The attracting force between the adjoining toners in the toner bridge is calculated as follows:

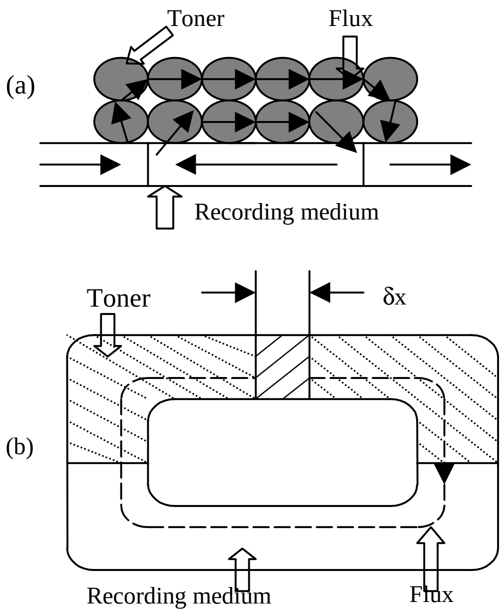

Figure 7. A model of a magnetic circuit comprising the toners and the recording medium

In Fig. 7(b), it is assumed that the part of the toner bridge is separated by δx by applying force *F*. *F* is equal to the attracting force between the adjoining toners. Magnetic force per unit section area, *Fs*, in the magnetic circuit is expressed as follows.

$$Fs=B^2/2\times(1/\mu_0-1/\mu) \qquad (6)$$

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

Since the magnetic toners cover the recording medium, image magnetic charge is generated and the magnetic flux density of the toner layer is expressed as follows.

$$B=2\mu/(\mu+\mu_0)\times\mu_0 H \qquad (7)$$

The magnetic attracting force in the toner layer at the middle point $x=15\mu m$ is obtained using the equation (6)-(7).

$$Fs(15,10)=61.5\ N/m^2 \qquad (8)$$

Assuming that the toner is cubic and a side is 10μm long, the section area of a toner is $10^{-10}m^2$ and the magnetic attracting force acting on a toner between adjoining toners is obtained as follows;

$$f\,s(15,10)=6.15\times10^{-9}\,N \qquad (9)$$

According to Fig. 3, the magnetic force acting on a magnetic particle at the point (0,10) is obtained as follows.

$$f(0,10)=1.02\times10^{-8}\,N \qquad (10)$$

Comparing equations (9) and (10), the magnetic force between adjoining toners at the middle point between adjoining transition regions is not zero but about 60% of the magnetic force between the toner and the recording medium near the center of the transition region. In addition, since the weight of a toner, that is gravitational force, is $w=2.1\times10^{-8}$ N, the ratio of the magnetic force vs. the gravitational force is obtained as follows.

$$f s(15,10)/w=300 \tag{11}$$

$$f(0,10)/w=500 \tag{12}$$

It is found that the magnetic force between the adjoining toners is about 300 times of the gravitational force.

Conclusion

The magnetic force acting on the magnetic toners from the adjoining magnetic transition regions with longitudinal recording is theoretically analyzed. For analysis a new model of a closed magnetic circuit which comprises the recording medium and the toners is proposed. The result of the analysis is coincident with the experimental fact.

(1) The synthesized magnetic force becomes weaker than that of an isolated transition region and becomes zero at the middle point between the adjoining transition regions.
(2) In the region between the adjoining transition regions, the adjoining toners are attracted each other due to magnetic induction in toners and toner bridge is formed.
(3) The magnetic attracting force in the toner bridge is about 300 times larger than the gravitational force. .

References

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2. N. Kokaji, *Proc. NIP-14*, IS&T, 1998,pg.349.
3. N. Kokaji et.al, *Proc. NIP-1*,SPSE, 1981,pg.769.

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., Iwatsu Electric Co., Ltd., and Meisei University in 1965, 1969 and 1997, respectively. At present he belongs to Department of Electrical Engineering of Meisei University as a professor. He has been engaged in R&D of printing technology, especially magnetography. His works include almost the whole areas of magnetography using longitudinal recording.
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