

Analysis on the Effect of the Thickness of the Recording Medium on Magnetic Force in Magnetography with Longitudinal Recording

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Abstract

This paper describes the effect of the thickness of the recording medium on magnetic force acting on the magnetic toner in magnetography with longitudinal recording. The thickness of the magnetic recording medium is one of the important factors in forming image. It has been reported that increasing the thickness leads to increasing the magnetic force acting on the magnetic toner from the isolated transition region in the recording medium. However, in the case of high resolution, the effect of the demagnetization phenomenon increases due to the closer adjacent transition regions. In the demagnetization phenomenon, increasing the thickness acts to decrease magnetization of the recording medium, which in turn acts to make the magnetic force lower. In this study the optimum thickness is found, considering the above conditions. While increasing the thickness acts to increase the magnetic force in the thinner thickness than the optimum thickness, increasing the thickness acts to decrease the magnetic force in the thicker thickness than the optimum thickness.

Introduction

The magnetic force acting on a magnetic toner from an isolated magnetic transition region of the recording medium and the magnetic force from the adjoining magnetic transition regions were already discussed in typical longitudinal recording magnetography.[1,2] This paper describes the effect of the thickness of the recording medium on the magnetic force. If the thickness of the recording medium increases, the magnetic charge will increase. In the case of an isolated magnetic transition, increase of the magnetic charge will contribute only to increase of the magnetic force. However, in the case of the adjoining magnetic transition regions, demagnetization phenomenon should be taken into account. It is important factor in the longitudinal recording magnetography especially in the case of high resolution such as 400 dpi or more. From the view point of demagnetization phenomenon, increase of the magnetic charge will increase the self demagnetizing field which decrease the magnetization of the magnetic recording medium in turn. Decrease of the magnetization will contribute to decrease of the magnetic force. That is, increase of the thickness of the magnetic recording medium will contribute not only to increase of the magnetic force but also to decrease of the magnetic force.

In this paper it will be discussed to get the optimum thickness of the magnetic recording medium considering above conditions.

Method of Analysis

Fig.1 shows the coordinate system of the transition regions. 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 the magnetization function, magnetic field and magnetic force are the same as employed in my previously published paper.[1,2] Arctangent function is employed as the magnetization function of the transition region.

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

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

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

where, M_r: residual magnetization in the recording medium, δ: thickness of the recording medium, μ_0: permeability of vacuum, r: the distance from the assuming charge center $(0,-a)$ to the point $P(x, z)$, 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 the 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 of the magnetic particle which is induced in the magnetic particle and $m=\chi H$, χ: effective susceptibility of the particle including demagnetization factor; F, H and r have the same or opposite direction respectively.

If there are adjoining transition regions, self demagnetizing field, H_d, is generated in the recording medium. The direction of the self demagnetizing 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. Demagnetizing factor is not yet solved for arc-tangent approximation and the demagnetizing factor for sine approximation will be employed instead. It is calculated as follows:

$$N=[1-(\lambda /2 \pi \delta)\{1-\exp(-2 \pi \delta / \lambda)\}] \quad (6)$$

Where N: demagnetizing factor, λ: wave length (the distance between the adjoining transition regions is 0.5 λ).

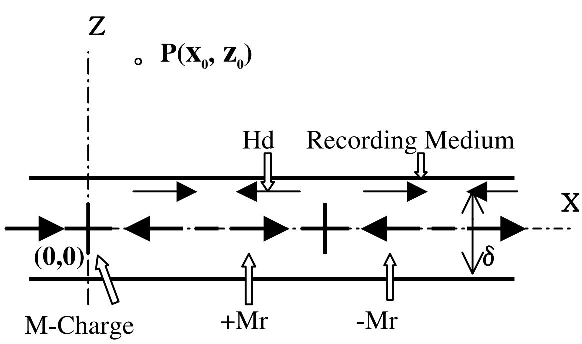

Figure 1. Coordinate system

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

Recording medium	*Co-Ni-P*
thickness	$\delta=0.2\text{-}2\mu m$
residual magnetization	$M_r=0.8Wb/m^2$
coecive force	$H_c=32\text{-}64kA/m$
squareness	$s=0.7$
Toner	*magnetically soft*
susceptibility	$\chi=1.58\times10^{-6}H/m$
relative permeability	$\mu_s=2$
Pixel density	*400dpi*

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.[3]

The Results of the Calculations and Studies

Relationship between the Thickness and the Magnetic Force

Fig.2 shows relationship between the thickness and the magnetization. As the thickness of the recording medium increases, the demagnetization factor increases and the magnetization of the recording medium decreases.

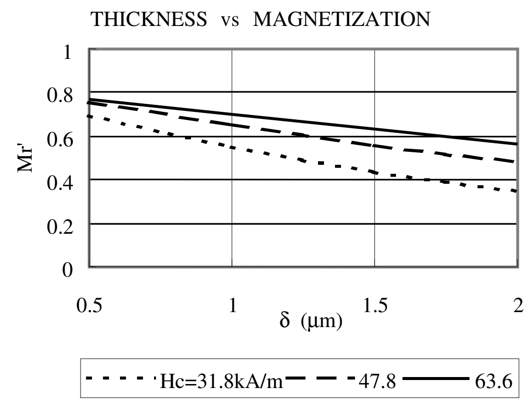

Figure 2.Relationship between the thickness of the recording medium and the magnetization

Fig. 3 shows relationship between the thickness of the recording medium and the magnetic force acting on a magnetic particle at $z_s=10\mu m$, where z_s is the distance between the surface of the recording medium and the position $P(x, z)$ of the magnetic particle. In these Figures z_s is $10\mu m$, unless otherwise noticed. The average diameter of the toner is about $10\mu m$ and the thickness of the toner layers deposited on the recording medium is about $20\mu m$. Then this value of z_s is average distance in the toner layers from the surface of the recording medium. Therefore, Fig. 3 shows the magnetic force which acts on a magnetic particle positioned at the average position of the toner layers.

As seen in Fig. 3, as the thickness of the recording medium increases, the magnetic force attracting the magnetic toner increases in the beginning. However the magnetic force decreases if the thickness is over a certain value. The magnetic force reaches its maximum at the thickness. The thickness is herein referred to optimum thickness δ_m. It is considered that if the thickness is relatively thin, contribution of increase of the thickness to increase of magnetic force wins contribution to decrease of magnetic force due to self demagnetization. On the other hand, if the thickness is relatively thick, contribution of increase of the thickness to decrease of magnetic force due to self demagnetization wins contribution to increase of magnetic force. That is, to get higher optical density it works positively to increase the thickness of the recording medium to an extent but it works negatively to increase the thickness over the extent. In the conditions of Fig. 3, the optimum thickness is $1\mu m$. It coincidents with the experimental facts.

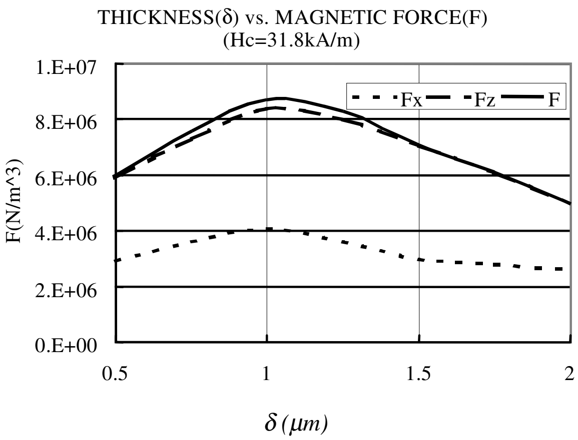

Figure 3. Relationship between the thickness of the recording medium and the magnetic force

Fig. 4 shows relationship between the thickness of the recording medium and the magnetic force acting on a magnetic particle at the various coercive forces of the recording medium. The optimum thickness changes with change of the coercive force of the recording medium. The optimum thickness shifts to higher values as the coercive force increases. In addition the magnetic force becomes higher as the coercive force increases.

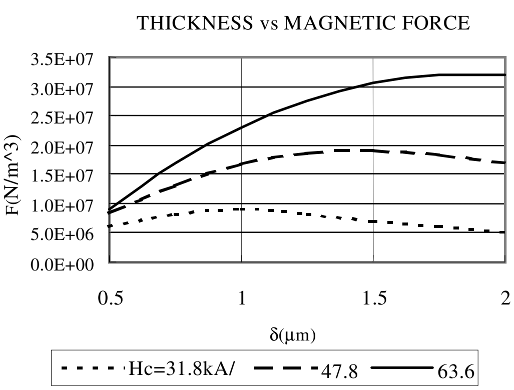

Figure 4. Relationship between the thickness of the recording medium and the magnetic force at the various coercive forces of the recording medium

Fig. 5 shows relationship between the coercive force of the recording medium and the optimum thickness of the recording medium. The higher the coercive force becomes, the less the self demagnetization becomes. Therefore, it is considered that with higher coercive force contribution of increase of the thickness to increase of magnetic force wins contribution to decrease of magnetic force due to self demagnetization in the wider range.

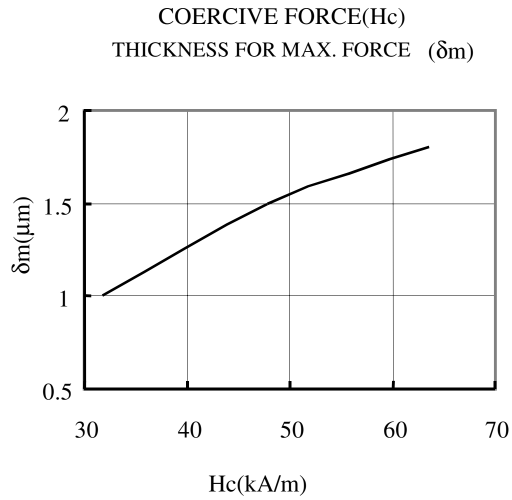

Figure 5. Relationship between the coercive force of the recording medium and the optimum thickness of the recording medium

Effect of the Size of the Magnetic Toner

Fig. 6 shows relationship between the thickness of the recording medium and the magnetic force acting on a magnetic particle at the various distances from the surface of the recording medium. Typically two toner layers are deposited on the recording medium. Therefore, z_s =10µm means average position of the toner layers if the toner of the diameter of 10µm is used as mentioned above and z_s =5µm means average position of the toner layers if the toner of the diameter of 5µm is used. It means that the optimum thickness is thinner if the toner of smaller size is used.

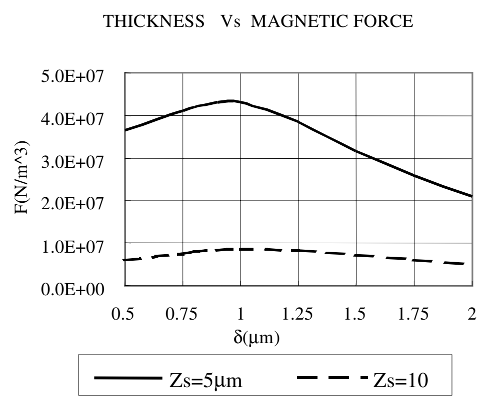

Figure 6. Relationship between the thickness of the recording medium and the magnetic force at the various distances from the surface of the recording medium

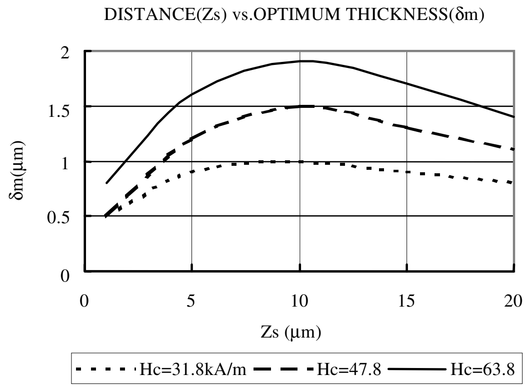

Figure 7. Relationship between the distance from the recording medium and the optimum thickness of the recording medium

Fig. 7 shows relationship between the distance from the recording medium and the optimum thickness of the recording medium. As the distance from the recording medium increases, the optimum thickness increases in the beginning. However the optimum thickness decreases if the distance is over a certain value. The optimum thickness reaches its maximum at the distance. That distance is about the same for various coercive forces. Therefore, the optimum thickness increases as the toner size increases if the diameter of the toner is less than about $10\mu m$.

Conclusion

The effect of the thickness of the recording medium on the magnetic force is theoretically analyzed. In the longitudinal recording magnetography, increase of the thickness of the magnetic recording medium will contribute not only to increase of the magnetic force but also to decrease of the magnetic force due to self demagnetization phenomenon. The following results are obtained.

(1) As the thickness of the recording medium increases, the magnetic force attracting the magnetic toner increases in the beginning. However the magnetic force decreases if the thickness is over a certain thickness. The magnetic force reaches its maximum at the thickness. The thickness is herein referred to optimum thickness.
(2) The optimum thickness increases as the coercive force of the recording medium increases.
(3) The optimum thickness increases as the toner size increases if the diameter of the toner is less than about $10\mu m$.

References

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2. N. Kokaji, *Proc. NIP-15,* IS&T, 1999,pg.517.
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. E-mail:kokaji@ee.meisei-u.ac.jp