Study on Magnetic Force Acting on the Magnetic Toner in the High Pixel Density Magnetic Printer With Longitudinal Recording

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Abstract

The purpose of this study is to realize much higher pixel density such as 2,000dpi than the current available magnetic printer of 600dpi. In the magnetic printer with longitudinal recording method, if the adjoining magnetic charges become near, self-demagnetizing field increases which decreases magnetization of the recording medium in turn. The higher the pixel density becomes, the weaker the magnetic force acting on the magnetic toner becomes. The magnetic forces acting on the magnetic toner are calculated with various characteristics of the recording medium and the toner. The analysis is effected from the view point of the magnetic force enough to attract the magnetic toner. The suitable combinations of the characteristics of the recording medium and the toner are discussed. The results are as follows. a) As the pixel density increases, the magnetic force decreases exponentially; b) At 2,000dpi the magnetic force becomes 1/10 of that of 400dpi. c) Even at 2,000dpi there exist some conditions which can generate the same magnetic force as that of 400dpi. d) One of the suitable condition is a combination of the recording medium with the residual magnetization of 0.8Wb/m^2, the coercive force of 64kA/m and the thickness of 0.37µm and the magnetic toner with the diameter of 5µm and the relative magnetic permeability of 2.

Introduction

The magnetic force acting on a magnetic toner from the magnetic latent image of the recording medium has been discussed in the typical longitudinal recording magnetography.[1-3] The purpose of this study is realize much higher pixel density such as 2,000dpi than the current available magnetic printer of 600dpi.

In the magnetic printer with longitudinal recording method, if the adjoining magnetic charges become near, self-demagnetizing field increases which decreases magnetization of the recording medium in turn. Accordingly the higher the pixel density becomes, the weaker the magnetic force acting on the magnetic toner becomes. Generally speaking, that will result in reproducing a print with unacceptable poor optical density under the high pixel density such as 2,000dpi.

It will be studied whether any suitable conditions exist to generate the magnetic force enough to reproduce a print with good optical density. The magnetic forces acting on the magnetic toner are calculated with various characteristics of the recording medium and the toner.

Method of Study

Figure 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 normal to the surface of the paper. Therefore the subject is solved as 2-dimensional problem.

As shown in Fig 1, magnetic charges are generated at the transition regions of magnetization. Then magnetic fields are generated from the transition regions and magnetic toners are attracted on the surface of the recording medium. A couple of the magnetic charge forms one dot line. In this paper it is studied whether one dot line with enough optical density can be formed under the high pixel density.

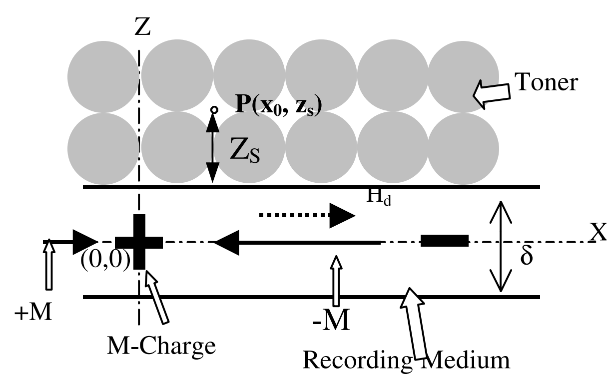

Figure 1. Coordinate system

Since two toner layers are placed on the recording medium,[1-2] the distance Z_s between the surface of the recording medium and the center of the toner layers is correspondent to the diameter of a toner. Then the magnetic force at the point $P(x_0, z_s)$ is assumed to be a representative magnetic force acting the toner layers.

Self-demagnetizing field Hd is generated between the adjoining magnetic charges in the recording medium. The direction of the self-demagnetizing field Hd is opposite to that of the magnetization M of the recording medium. As a result, the magnetization of the recording medium is reduced. As the adjoining magnetic charges become near, the self-demagnetizing field increases, which decreases the magnetic force accordingly.

The equations of the magnetization function, magnetic field and magnetic force are the same as employed in my previously published paper.[1-3] 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 the following approximate equations[(1)] 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 of the recording medium, δ: thickness of the recording medium, μ_0: permeability of vacuum, r: the distance from the assuming charge center[(1)] $(0,-a)$ 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 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.

Table 1 shows the values of the parameters used for calculations. They are typical values which can be employed in the magnetic printer with longitudinal recording method[(4)]. As mentioned above, the toner size is assumed to be correspondent to the distance Z_s between the surface of the recording medium and the center of the toner layers.

Table 1. Values of the Parameters Used for Calculation of the Magnetic Force

Recording medium	*Co-Ni-P*
thickness	$\delta=0.1\text{-}20\mu m$
residual magnetization	$M_r=0.8Wb/m^2$
coercive force	$H_c=32\text{-}64kA/m$
squareness	$s=0.7$
transition constant	$a=1.75\text{-}3.67$[(6)]
Toner	*magnetically soft*
susceptibility	$\chi=1.58\times10^{-6}H/m$
relative permeability	$\mu_s=2$
size	$Zs=5\text{-}10\mu m$
Pixel density	*400-2000dpi*

The Results of the Calculations and Studies

Relationship Between The Pixel Density and the Magnetic Force

Figure 2 shows an example of relationship between the pixel density and the magnetic force. As mentioned above, the higher the pixel density becomes, the weaker the magnetic force acting on the magnetic toner becomes due to the self-demagnetizing phenomenon. The magnetic force acting on a toner decreases exponentially as the pixel density increases. For example, the magnetic force under the pixel density of 2,000 dpi becomes about 1/10 times of that of 400 dpi. It means that the optical density of the print decreases as the pixel density increases and a print of poor image quality is reproduced under the high pixel density. It has been already experimentally assured.[5]

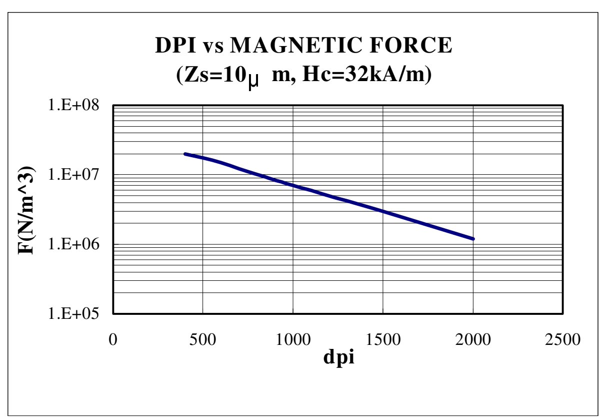

Figure 2.Relationship between the pixel density and the magnetic force

Relationship Between the Various Parameters and the Magnetic Force

Figure 3 shows relationship between the various parameters and the magnetic force under the high pixel density. In the figures the magnetic forces are compared with the standard magnetic force. The standard magnetic force is correspondent to the magnetic force which is obtained under the condition of a combination of the recording medium with M_r=0.8Wb/m^2, δ=1µm, H_c=32kA/m and toner with μ_s=2, Zs=10µm and the pixel density of 400dpi. It has been already reported that the suitable image quality is reproduced under the condition both experimentally and theoretically[1-2]. F_s=1.7x10^{7}N/m^3 is employed as the standard magnetic force.

Effect of the Coercive Force of the Recording Medium

Referring to Fig. 3 (a), only a combination of 600dpi, δ=2.4µm, H_c=32kA/m and Z_s =10µm satisfies the standard magnetic force. As long as the combination of H_c=32kA/m and Z_s=10µm are employed, no suitable δ is found over 600dpi.

Referring to Fig.3 (b), if higher Hc of 64kA/m is employed, suitable ranges of δ are obtained at 600 dpi and 1,000 dpi where the magnetic force is over the standard magnetic force F_s. It is effective to increase the coercive force of the recording medium but the combination is not enough for 2,000 dpi, since no suitable δ is found at 2,000 dpi.

Effect of the Size of the Toner

Referring to Fig. 3 (c), if smaller Zs of 5 µm is employed with H_c = 32kA/m, suitable ranges of δ are obtained at 600 dpi and 1,000 dpi where the magnetic force is over the standard magnetic force F_s. It is effective to decrease the size of the toner but the combination is not enough for 2,000dpi, since no suitable δ is found at 2,000 dpi.

Referring to Fig. 3 (d), if both higher H_c of 64kA/m and smaller Z_s of 5 µm are employed, suitable ranges of δ are obtained even at 2,000dpi where the magnetic force is over the standard magnetic force F_s. Combination of higher Hc and smaller Z_s is effective.

Suitable Range of the Thickness of the Recording Medium

As seen in Fig.3 the magnetic force are over F_s between the thinner thickness (referred to as δ_1) and the thicker one (referred to as δ_2).

Figure 4 shows relationship between the pixel density and the range of the suitable thickness with the parameter of Z_s. As the pixel density increases, the range of the suitable thickness decreases. The larger Z_s becomes, the narrower the range of the suitable thickness becomes. For example, if Z_s of 10 µm is employed, the suitable thickness disappears over 1,200 dpi. If Z_s of 7.5 µm is employed, the suitable thickness exists even at 2,000 dpi. If Z_s of 5 µm is employed, the range of the suitable thickness becomes wider than that of Z_s of 7.5 µm.

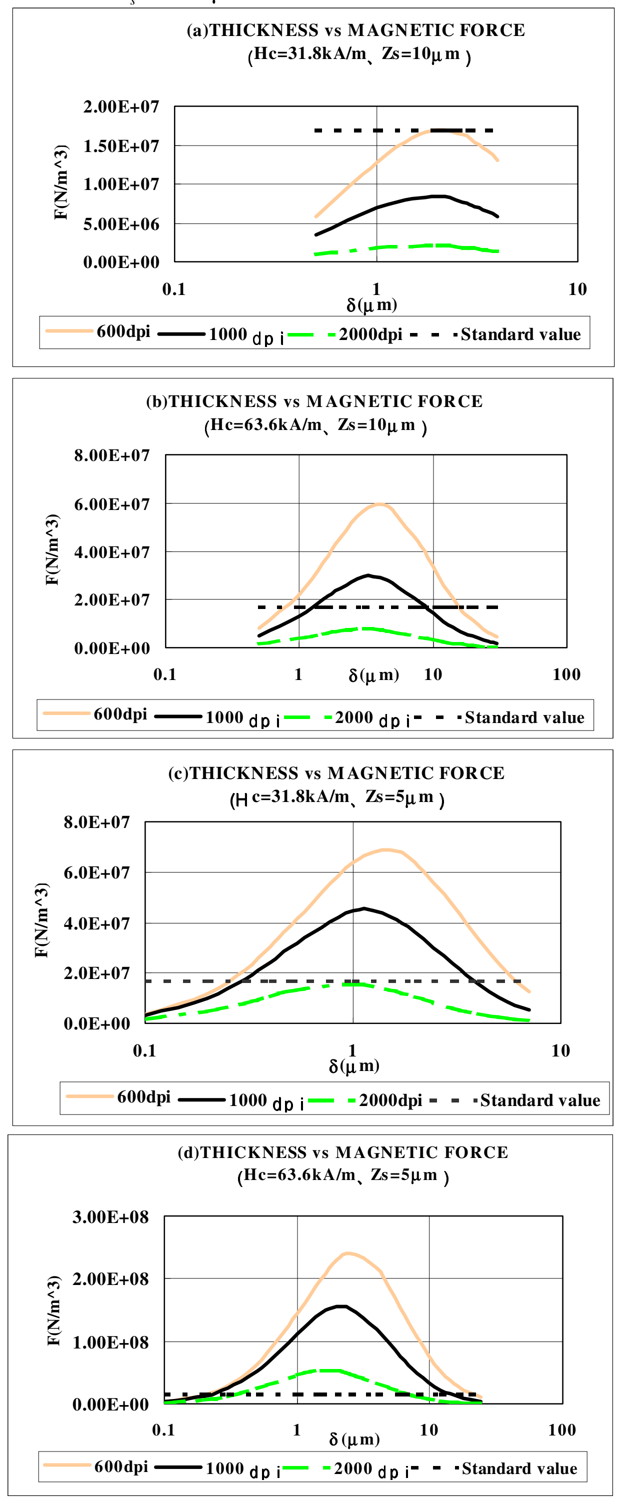

Figure 3. Relationship between the various parameters and the magnetic force

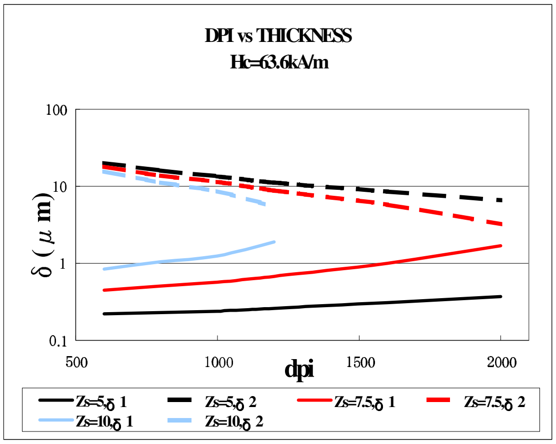

Figure 4. Relationship between the pixel density and the range of the suitable thickness

Suitable Combinations

Table 2 shows the suitable combinations of the various parameters to generate the magnetic force which is stronger than the standard magnetic force.

Table 2. Suitable Combinations of the Various Parameters

(a) Hc=31.8kA/m

dpi	Zs=5μm		Zs=7.5		Zs=10	
	δ1	δ2	δ1	δ2	δ1	δ2
600	0.26	6	0.6	4.6	2.4	
800	0.28	4.6	0.77	3	-	
1000	0.3	3.75	1.2	1.9	-	
1200	0.35	2.9	-		-	
1600	0.5	1.75	-		-	
2000	-		-		-	

(b)Hc=47.8kA/m

dpi	Zs=5μm		Zs=7.5		Zs=10	
	δ1	δ2	δ1	δ2	δ1	δ2
600	0.23	12.5	0.49	10.7	0.95	8.7
800	0.24	9.7	0.56	8	1.3	5.7
1000	0.26	8.3	0.65	6.4	2	3.5
1200	0.28	6.7	0.85	4.6	-	
1600	0.35	4.8	-		-	
2000	0.45	3.6	-		-	

(c) Hc=63.6kA/m

dpi	Zs=5μm		Zs=7.5		Zs=10	
	δ1	δ2	δ1	δ2	δ1	δ2
600	0.22	20	0.45	18	0.84	15.5
800	0.23	16	0.51	13.7	1.05	11.2
1000	0.24	13.5	0.57	11.4	1.25	8.6
1200	0.26	11.2	0.68	8.8	1.9	5.5
1600	0.31	8.5	1	5.8	-	
2000	0.37	6.6	1.7	3.2	-	

As the pixel density increases, the number of suitable combination decreases gradually. Smaller Z_s and higher H_c are effective for higher pixel density. The range for suitable δ decreases gradually. H_c should be higher than 48kA/m and Z_s should be less than 7.5μm.

Conclusion

In order to realize high pixel density magnetic printer, the suitable combinations of the characteristics of the recording medium and the toner have been sought. It has been studied about the magnetic force enough to reproduce one dot line with enough toner. The results are as follows.

a) As the pixel density increases, the magnetic force decreases exponentially. For example, at 2,000dpi the magnetic force becomes 1/10 of that of 400dpi.
b) Under the high pixel density, the recording medium of higher coercive force and the toner of smaller size are effective.
c) The range of the suitable thickness of the recording medium decreases as the pixel density increases.
d) Even at 2,000dpi there exist some conditions which can generate the suitable magnetic force. One of the suitable condition is a combination of the recording medium with the residual magnetization of 0.8Wb/m^2, the coercive force of 64kA/m and the thickness of 0.37μm and the magnetic toner with the diameter of 5μm and the relative magnetic permeability of 2.

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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., 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