Study on Magnetic Force Acting on the Magnetic Toner in the High Pixel Density Magnetic Printer with Longitudinal Recording (2)

Norio Kokaji
Department of Electrical Engineering, Meisei University
Hino, Tokyo, Japan

Abstract

The purpose of this study is to realize much higher pixel density magnetic printer with such as 2,000dpi than the current 600dpi one. The author has already presented a calculative simulation wherein even at 2,000dpi there exist some conditions that can form one dot black line with sufficient magnetic toner. The second concern is whether white line can be formed between the black lines from the viewpoint of resolution. In this study it is studied whether any suitable conditions exist to form one dot white line between black lines under the high pixel density. The magnetic forces acting on the magnetic toner are calculated with various characteristics of the recording medium and the toner. The parameters are selected from the practical point of view. As a result, it is found that there exist some conditions which satisfy the above condition even at 2,000dpi.

Introduction

It is one of the important subjects for digital printers to realize higher pixel density. The magnetic printer as well as the laser printer with the pixel density of 600dpi (dots per inch) is commercially available. They are partly replacing the offset printer in the field of short run on-demand printing from the viewpoint of convenience. If the higher pixel density were realized, the application of the digital printers would be expanded. The purpose of this study is to realize much higher pixel density such as 2,000dpi than the current 600dpi in the magnetic printer. The author et al. has already presented a calculative simulation wherein even at 2,000dpi there exist some conditions that can form one dot black line with sufficient magnetic toner.[4]

The second concern is whether white line can be formed between the black lines from the viewpoint of resolution.

As the pixel density increases, the distance between the adjoining magnetic charges in the white area decreases. As a result, the toner bridge is apt to be formed in the white area, too. Therefore the desired white area may not be obtained. In this paper it is studied by calculative simulation whether any suitable conditions exist to form one dot white line between black lines under the high pixel density. The magnetic forces acting on the magnetic toner are calculated with various characteristics of the recording medium and the toner.

Method of Study

Toner Imaging Model

Figure 1 shows the cross-sectional view of the recording medium and the toner layers with the toner imaging model. The figure illustrates the image consisting of 1 dot white line with 1 dot black line on both sides thereof. Since longitudinal recording method is employed, it is assumed that the recording medium is magnetized only along the x-direction. The z-direction is extended vertically. For the purpose of simplification, the subject is solved as 2-dimensional problem at x to z plane.

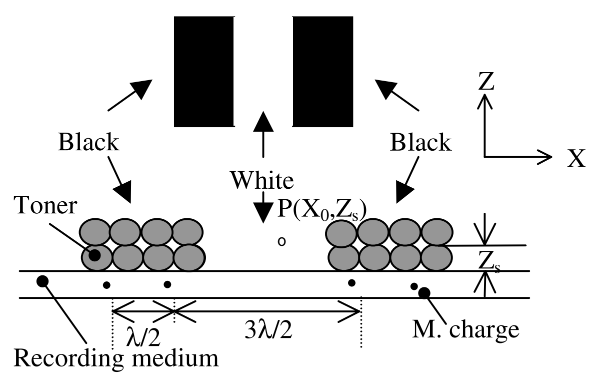

Figure 1. Cross Sectional view of the recording medium and the toner layers

Magnetic charges are generated at the transition regions of magnetization. In magnetography (+) charge means Northern pole and (-) charge means Southern pole. Then magnetic fields are generated from the magnetic charges and magnetic toners are attracted on the surface of the recording medium.

Since two toner-layers are formed on the recording medium, 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 $P(x_0,z_0)$ is assumed to be representative magnetic force acting on the toner layers.

A couple of the adjoining magnetic charges with the distance of (1/2)λ forms one dot black line. λ corresponds to one dot size. The area with the distance of (3/2)λ between the adjoining magnetic charges forms one dot white line. The distance between the adjoining magnetic charges in the white area is three times longer than that of the black area. That is, there are significant differences of the distances between the adjoining magnetic charges between the black area and the white area. It is so as to distinguish whether the area should be formed as the black area or the white area.

Equations/Parameters

The equations of the magnetization function, magnetic field and magnetic force are the same as employed in my previously published papers.[1-4]

Arctangent function is employed as the magnetization function of the transition region.

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:

$$F(x,z)=\chi H\times dH/dr \qquad (1)$$

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.

The parameters used for calculations are the almost same as employed in my previously published papers.[3,4] They are typical values which can be employed in the magnetic printer with longitudinal recording method.

The coercive force of the recording medium H_c, the thickness of the recording medium δ, the toner size Z_s, and the pixel density are selected as the variable parameters from the practical view of point.

Standard Values

The calculated results are compared with the standard values. The standard values are determined as the values which are suitable for 400dpi magnetic printer, since the suitable image quality has been reproduced.[1,2]

It is assumed that the magnetic force in the black area should be larger than the standard magnetic force F_s, in order to attract enough toner. In addition, it is assumed that the magnetic field in the white area should be smaller than the standard magnetic field H_s, in order not to form the toner bridge. The following values are employed as each standard value.

$$F_s=1.7x10^7 N/m^3 \qquad (2)$$

$$H_s=6kA/m \qquad (3)$$

The Results of the Calculations and Studies

The Magnetic Force in the Black Area and the Magnetic Field in the White Area

Figure 2 shows an example of relationship between the various parameters and the magnetic force and the magnetic field. The magnetic force in the black area and the magnetic field in the white area are compared with the above standard values. The magnetic force at the black area should be higher than the standard value and the magnetic field at the white area should be lower than the standard value.

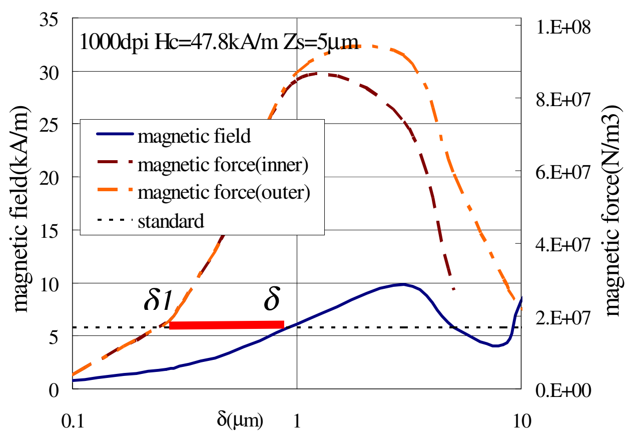

Figure 2. Relationship between the various parameters and the magnetic force and the magnetic field. (Hc: coercive force of the recording medium, δ: thickness of the recording medium, Zs: toner size)

If the thickness of the recording medium is larger than 0.25µm denoted by *δ1*, the values of the magnetic force are larger than the standard value. Therefore it is assumed that the thickness of the recording medium should be larger than 0.25µm to form good black image.

On the other hand, if the thickness of the recording medium is smaller than 0.93µm denoted by *δ2*, the value of the magnetic field in the white area is smaller than the standard value. Therefore it is assumed that the thickness of the recording medium should be smaller than 0.93µm to keep white image.

Thus the suitable thickness of the recording medium which satisfies both conditions ranges from 0.25 to 0.93 µm. As a result, the combination of the recording medium with the coercive force of 48kA/m and the thickness of 0.25µm to 0.93µm and the toner with the diameter of 5µm is assumed to be suitable to realize 1,000 dpi image.

Width of the White Area

The second check point is to keep the width of the white area. It means that the width of the white area should be one dot size λ.

As shown in Fig. 3 (a), the width of the white area that has lower magnetic field than the standard value should be nearly equal to that of the black area. Each of them corresponds to one dot size. Therefore this is assumed to be a suitable case. On the other hand, as shown in Fig.3 (b), the width of the white area is much smaller than the one dot size λ. This is assumed to be an unsuitable case. By adding this check, the ranges of suitable combinations become smaller than the results by the first step.

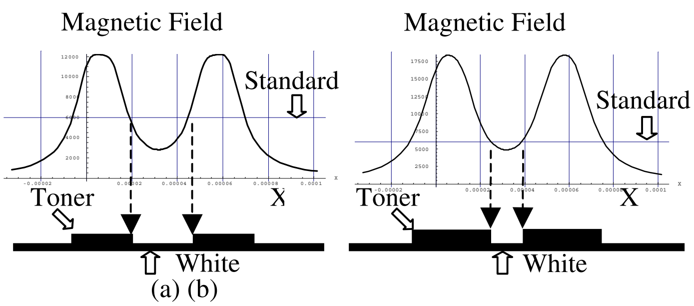

Figure 3. Relationship between distribution of the magnetic field and the toner image. (a) 1,000dpi, Hc=32kA/m, Zs=5µm, δ=0.42 µm; (b) 1,000dpi, Hc=32kA/m, Zs=5µm, δ=0.83 µm; (Hc: coercive force of the recording medium, δ: thickness of the recording medium, Zs: toner size).

Suitable Combinations of the Parameters at 600dpi

Fig.4(a) shows an example of the results of the above operations. It shows the suitable combinations of the parameters at 600dpi.

The dotted line denoted by "*δu*" shows the upper limit of the thickness of the recording medium. The solid line denoted by "*δl*" shows the lower limit of the thickness of the recording medium. The suitable range of the thickness of the recording medium exists between the "*δu*" and "*δl*".

It is found that as the coercive force of the recording medium increases, the range of the thickness of the recording medium moves to the thinner one.

As the toner size decreases, the range of the thickness of the recording medium increases and it moves to the thinner one.

It is noted that the case of the toner size of 10•µm is not shown in this figure. If the toner size of 10 µm is employed, there is no suitable thickness of the recording medium, though the toner size of 10 µm satisfies the conditions in the case of 400dpi.

Therefore the size of the toner is considered to be the first key factor. Smaller toner is found to be effective for higher pixel density.

Suitable Combinations of the Parameters at 1000dpi

Fig. 4(b) shows the suitable combinations of the parameters at 1000dpi. It is seen that the range of the suitable condition decreases compared with the case of 600dpi.

If the toner size of 7.5 µm is employed, the coercive force of the recording medium should be more than or equal to 64 kA/m. The range which is less than 64kA/m is excluded.

Accordingly the coercive force of the recording medium is considered to be the second key factor. Higher coercive force of the recording medium is found to be effective for higher pixel density.

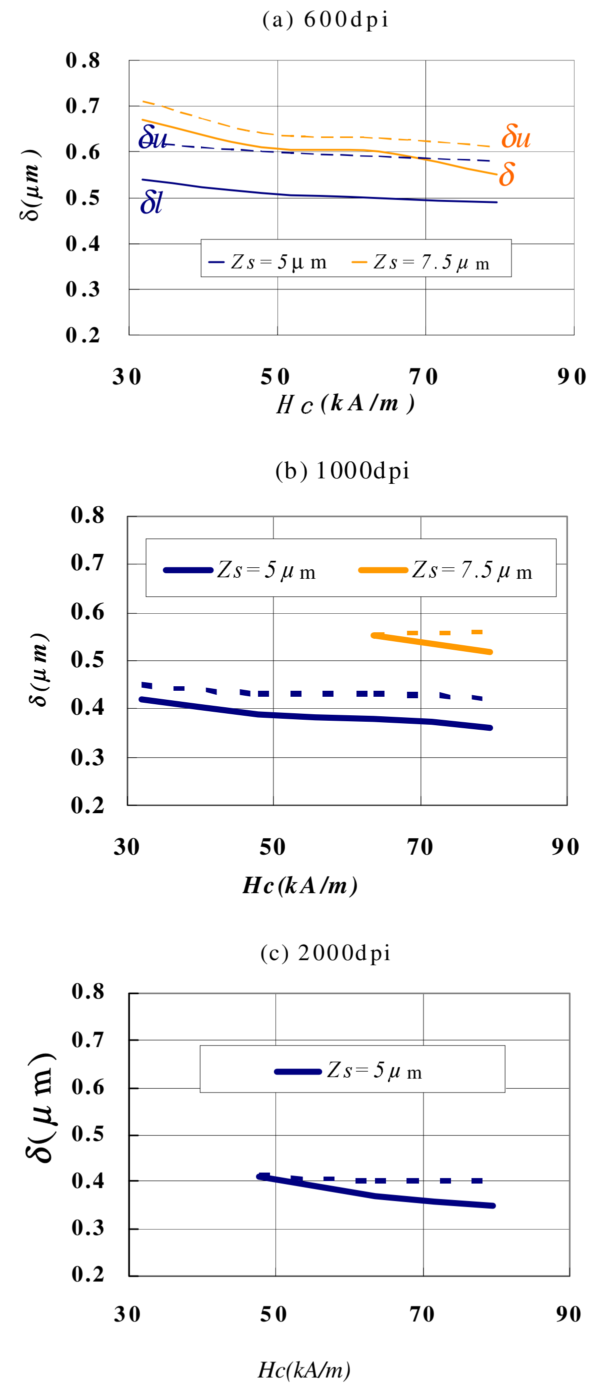

Figure 4. Range of suitable combination of the parameters. (Hc: coercive force of the recording medium, δ: thickness of the recording medium, Zs: toner size)

In addition, the range of the suitable thickness of the recording medium decreases and at the same time moves to thinner one compared with that of 600dpi.

Suitable Combinations of the Parameters at 2000dpi

Fig.4(c) shows the suitable combinations of the parameters at 2000 dpi. It is seen that the range of the suitable condition further decreases compared with the case of 1000dpi.

The case of the toner size of 7.5 µm has also disappeared. Only the case of the toner size of 5 µm survives.

In addition, the coercive force of the recording medium should be more than or equal to 48 kA/m. The range that is less than 48kA/m is excluded.

Therefore the combination of smaller size of the toner and higher coercive force of the recording medium is found to be effective for higher pixel density.

Suitable Combinations of the Parameters (Table)

Table 1 shows the suitable combinations of the various parameters in the form of table. It is seen that as the pixel density increases, the range of the suitable combination decreases. As the size of the toner decreases, the suitable range is expanded to higher density. In addition, as the coercive force of the recording medium increases, the suitable range is expanded to higher density.

Although these features are similar to the conditions to form one dot black line,[4] the range of the suitable combinations is much smaller compared with the conditions to form one black line.

Table 1 Suitable combinations of various parameters (Figures in the middle part of the table show the suitable range of the thickness of the recording medium)

Hc=32kA/m

dpi	Zs=5µm	Zs=7.5 µm	Zs=10 µm
600	0.54~0.60 µm	0.66~0.71	-
1000	0.42~0.45	-	-
2000	-	-	-

(b) Hc=48kA/m

dpi	Zs=5 µm	Zs=7.5 µm	Zs=10 µm
600	0.51~0.60 µm	0.66-0.64	-
1000	0.39~0.43	-	-
2000	0.41	-	-

(c) Hc=64kA/m

dpi	Zs=5 µm	Zs=7.5 µm	Zs=10 µm
600	0.50~0.59 µm	0.60~0.63	-
1000	0.38~0.43	0.55	-
2000	0.37~0.40	-	-

(d) Hc=80kA/m

dpi	Zs=5 µm	Zs=7.5 µm	Zs=10 µm
600	0.50~0.58 µm	0.55~0.61	0.74~0.81
1000	0.36~0.42	0.52~0.56	-
2000	0.35~0.39	-	-

Conclusion

In order to realize higher pixel density magnetic printer, it has been studied by calculative simulation whether any suitable conditions exist to form one dot white line between black lines under the high pixel density. The results are as follows.

a) As the pixel density increases, the range of the suitable combination decreases.
b) Under the higher pixel density, the recording medium of higher coercive force and the toner of smaller size are effective.
c) The suitable thickness of the recording medium has limited range depending on the coercive force of the recording medium, the toner size and the pixel density. As the pixel density increases, the range of the suitable thickness of the recording medium decreases and moves to thinner range.
d) Even at 2,000dpi there exist some conditions which can form one dot white line between black lines, though they are limited compared with the conditions to form one black line.

References

1. N. Kokaji, Proc. NIP-14, IS&T, 1998, pg. 349.
2. N. Kokaji, Proc. NIP-15, IS&T, 1999, pg. 517.
3. N. Kokaji et.al, Proc. NIP-16, IS&T, 2000, pg. 855.
4. N. Kokaji et al., Proc. NIP-17, IS&T, pg.375.

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