Analysis of the Magnetic Force Acting on the Toner in the Black Image Area and White Image Area in Longitudinal Recording Magnetography

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Abstract

In order to get suitable ratio of the intervals between the adjacent transition regions in the recording medium in the black image area and white image area, distribution of magnetic force acting on the toners is analyzed using finite element method and proximate equations in longitudinal recording magnetography. Distance of 1/2λ between the adjoining transition regions in the recording medium was allocated to form one dot black image, while the distance of 3/2λ between the adjoining transition regions was allocated to form one dot white image, where λ is defined as regular size of one dot. The toner with the diameter of 10μm was employed. As pixel density of 400 dpi was employed, 1 dot corresponded to about 60μm. Then the distance of 1/2λ for a black dot corresponded to about 30μm and the distance of 3/2λ for a white dot corresponded to about 90μm. The following results are found. Toner is attracted strongly to the recording medium at the transition regions and that toner is attracted to the next toners each other at the intermediate region between the adjoining transition regions in the 1/2λ area. Then black image is formed around the 1/2λ area. On the contrary toners far from the transition regions get very weak attractive force. Then white image is formed around the 3/2λ area. However, the toners at the end of the 3/2 λ area get strong force from the recording medium and become a part of the black image. As a result it is considered that black image of λ and white image of λ are formed.

Introduction

It is important in longitudinal recording magnetography to set appropriately the ratio of the intervals between the adjacent transition regions in the recording medium, so as to form distinct black image and white image. For that purpose there should be definite difference of magnetic forces acting on the toners between the black image area and white image area. In this paper a certain model is assumed on the ratio of the intervals between the adjacent transition regions in the recording medium and the corresponding arrangement of the toners in the black image area and white image area. Calculative simulation is carried out using finite element method and the proximate equations.[1,2]

Method of Study

A Model for Calculation

Imaging model:
Black 1dot + white 1dot+black 1dot;
Pixel density: 400dpi;
1 dot size: λ = 60μm
Toner size: 10μmϕ

Distance between adjoining transition regions in the recording medium: black area 1/2λ = 30μm, white area 3/2 λ= 90μm.

Supposition: As seen in Fig. 1, the area where the distance between adjoining transition regions in the recording medium is 1/2λ will have strong magnetic force and attract 5 toners. It will form 1 dot black image. After the heat fusing process, the toner image will be spread by one dot size and the total size of the image will grow as large as 6 toners. Thus the size of the black image on the paper will be 60μm = λ.

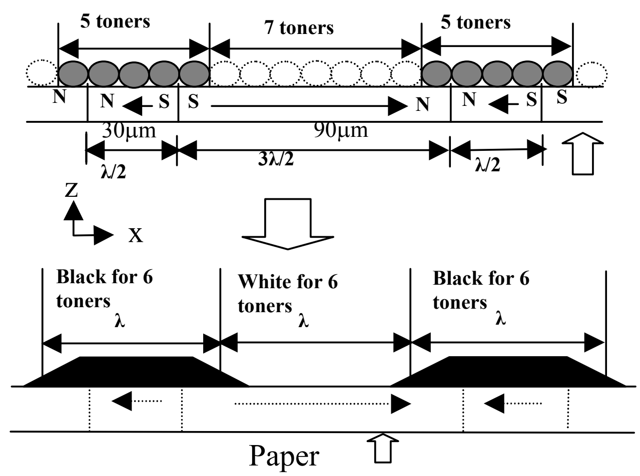

Figure 1. Imaging model of 2 black dots with 1 white dot in between

On the other hand, the area where the distance between adjoining transition regions is 3/2 λ = 90μm will have weak magnetic force and form white image. It will have room to contain 7 toners at the developing stage. After the heat fusing process, this room will be reduced by the adjacent fused toners by 1 portion of toner and form white image of 60μm = λ. As a result each of black image and white image will be formed with 60μm = λ long.

Means of Calculation

Calculation is carried out using the following three means.

1) Calculation using finite element method is carried out with electromagnetic analyzing software which is available from The Japan Research Institute, Limited and named "JMAG-Studio".

2) Magnetic force acting on a small magnetic particle in the space above the recording medium is calculated.[1]

Each magnetic field which emerges from each transition region in the recording medium is superposed to form the resultant magnetic field at a point in the space above the recording medium. Then the magnetic force acting on a magnetic particle at the point is calculated by the equation (1).

$$F = \chi H \times dH/dr \quad [N/m^3] \tag{1}$$

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.

3) Magnetic force between the adjoining toners at a cross section of the toner layer is calculated by the equation (2).[2]

$$Fs = B^2/2 \times (1/\mu_0) \times (1-1/\mu_s) \quad [N/m^2] \tag{2}$$

Where B: magnetic flux density in the toner layer which is expressed by the equation (3), μ_0: permeability of vacuum, μ_s: relative permeability of the toner.

$$B = \{2\mu_s \mu_0/(\mu_s+1)\}H \quad [T] \tag{3}$$

The calculations are carried out using the parameters shown at Table 1.

Table 1: Values of the Parameters Used for Calculation

Recording medium	*Co-Ni-P*
thickness	$\delta = 1\mu m$
residual magnetization	$M_r = 0.8Wb/m^2$
coercive force	$H_c = 32kA/m$
squareness	$s = 0.7$
transition constant	$a = 3.67$
Toner	*magnetically soft*
susceptibility	$\chi = 1.26\times10^{-6}H/m$
relative permeability	$\mu_s = 2$
Pixel density	*400dpi*

Results and Discussion

Distribution of the Magnetic Force Acting on the Toner

Figure 2 shows the contour of the magnetic force acting on the toners calculated using the finite element method. It is shown that strong magnetic force acts on the toners located at the 2 black image areas and that weak magnetic force acts on the toners located at the white image areas which exist between the 2 black areas and outside of each black image areas.

Figure 3 shows an enlarged figure of the circled black image areas of Fig. 2. As shown in the circle indicated by "A" in Fig. 3, strong magnetic force acts on the part of the toners near the transition regions of the recording medium. In addition, strong magnetic force also acts on the part of the toners at the boundary surface between the adjoining toners which are located at the intermediate position between the adjoining transition regions as shown in the circle indicated by "B". Weak magnetic force acts on the other parts of the toners than the parts indicated "A" or "B".

Figure 4 shows distribution of the magnetic force acting on a small magnetic particle using the equation (1). It shows distribution at the center of the first toner layer, that is $Z_s = 5\mu m$. It is shown that strong magnetic force acts on a toner near the transition regions of the recording medium, that is X = 0, 30, 120 or 150 μm, and that weak magnetic force acts on a toner near the intermediate position between the adjoining transition regions. The magnetic force is also weak at the white image area.

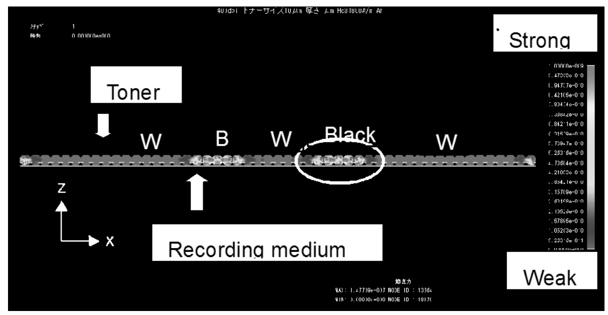

Figure 2 Contour of the magnetic force acting on the toners

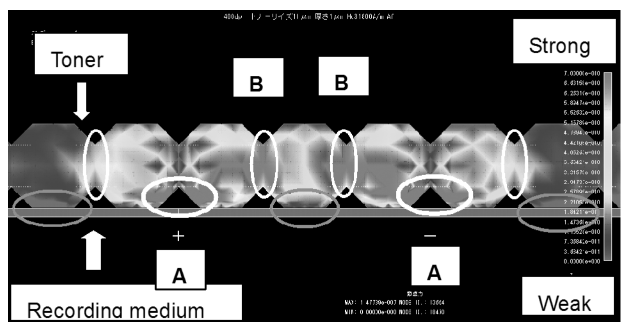

Figure 3. Enlarged contour the magnetic force at the region of black image

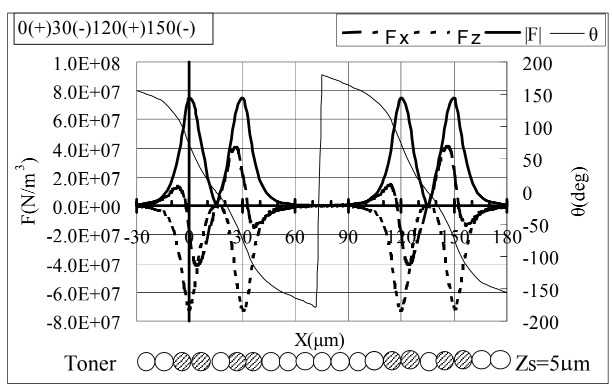

Figure 4. Distribution of the magnetic force acting on a small magnetic particle

Figure 5 shows distribution of the magnetic force at the cross section of the toner layer. It shows distribution at the center of the first toner layer, that is Z_s = 5μm. It is shown that strong magnetic force acts on the toners located at the black image areas and that weak magnetic force acts on the toners located at the white image areas between the black image areas.

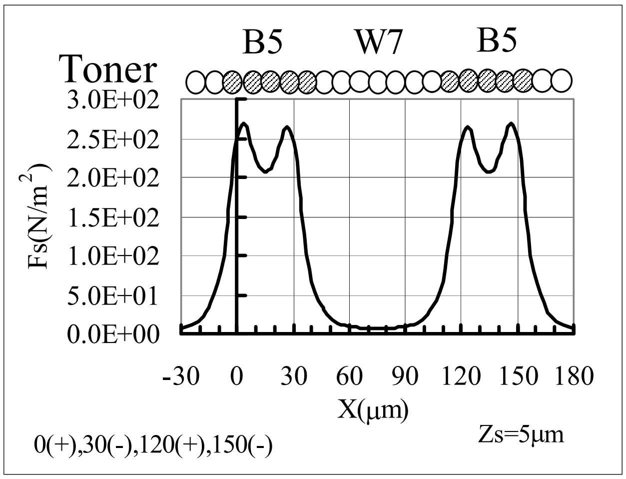

Figure 5. Distribution of the magnetic force at the cross section of the toner layer

Z Direction Component of the Magnetic Force Acting on the Toner

Figure 6 shows the contour of Z direction component of the magnetic force acting on the toners calculated using the finite element method. It is shown that strong magnetic force acts on only the part of the toners near the transition regions of the recording medium which are indicated by circles. The toners numbered 30, 31, 33 and 34 are attracted strongly to the recording medium, while the toners numbered 29, 32, 35 and the others are attracted weakly to the recording medium.

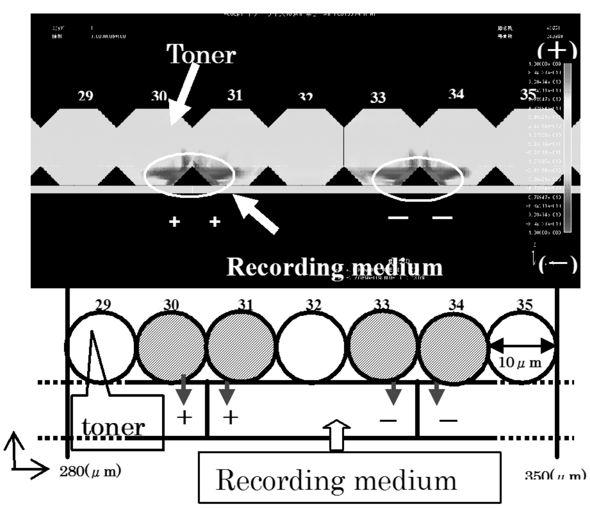

Figure 6. Contour of z-direction component of the magnetic force

Figure 7 shows distribution of Z direction component of the magnetic force acting on a small magnetic particle using the equation (1). It shows distribution at the part of the first toner layer near the recording medium, that is Z_s = 1μm. It is shown that strong magnetic force acts on the part of the toners near the transition regions of the recording medium, that is toner numbered 30, 31, 33 and 34, and that weak magnetic force acts on a toner near the intermediate position between the adjoining transition regions, that is toner numbered 32. The magnetic force is also weak at the white image area (~29, 35~).

Figure 8 shows distribution of Z direction component of the magnetic force acting on the cross section of the toner layer. It is similar to what is shown in Fig. 7.

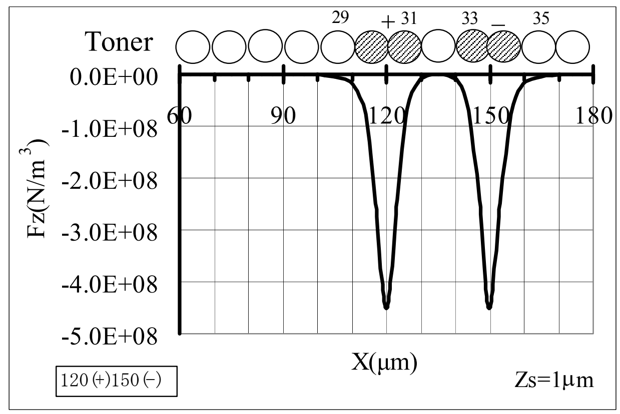

Figure 7. Distribution of z-direction component of the magnetic force acting on a small magnetic particle

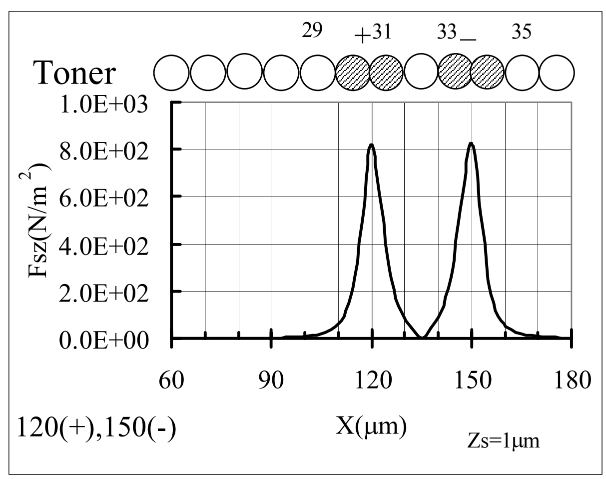

Figure 8. Distribution of z-direction component of the magnetic force at the cross section of the toner layer

X Direction Component of the Magnetic Force Acting on the Toner

Figure 9 shows the contour of X direction component of the magnetic force acting on the toners calculated using the finite element method. It is shown that strong magnetic force also acts on the part of the toners of at the boundary surface between the adjoining toners which are located at the intermediate position between the adjoining transition regions, namely toners numbered 31-32 and 32-33. Since the direction of the force is inversed at the respective side of the boundary between the adjoining toners, it is absorbing force. It means that the toner numbered 32 attracts next toners numbered 31 and 33 each other. In addition, strong magnetic force is seen also on the part of the toners near the transition regions of the recording medium.

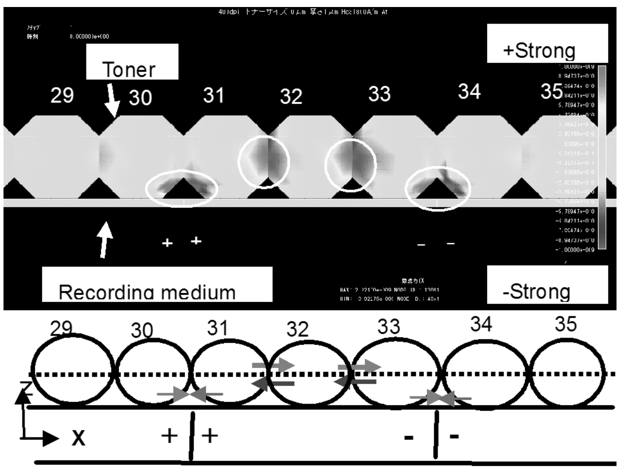

Figure 9. Contour of x-direction component of the magnetic force

Figure 10 shows distribution of X direction component of the magnetic force acting on a small magnetic particle using the equation (1). It is shown that relatively strong magnetic force acts on a toner near the transition regions of the recording medium, namely toner numbered 30, 31, 33 or 34. The magnetic force is directed to the center of the transition regions of the recording medium. X direction component of the magnetic force is weak at the other part.

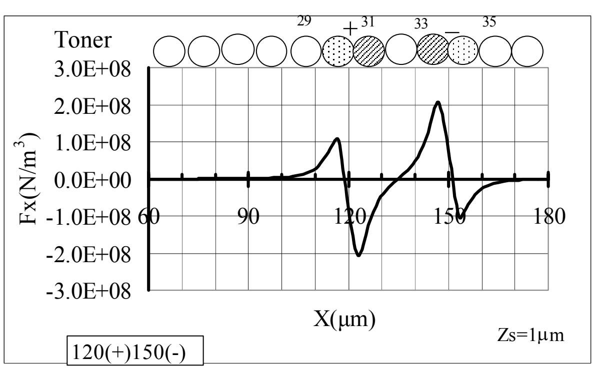

Figure 10. Distribution of x-direction component of the magnetic force acting on a small magnetic particle

Figure 11 shows distribution of X direction component of the magnetic force acting on the cross section of the toner layer calculated by the equation (2). It is shown that strong magnetic force acts on the toners located inside of the transition regions of the recording medium, namely toners numbered 31, 32 and 33. X direction component of the magnetic force is weak at the other part.

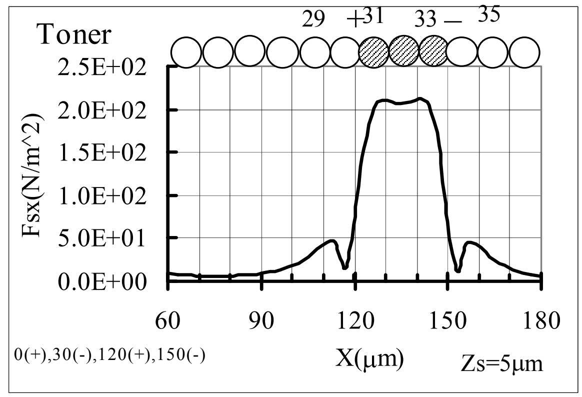

Figure 11. Distribution of x-direction component of the magnetic force at the cross section of the toner layer

Discussion

Taking the above results together into consideration, the following things are found. Toners are attracted strongly to the recording medium near the transition regions of the recording medium, as shown in the toner numbered 30, 31, 33 or 34. The toner located at the intermediate region between the transition regions of the recording medium, which is included in the black image area, numbered 32, is weakly attracted to the recording medium but strongly attracted to the next toners, numbered 32 or 33, at the boundary surface. Therefore toner-bridge is formed between the adjoining transition regions of the recording medium by the toners numbered 31, 32 and 33. As a result it is considered that 5 toners which get strong magnetic force, numbered 30 to 34, form 1 dot black image, while the other toners which get weak magnetic force can be removed easily to form white image. Accordingly the supposed model shown in Fig.1 is reasonable.

Conclusions

In order to get suitable ratio of the intervals between the adjacent transition regions in the recording medium in the black image area and white image area, distribution of magnetic force acting on the toners is analyzed using finite element method and proximate equations. In the proposed model the distance of 1/2λ between the adjoining transition regions of the recording medium is allocated to 1 dot black image area, while the distance of 3/2λ between the adjoining transition regions of the recording medium is allocated to 1 dot white image area. It is found that the proposed ratio is proper to realize 1:1 black image and white image. In this study it was calculated in the case of 400dpi. Another model of another pixel density, especially with higher density, will be studied after this.

References

1. N. Kokaji, Analysis of the magnetic force acting on a magnetic toner in magnetography with longitudinal recording, Proc. NIP-14, IS&T, pg. 349. (1998).
2. N. Kokaji, Analysis of the magnetic force acting on the magnetic toners from the adjoining magnetic transition regions in magnetography, Proc. NIP-15, IS&T, pg. 517. (1999).

Author 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 digital printing technology, especially magnetography. His works include almost the whole areas of magnetography using longitudinal recording. His recent interest is also in R&D of magnetic display.