Analysis of the magnetic force acting on the toner in the black image area and white image area in longitudinal recording magnetography (2)

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Abstract

Magnetic force acting on the toner from the magnetic latent image in the black image area and white image area was analyzed in the longitudinal recording magnetography. Simulative calculations were made using electromagnetic field simulator with finite element method and proximate equations. Experiment was also made using the enlarged model. Distance of 1/2 dot between the adjoining transition regions in the recording medium was allocated to form one dot black image and the distance of 3/2 dots between the adjoining transition regions was allocated to form one dot white image. Calculation was made in the case of 400dpi and toner with diameter of 10 micrometers. In the first model published at the past NIP conference toners were placed facing each other across the center of the transition region. In the second model described in this paper a toner is placed at the center of the transition region and the other toners are placed side by side. The toners are attracted strongly to the recording medium at the transition regions and they cross the border of the black latent image area. Then the black image is enlarged more than 1/2 dot. Consequently the white image area is reduced less than 3/2 dots. As a result, the size of the one dot black image and that of the one dot white image become almost same in both models.

Introduction

It is important to know the magnetic force acting on the toner in the black image area and white image area in magnetography. In the previously published paper at the NIP21 conference the author proposed an appropriate ratio of the interval between the adjacent transition regions in the recording medium using an imaging model [1]. In that paper one dot black image and one dot white image were arranged side by side. The toners were placed facing each other across the center of the transition region and the other toners are placed side by side. In this paper another toner arrangement model will be studied wherein a toner is placed at the center of the transition region and the other toners are placed side by side. Calculative simulation will be carried out on distribution of magnetic force acting on the toners, using finite element method and proximate equations. Experiment will be also made using the enlarged model. An appropriate toner attracting model in the black image area and white image area will be considered.

Method of Study

Toner arrangement model for calculation

Imaging model:

black 1dot + white 1dot+black 1dot;

toner size=10μmϕ (multiple surface body in the finite element method);

pixel density=400dpi;

1 dot size: λ=60μm (It corresponds to 6 toners.)

distance between adjoining transition regions in the recording medium:

black image area: 1/2 λ =30μm (It corresponds to 3 toners.),

white image area: 3/2 λ = 90μm (It corresponds to 9 toners.).

As seen in Fig.1, a toner is assumed to be placed at the center of the transition region and the other toners are assumed to be placed side by side. For the purpose of simplicity one layer toner model and 2 dimensions with *X-Z* cross section will be studied. On development the toners are provided in the chain-like state by developing magnetic field. The area where the distance between adjoining transition regions in the recording medium is 1/2 λ has stronger magnetic force than the toner connecting force by the developing magnetic field. Therefore the area can take the toners from the developing magnetic field and forms black image. On the other hand the area where the distance between adjoining transition regions in the recording medium is 3/2 λ has weaker magnetic force than the toner connecting force by the developing magnetic field. Therefore the area cannot take the toners from the developing magnetic field and forms white image. Number of the toners attracted in the black image area will be considered and resultant ratio of the size of the black image and the white image will be determined.

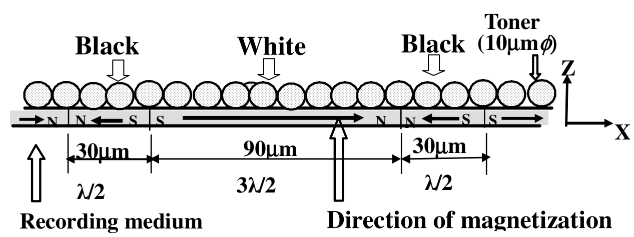

Figure 1. *Model of toner arrangement on the recording medium*

Means of calculation

Calculation is carried out using the following three means.

(a) Calculation using finite element method is carried out with electromagnetic simulator which is electromagnetic analyzing software and available from The Japan Research Institute, Limited and named “JMAG-Studio” v.8.

(b) Magnetic force acting on a small magnetic particle in the space above the recording medium is calculated as described in my previously published paper [2].

Each magnetic field which emerges from each transition region in the recording medium is superposed to form the resultant magnetic field at the 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).

$$F = \chi H \times dH/dr \quad [N/m^3] \qquad (1)$$

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.

(c)Magnetic force at a cross section of the toner layer is calculated by the equation (2) as described in my previously published paper [3].

$$F_s = B^2/2 * (1/\mu_0) * (1 - 1/\mu_s) \quad [N/m^2] \qquad (2)$$

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.

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

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	$M_r = 0.8 Wb/m^2$
coercive force	$H_c = 32 kA/m$
squareness	$s = 0.7$
transition constant	$a = 3.67 \mu m$
Toner	*magnetically soft*
susceptibility	$\chi = 1.26 \times 10^{-6} H/m$
relative permeability	$\mu_s = 2$
Pixel density	*400dpi*

Results and Discussion

Distribution of the magnetic force acting on the toner

Fig.2 shows the contour of the nodal force of the magnetic force acting on the toners calculated using the electromagnetic simulator. It shows that strong magnetic force acts on the toners located at the 2 black image areas with circles 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.

Fig.3 shows an enlarged contour of the black image areas of Fig.2 at the top and it shows a toner attracting model at the bottom. As shown by "A", strong magnetic force acts on the toners across the center of the transition regions of the recording medium (toner #9 and #12). 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 by "B" (between toner #9 and #10, between toner #10 and #11, and between toner #11 and #12). Therefore strong force acts on 4 toners in the black image area. Rather strong force acts on 2 toners, #8 and #13.Weak magnetic force acts on the other parts of the toners than the parts indicated by "A" or "B".

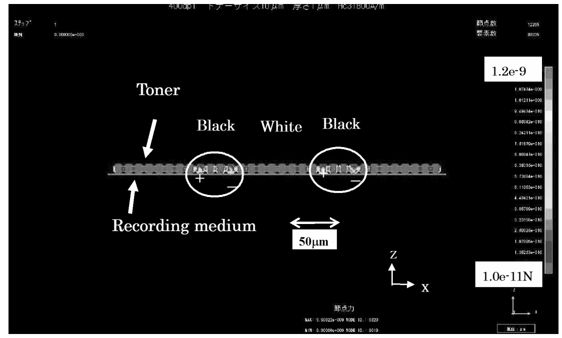

***Figure 2**. Contour of the magnetic force acting on the toners*

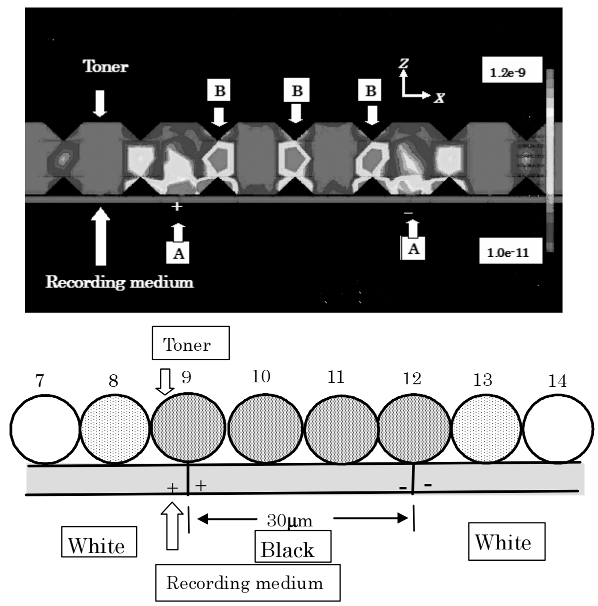

***Figure 3**. Contour of the magnetic force acting on the toners at the black image region*

Fig.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=5μm. It is shown that strong magnetic force acts on a toner near the transition regions of the recording medium, that is at X=0, 30, 120 or 150μm, and that weak magnetic force acts on the toners near the intermediate position between the adjoining transition regions, though they are positioned in the black image area . The magnetic force is also weak at the white image area.

Fig.5 shows distribution of the magnetic force at the cross section of the toner layer using the equation (2). 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 4 toners located at the black image areas and that weak magnetic force acts on the toners located at the white image areas in between the black image areas.

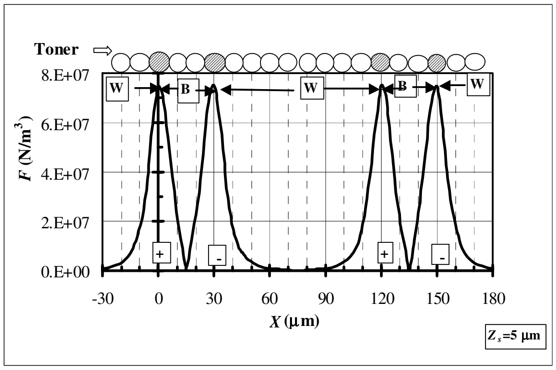

***Figure 4**. Distribution of the magnetic force acting on a small particle.*

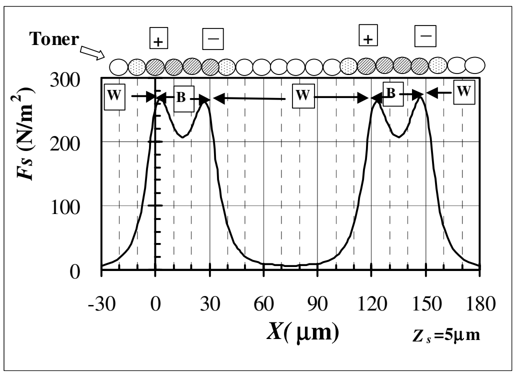

***Figure 5**. Distribution of the magnetic force at the cross section of the toner layer.*

Z direction component of the magnetic force acting on the toner

Fig.6 shows distribution of Z direction component of the nodal force of the magnetic force acting on the toners calculated using the electromagnetic simulator. It shows distribution at the part of the first toner layer near the recording medium, that is Z_s=1µm, since strong force acts on the part of the toners adjoining the recording medium as shown by "A" in Fig.3. It is shown that strong magnetic force acts on only the toners on the center of the transition regions of the recording medium, that is toner #9 and #12. The toners #10 and #11 are not attracted strongly to the recording medium, though they are positioned in black image area.

Fig.7 shows distribution of Z direction component of the magnetic force acting on the cross section of the toner using the equation (2). 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 only the toners on the center of the transition regions of the recording medium, that is toner #21 and #24. The toners #22 and #23 are not attracted strongly to the recording medium, though they are positioned in black image area. The result of calculation of distribution of Z direction component of the magnetic force acting on a small magnetic particle using the equation (1) is similar to what is shown in Fig.7.

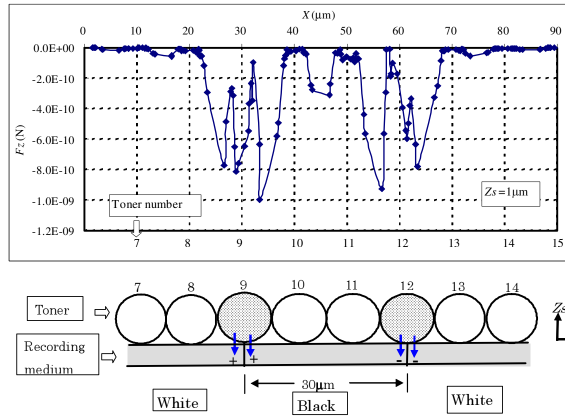

***Figure 6**. Distribution of z-direction component of the magnetic force acting on the toners by FEM.*

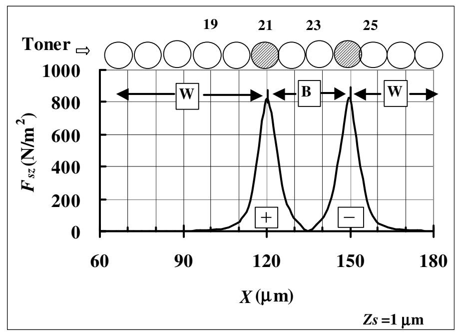

***Figure 7**. Distribution of the magnetic force of z-direction at the cross section of the toner layer.*

X direction component of the magnetic force acting on the toner

Fig.8 shows distribution of X direction component of the magnetic force acting on the toners calculated using the electromagnetic simulator.

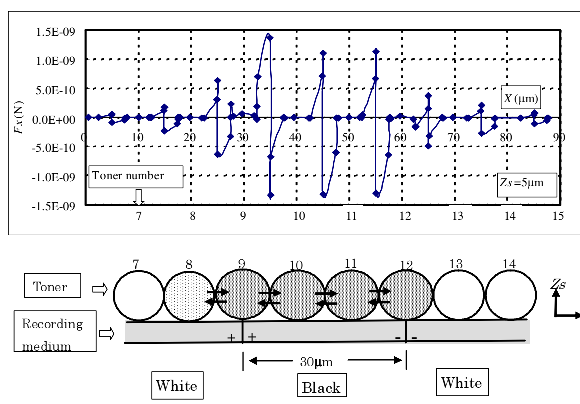

***Figure 8**. Distribution of x-direction component of the magnetic force acting on the toners by FEM.*

It is shown that strong magnetic force acts on the part of the toner at the boundary surface between the adjoining toners, which are located in the black image area, between toner #9 and #10, between toner #10 and #11, and between toner #11 and #12. Therefore strong force acts on 4 toners in the black image area. The force with positive sign is directed to "+X" direction while the force with negative sign is directed to "-X" direction. Since the direction of the force is inversed at the respective side of the boundary between the adjoining toners, it is absorbing force. Therefore the adjoining toners #9 and #10, toners #10 and #11, and toners #11 and #12 are attracted to each other respectively.

Experiment with an enlarged mode

Fig.9 shows distribution of the magnetic force using an enlarged model. As shown in my previously published paper, permanent magnet bars are likened to recording medium and steel ball is likened to toner [4]. Magnetic force acting on a steel ball is measured by a balance. Magnification is 1000. The diameter of the steel ball is 10mm which corresponds to toner with 1µm. A magnetic bar is 30mm long, which corresponds to the black image area of the recording medium with 30µm long and another magnetic bar is 90mm long, which corresponds to the white image area of the recording medium with 90µm long .

Fig.9 shows that 5 toners have strong attracting force in the black image area to form black image and 7 toners have weak attracting force in the white image area to form white image.

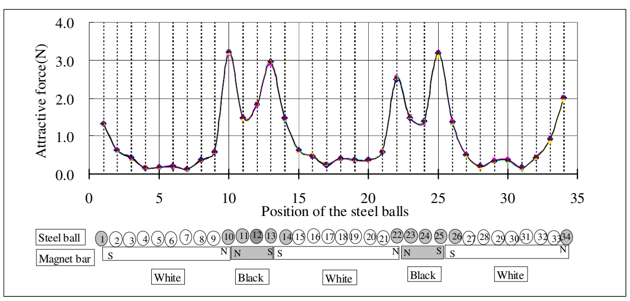

Figure 9*. Distribution of the magnetic force acting on a steel ball in the enlarged model experiment.*

Consideration

Taking the above results together into consideration, the following things are found. Toner is attracted strongly to the recording medium across the center of the transition regions of the recording medium, such as the toner numbered 9 or 12. It is as if foundation is built. The toner located at the intermediate region between the transition regions of the recording medium, which is included in the black image area, such as the toner numbered 10, or 11, is weakly attracted to the recording medium but strongly attracted to the next toners at the boundary surface. It is as if a girder is built. Therefore toner-bridge is formed between the adjoining transition regions of the recording medium by the toners numbered 9, 10, 11 and 33.

As a result it is considered that 4 toners contribute to form black image. On the other hand, since the white image area comprises 8 toners which get weak magnetic force, they can be removed easily by the developing magnetic field and form white image. If it is assumed that the toner image is spread by one toner size after the heat fusing process, the resultant size of the black image on paper will grow as large as 5 toners and the white image will be reduced as large as 7 toners.

In addition, if the toners numbered 8 and/or 13which has rather strong force join the black image, 6 or 7 toners contribute to form black image and resultantly the white image will be as large as 6 toners or 5 toners, respectively. In either case, each of the black image and the white image will have almost the same size, namely 1:1 long.

Conclusions

In order to get suitable ratio of the interval 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 of1/2dot between the adjoining transition regions of the recording medium is allocated to 1 dot black image area, while the distance of 3/2 dot between the adjoining transition regions of the recording medium is allocated to 1 dot white image area. A toner arrangement model is assumed wherein a toner is placed at the center of the transition region and the other toners are placed side by side. It is found that the proposed ratio of magnetic latent image is proper to realize almost 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 higher density, will be studied after this.

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References

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Author Biography

Norio Kokaji received his 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.