Improvement of gradient index array using illumination analysis

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Abstract

A gradient index array, which has plural gradient index rods, is installed in the LED print head. In order to improve optical resolving power of the gradient index array, shielding the rays which blurred images was investigated by using the illumination analysis. In the calculation model, apertures arranged in such a position that outer portions of surfaces of rods in the gradient index array were shielded and the rays near axes of the rods were transmitted.

The illumination analysis was a certain kind of the Monte Carlo calculation; a large amount of random rays was radiated from light sources to images in optical models.

In this study, alterations of the dot diameter and the dot irradiance caused by radiuses of apertures change were analyzed by using the illumination analysis.

The current results in the illumination analysis showed that arranging apertures in the gradient index array provided small dots. Arranging the smaller apertures caused the dots became smaller. At the same time, the reduction in the radius of the apertures increased amounts of the shielded rays so that the dot irradiance became lower.

In addition, arranging the apertures and the reduction in the radius of the apertures enlarged the focus of the gradient index array.

Furthermore, the reduction in the radius of the apertures provided the larger focal depth.

Arranging apertures in gradient index array are effective to control the aberrations. The current analysis shows the LED print head with the apertures will expose smaller dots than a LED print head without the apertures does. In addition, arranging the apertures will permit to ease assembly accuracy of the LED print head.

The apertures are effective to correct the aberrations; however, apertures cannot correct the field curvatures and the distortions. Therefore, the higher resolution images require other investigations to correct these optical problems.

Introduction

Printing the high-quality toner images requires electrostatic field to be high-contrast between the image and the background. High-contrast latent images will not affect on toner charge instability, toner size distribution and compositional tolerance so that high-contrast latent images will provide a consistent quality of the toner images. Furthermore, high-contrast latent images require sufficiently small and sharp light images of the dots with the exposure device.

A LED print head has plural LED elements arranged in a line and the gradient index array. The LED elements in the LED print head are arranged in same resolution of the image and are arranged same long as width of a printing area.

The gradient index array has the plural gradient index rods which had index distribution in the radial direction of the rods. The gradient index array aligned parallel with the LED elements arranged in a line. Elected images are exposed at same magnification of the source by the gradient index array.

Figure 1 shows an appearance of a model of the gradient index array, which is installed in the LED print head. The gradient index rods are arranged in two lines with the optical axes in parallel with one another.

A typical gradient index array has parabolic distribution of the index. Index distributions $n(r)$ of the gradient index array are indicated as following expression[1];

$$n(r) = n_0\left(1 - g\, r^2/2\right) \qquad (1)$$

Where r is radius of the rod, n_0 is the index of the axis of the rod and g is the gradient coefficient of the index distribution of the rod.

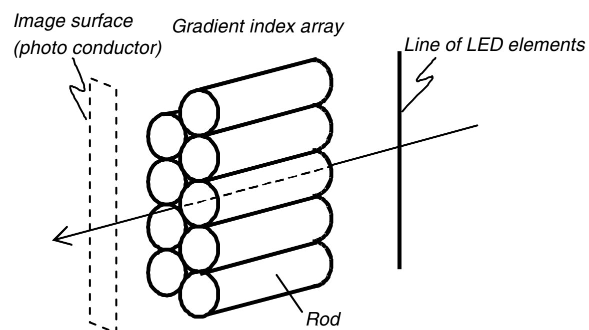

***Figure 1**. Configuration of LED print head.*

Rays from an emitting source point pass through the plural rods. In other words, images of the source are exposed by the plural rods. Therefore, if the aberrations of each rod blurred the images, these images will be accumulated and will be more blurry.

To correct the aberrations of the gradient index array, optimization of the distribution of the index of the rod is probably effective. However, it is difficult to control the distribution of the index of the rod made by the ionic diffusion.

Therefore, shielding the rays which blurred images was investigated by using the illumination analysis. In the calculation model, the apertures were arranged in such a position that outer portions of the surfaces of the rods were shielded and the rays near the axes of the rods were transmitted.

Theory

Figure 2 shows the light path from one of the sources to the image; the rays which pass through the nearest rod from the source and pass through the rod separately located from the source are drawn.

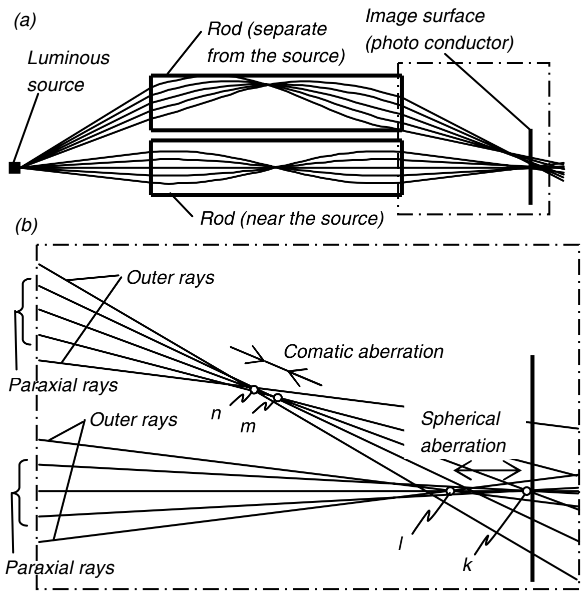

Figure 2*. The light path from one of the sources to the image;(a) The rays, the nearest rod from the source and the rod separately located from the source; (b) Enlarged view along the broken line.*

As shown in figure 2, the spherical aberrations and the comatic aberrations are occurred in this optical system. Paraxial rays which are conically-shaped pass through near the axis of the nearest rod are collected at *k*. Meanwhile, outer rays from the nearest rod are collected at *l*. The paraxial rays from the nearest rod have the longer focus than the outer rays have. Thus, the gradient index array has positive spherical aberrations. In the same way, the paraxial rays from another rod are collected at *m*, and outer rays from another rod are collected at *n*. The paraxial rays from another rod have the longer focus than the outer rays have, and the gradient index array has positive comatic aberrations.

As apertures are arranged in such a position that outer portions of surfaces of rods in the gradient index array are shielded and the rays near axes of the rods are transmitted, the rays pass through circumference of the rods are shielded. As a result, the spherical aberrations and comatic aberrations are correct in the optical system.

In figure 2, a discrepancy between *k* and *m* is caused by the field curvatures and the distortions. The apertures are unable to correct these problems.

Analysis

The image surface, the apertures, the gradient index rod and the source were arranged in a calculation model as figure 3. In the calculation model, apertures arranged in such a position that outer portions of the surfaces of the rods were shielded and the rays near axes of the rods were transmitted; where *TL* is distance from the object surface to the source, L_I is distance from the image surface to the rods, L_R is length of the rods and L_O is distance from the rods to the source.

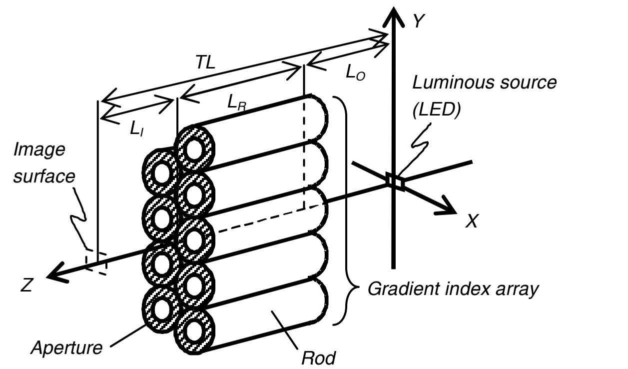

Figure 3*. Configuration of the calculation model; where TL is distance from the source to the image surface, L_I is distance from the image surface to the rods, L_R is length of the rods and L_O is distance from the rods to the source. The apertures shield outer portions of the surfaces of the rods, and transmit the rays of near axis of the rod*

The calculation model had one luminous source. The source was same shape as 1200dpi LED print head, which had LED elements arranged in a line at 0.021mm interval. The source had uniform irradiance spatial distribution and Lambert irradiance angular distribution.

Figure 4 was an irradiance distribution of an image on the image surface. The dot diameter, *D* was defined as figure 4; Where I_{max} was the maximum value of irradiance distributions.

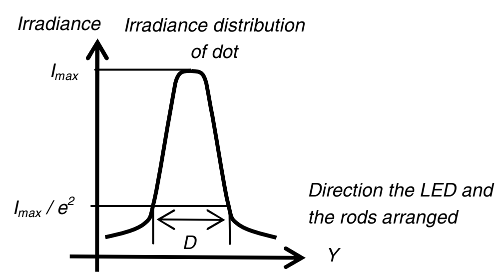

Figure 4*. An irradiance distribution of a dot on the image surface; D is defined as a dot diameter; Where I_{max} is the maximum value of irradiance distributions.*

The alterations of the dot diameter and the dot irradiance caused by *TL* and the radius of apertures change were analyzed under $L_O = L_I$ and L_R fixed.

Figure 5 is the results of the relation of *TL* and the dot diameters, *D*; the aperture radiuses, R_A are indicated as a ratio of the aperture radius to the radius of the rod.

As illustrated figure 5, the smaller the radius of apertures was, the smaller the dot became. In addition the smaller the radius of apertures was, alterations of the diameters by *TL* were less steep. In other words, the smaller radius of apertures was, the larger the focal depth was.

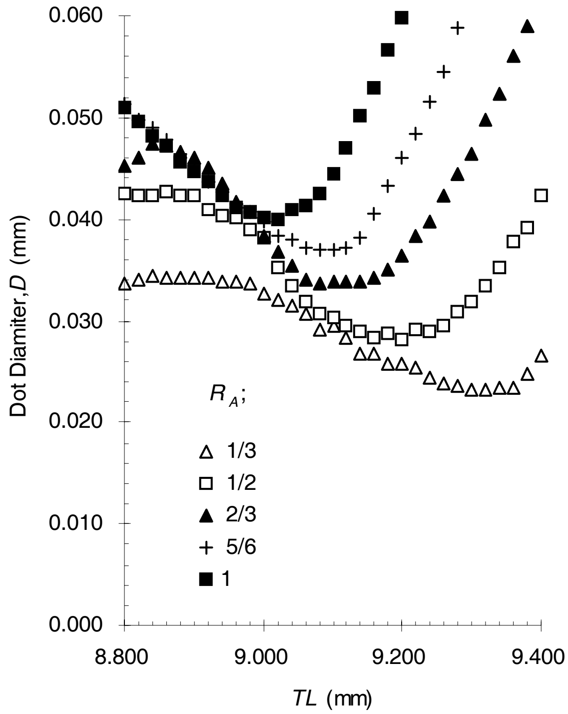

***Figure 5**. The relations of TL and the dot diameters D; the aperture radiuses, R_A are indicated as a ratio of the aperture radius to the radius of the rod*

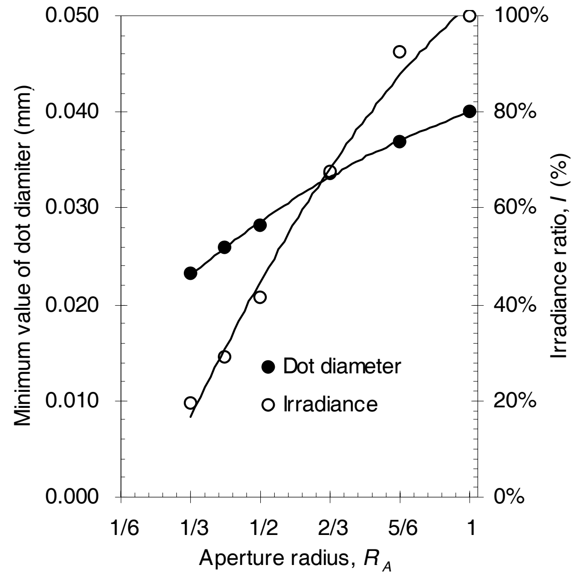

***Figure 6.** The relation of the radius of the apertures, R_A and the minimum dot diameters are shown on the left coordinate. The relation of R_A and the irradiance ratio, I are shown on the right coordinate; The irradiance ratio, I indicated as a ratio to the dot irradiance without the apertures; Lines are to guide the eye.*

Figure 6 is redrawn the relation of the radius of the apertures and the minimum dot diameters on the left coordinate. The dot diameter was 0.040mm without the apertures, but the dot diameter was 0.028mm at which the aperture radius was half a size of radius of the rod. The smaller the radius of apertures was, the smaller the dot became.

Figure 6 shows the relation of the radius of aperture, R_A and a dot irradiance ratio, I on the right coordinate. The irradiance ratio, I indicated as a ratio to the dot irradiance without the apertures. The irradiance ratio, I was 48% in which the aperture radius was half a size of radius of the rod. The smaller the radius of apertures was, the lower the dot irradiance was.

In figure 7, the relation of the radius of aperture, R_A and *TL* at which the dot diameters became the minimum value are shown on the left coordinate. *TL* was 9.000mm without the apertures, but *TL* is 9.200mm in which the aperture radius was half a size of radius of the rod. The smaller the radius of apertures was, the longer *TL* became.

In addition the relation of R_A and focal depth are shown in figure 7 on the right coordinate; The focal depth were defined as displacement of *TL* within 10% alteration of the dot diameter compare to the minimum dot diameter. The focal depth, without the apertures, was 0.17mm. But the focal depth was 0.20mm with the aperture radius was half size of radius of the rod. The smaller the aperture radius was, the larger the focal depth was.

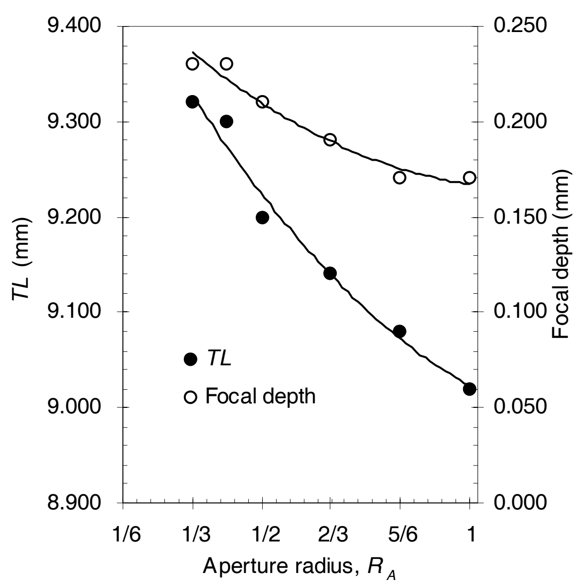

***Figure 7.** The relation of the radius of aperture, R_A and TL at which the dot diameters became the minimum value are shown on the left coordinate. The relation of R_A and the focal depth are shown on the right coordinate; Focal depth was defined as displacement of TL within 10% alteration of the dot diameter compare to the minimum dot diameter. Lines are to guide the eye.*

Discussion

The current results in the illumination analysis showed that arranging apertures in the gradient index array provided small dots. Arranging the smaller apertures caused the dots became smaller. The apertures shielded rays pass through outer circumference of the rods, and the spherical aberrations and comatic aberrations were corrected in the gradient index array.

At the same time, the reduction in the radius of the apertures increased amounts of the shielded rays so that the dot irradiance became lower.

As mentioned above, the gradient index array had positive spherical aberrations and comatic aberrations. The rays passed through outer circumference of the rods had the shorter focus and the rays were collected in front of the image surface (the photo conductor). The apertures shielded these rays so that arranging the apertures and the reduction in the radius of the apertures enlarged the focus of the gradient index array.

Furthermore, the reduction in the radius of the apertures caused alterations of the diameters by the focus became less steep. In other words, the reduction in the radius of the apertures provided the larger focal depth. Arranging the apertures will permit to ease accuracy of the gradient index array positioning.

As with this study, arranging a slit which had an aperture as a thin line parallel with a gradient index array provided small dots on the prior study[2]. However, the reduction of the slit width maintained a focus length and focal depth of the gradient index array on the prior study.

The current analysis showed that arranging apertures in gradient index array were effective to control the aberrations. Nevertheless, apertures cannot correct the field curvatures and the distortions, because, apertures are unable to confirm m to k in figure 2. Therefore, the higher resolution images require other investigations to correct these optical problems.

Conclusion

In the analysis, arranging apertures in gradient index array are effective to correct aberrations. The current analysis shows the LED print head with the apertures will expose smaller dots than a LED print head without the apertures does. In addition, arranging the apertures will permit to ease assembly accuracy of the LED print head.

By arranging the apertures in the LED print head, high-contrast electrostatic latent image will be acquired, and we will be able to print high-quality toner images.

Hereafter, toner images which are produced by the LED print head with the apertures will be investigated.

The apertures are effective to correct the aberrations; however, the higher resolution images require correcting the field curvatures and the distortions.

References

[1] Iga et al., Super-precisional manufacturing and mass producing of micro lens array (in Japanese), Technical Information Institute. (2003)

[2] A. Yamamura., Improvement of optical characteristics of gradient index array (in Japanese), proc. Imaging Conference JAPAN 2007, pg. 291 (2007)

Author Biography

Akihiro Yamamura received his Master of engineering degree in Yokohama National University in 2000, and joined Oki Data Corporation. He has worked at Strategic Technology Development Group, and engaged in research and development into developing process and exposure devices.