Simulating resolution of gradient index array using illumination analysis

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Abstract

An LED print head has a gradient index array. In order to improve resolving power of the array, resolution of the arrays were analyzed by using the illumination analysis. The array has plural gradient index rods, which have a refractive index distribution in the radial direction of the rods. An erected image is exposed at same magnification of an object by the array. In the illumination analysis, a large amount of random rays was radiated from light sources to images in a simulation models. The current results showed the resolution of the array depend on a coefficient of refractive index distribution (gradient coefficient) and a rod radius. A small gradient coefficient improved the resolution of the array. A reduction in the radius improved the resolution of the array. The small gradient coefficient and the reduction in the radius causes small aperture angle of the rod. The rod has a small aperture angle don't pass through rays which have a large comatic aberration and causes a large field curvature. If the rod has a stable refractive index distribution in manufacturing but poor resolution, it seems to be effective that after forming the refractive index distribution, the rod is trimmed and the radius is reduced to improve the resolution.

Introduction

It is expected that a high-definition print image will be required. It requires a high contrast latent image and a high-resolution optical system.

In addition, optical uniformity in a scan direction of an LED print head is required. More specifically, optical uniformity in rods arranged direction of an array is required. Therefore it is desirable that a refractive index distribution of a rod is stable in manufacturing.

In this study, it was investigated how much the reduction in the radius improve the resolution by the simulation, and whether trimming the rod and reducing its radius after forming the refractive index distribution was effective or not.

Theory

A gradient index rod of an array has a refractive index distribution in its radial direction. A typical gradient index array has parabolic distribution of the refractive index. A refractive index distribution $n(r)$ of the gradient index array is indicated as following expression;

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

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

As the following expression, an angle of aperture of the rod, α is proportional to the product of the radius and the gradient coefficient;

$$\alpha = n_0 \cdot g \cdot r \tag{2}$$

The small radius and the small gradient coefficient make the angle of aperture small.

Rays pass through the rod from a distant object have large field curvature. However, rays from a distant object can't pass through the rod has the small angle of aperture. Therefore the small angle of aperture decreases field curvatures of the rod. Consequently, the reduction in the radius and the small gradient coefficient decreases field curvatures of the rod.

Additionally rays from a distant object have large comatic aberrations. The reduction in the radius and the small gradient coefficient decreases comatic aberrations of the rod. Furthermore rays incoming an outer portion of a rod have a large comatic aberration. The reduction in the radius decreases comatic aberrations of the rod.

Simulation model

In this study, a resolution of an array is calculated by the illumination analysis. The illumination analysis is a certain kind of the Monte Carlo calculation; a large amount of random rays is radiated from light sources to a receiver in a simulation model.

The simulation model is described. As shown in figure 1, a receiver, the gradient index rods and a luminous source were arranged in the simulation model; where L_I is an image length, a space from the receiver to the rods, L_O is an object length, a space from the rods to the luminous source and L_R is a rod length.

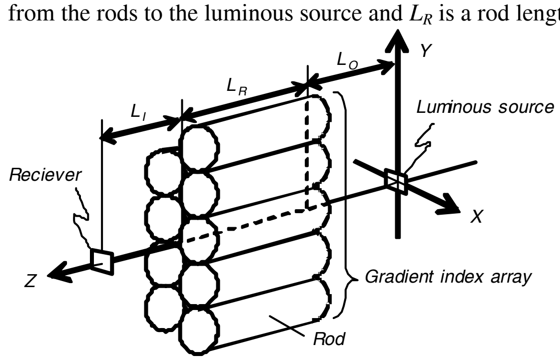

***Figure 1**. Configuration of the simulation model; where L_I is image length, distance from receiver to rods, L_R is rod length and L_O is object length, distance from rods to source.*

In this study the rod length, L_R is defined as following typical condition;

$$L_R = 7L_P/12 \quad (3)$$

Rays in the rod follow sinusoidal tracks. Where L_P is a period length of the sinusoidal track;

$$L_P = 2\pi/g \quad (4)$$

The simulation model had one luminous source. Figure 2 is a target used as the luminous source in the simulation; P_D was equal to luminous sources intervals of 2400dpi print head, which had luminous sources arranged in a line at 0.0106mm intervals. Light emitting portions of the target had uniform irradiance spatial distribution and Lambert irradiance angular distribution.

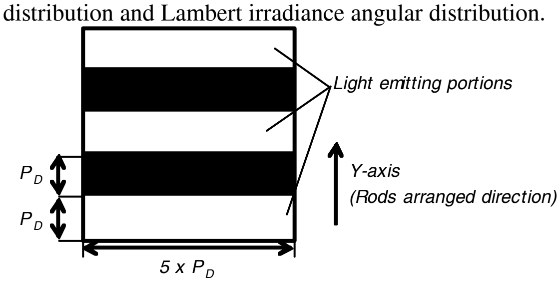

Figure 2. *Target used as luminous source in the simulation; P_D is equal to source interval of 2400dpi print head, P_D = 0.0106mm.*

MTF (Modulated Transfer Function) was calculated from an illuminance distribution of the image on the receiver. Figure 3 shows the illuminance distribution; where I_{MAX} is maximum value of the illuminance distribution, and I_{MIN} is minimum value of the illuminance distribution. MTF is defined as follows;

$$\frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} \times 100 \ (\%) \quad (5)$$

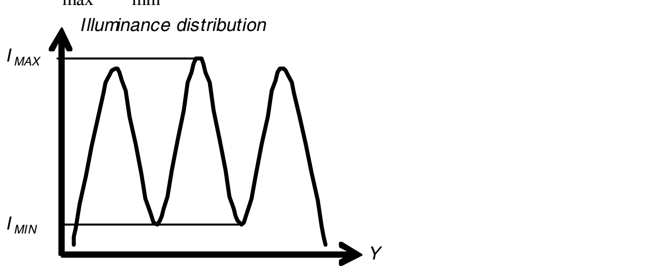

Figure 3. *Graph showing illuminance distribution of image on receiver; I_{MAX} is maximum value of illuminance distribution, and I_{MIN} is minimum value of illuminance distribution.*

Simulation results

Alterations of the illuminance distributions caused by the object length L_O change were analyzed by the illumination analysis under $L_I = L_O$ with the gradient coefficient g at 0.420, 0.630 and 0.841 and the rod radius R at 0.170, 0.225, 0.280 and 0.340. MTF alterations caused by the object length L_O change under $L_I = L_O$ were calculated from the illuminance distributions.

Figure 4 shows the relation between object length L_O and MTF with gradient coefficient g at 0.420, the rod radius R at 0.170, 0.225, 0.280 and 0.340. The smaller the rod radius was, the higher the resolution became. It was shown that the radius smaller than 0.25mm caused the resolution higher than 80%. The small radius made the object length slightly large.

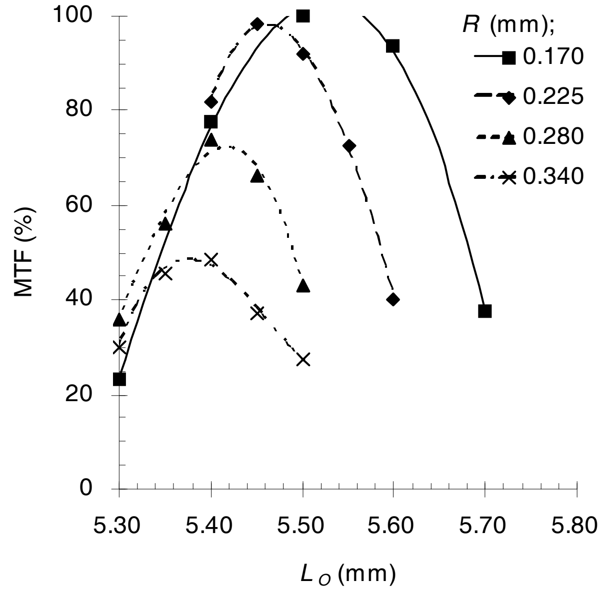

Figure 4. *Relations MTF and object length L_O with gradient coefficient g at 0.420, with rod radius R at 0.170, 0.225, 0.280 and 0.340; Lines are to guide the eye.*

Figure 5 shows the relation between object length L_O and MTF with gradient coefficient g at 0.630, the rod radius R at 0.170, 0.225, 0.280 and 0.340. It was shown that the radius smaller than 0.20mm caused the resolution higher than 80%.

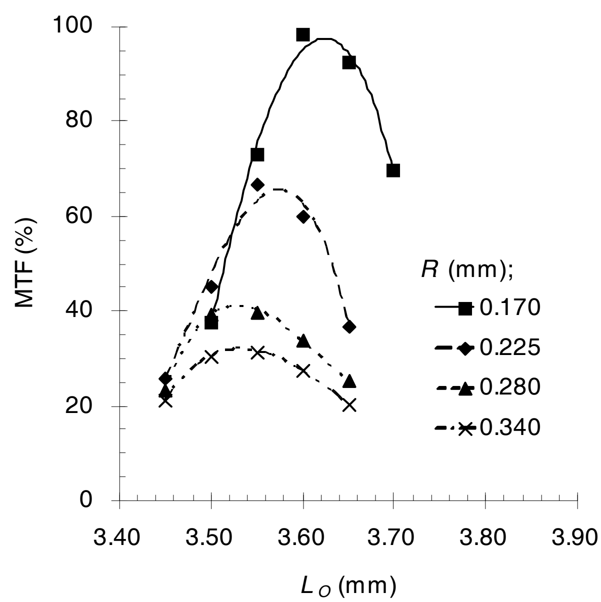

Figure 5. *Relations MTF and object length L_O with gradient coefficient g at 0.630, with rod radius R at 0.170, 0.225, 0.280 and 0.340; Lines are to guide the eye.*

Figure 6 shows the relation between object length L_O and MTF with gradient coefficient g at 0.841, the rod radius R at 0.170, 0.225, 0.280 and 0.340. It was shown that the radius smaller than 0.17mm caused the resolution higher than 80%.

Figure 4, 5 and 6 shows that the smaller the gradient coefficient was, the larger the object length became.

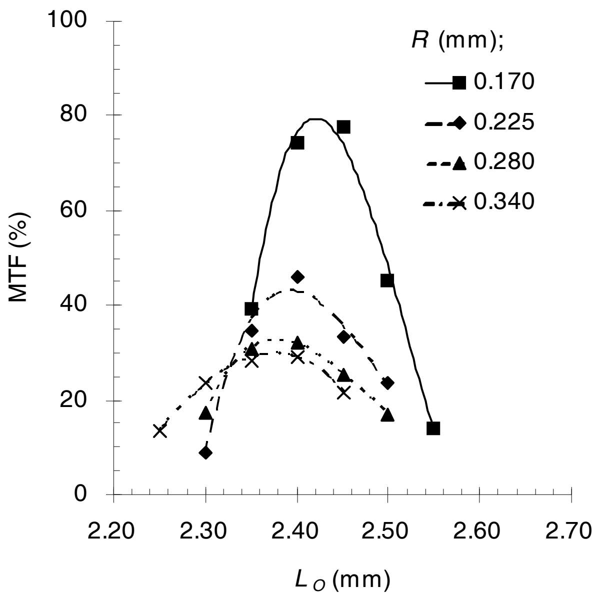

Figure 6. *Relations MTF and object length L_O with gradient coefficient g at 0.841, with rod radius R at 0.170, 0.225, 0.280 and 0.340; Lines are to guide the eye.*

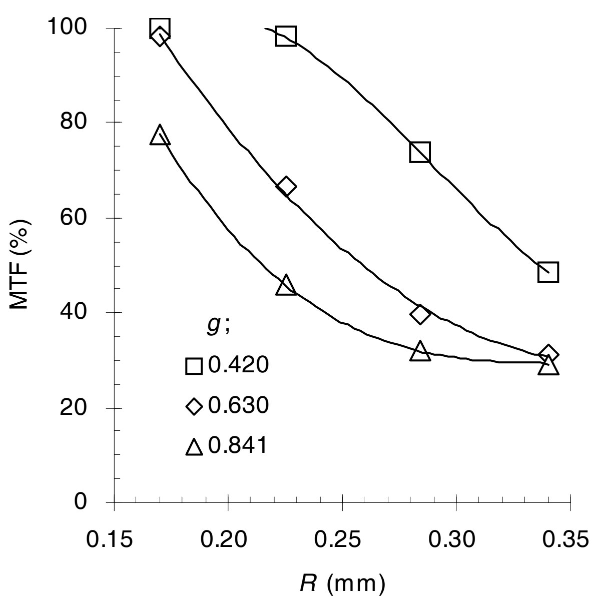

Figure 7. *Relations maximum value of MTF and rod radius R with gradient coefficient g at 0.420, 0.630 and 0.841; Lines are to guide the eye; Reproduced from figure 4, 5 and 6.*

Figure 7 was reproduced from figure 4, 5 and 6. Figure 7 shows the relation between the rod radius and maximum value of MTF with gradient coefficient g at 0.420, 0.630 and 0.841. It is confirmed the smaller the rod radius was, the higher the resolution became and the smaller the gradient coefficient was, the higher the resolution became.

A reduction in the radius improved the resolution of the array. It is effective that the rod is trimmed and the radius is reduced to improve the resolution after forming the refractive index distribution.

Conclusion

Since the reduction in the radius improved sufficiently the resolution of the array, trimming a rod and reducing a rod radius is effective to improve a resolution. In addition it was confirmed that the smaller the gradient coefficient of the rod was, the higher the resolution of the array was.

The reduction in the radius reduced the angle of aperture of the rod. And the small gradient coefficient made the angle of aperture small. The small angle of aperture decreased the comatic aberration of the rod and the field curvature of the rod.

This result showed the improvement of the resolution of the rod by the radius reduction allowed to control the resolution after forming a refractive index distribution of the rod.

It is desirable that a refractive index distribution of a rod is stable in manufacturing, because optical uniformity in rods arranged direction of an array is required. It is effective that the rod is trimmed and the radius is reduced to improve the resolution after forming the refractive index distribution. Incidentally a chemical etching can trim a rod.

References

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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 toner developing system and optical system of LED print head.