Four-Beam Scanning Optical System with a Converting Function of Seven-Level Print-Dot-Density

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Abstract

Multiple-beam scanning optical systems are widely used for high-speed and high-resolution printers. One of the requirements that the printer with several levels of print-dot-density has is conversion of intervals of scanning lines formed by multiple beams. For this purpose, we developed a converting lens system, which consists of a couple of lenses, and designed four-beam optical system with a converting function of seven-level print-dot-density.

Introduction

Laser printers are advancing steadily toward high-speed, high-resolution, and wide printing area. Simultaneous scanning of multiple beams in an array is widely used for these printers in order to keep the rotating speed of the polygonal mirror and the data rate for printing in the practical limits. Besides that, some clients need to print an original data with various sizes. For this situation, some different print-dot-density are required with one printer.

To achieve this, converting intervals of scanning lines formed by multiple beams is the question proper to multiple-beam scanning system. At first, we developed a converting lens system that consists of two spherical lenses, which have an ability to convert the magnification ratio in the sub-scanning direction. However, it was appeared that the converting lens system would make the printing area narrower. To compensate it, we found that the addition of a spherical lens would be effective. In this paper, the optimization of the converting lens system and an example of several levels of print-dot-density using this system are discussed.

Configuration of Scanning Optical System

A typical configuration of the optical system for laser beam printer is shown in Fig. 1.

Multiple beams emitted from multiple light sources such as laser diode array are fed to a rotating polygonal mirror. Then, the beams are deflected and focused on a photoconductor drum with scanning lenses. Finally, we obtain multiple scanning lines simultaneously. The interval of scanning lines P_D is given by

$$P_D = MP_S \qquad (1)$$

where M is the magnification ratio in the sub-scanning direction, P_S is the interval of the light sources in the sub-scanning direction.

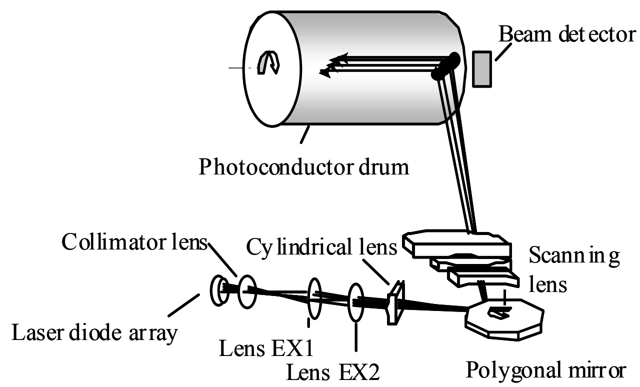


Figure 1. Configuration of optical system.

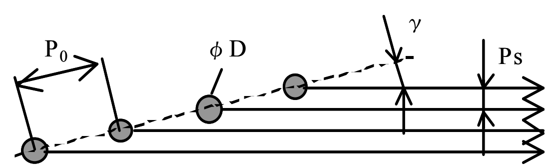


Figure 2. Arrangement of laser diode array.

As regards general laser diode array, the period of light sources P_0 is several tens of times larger than the diameter of light sources D. Therefore they are necessarily arranged in a slant angle γ to the scanning direction,[1] as shown in Fig. 2.

The configuration of the optical elements that are placed between the light source and the polygonal mirror in the scanning direction is shown in Fig. 3(a), that in the sub-scanning direction is shown in Fig. 3(b), where the focal length of collimator lens, lens EX1, lens Ex2, and cylindrical lens are f_{COL},f_{EX1},f_{EX2}, and f_{CYL} respectively.

Every light source is placed separately each other not only in the sub-scanning direction but also in the scanning direction because of the reason mentioned above. Lens EX1 and lens EX2, which are spherical lenses, are arranged in a telescopic configuration and expand the width of the parallel beams. The facet of the polygonal mirror is placed at the back focal plane of lens EX2 so that all the parallel beams are incident upon nearly the same position of the facet. Accordingly, we do not have to make the facets larger even if multiple beams are used. A cylindrical lens in front of the polygonal mirror is used, as is generally known, for correcting the deterioration caused by wobbles of the polygonal mirror.

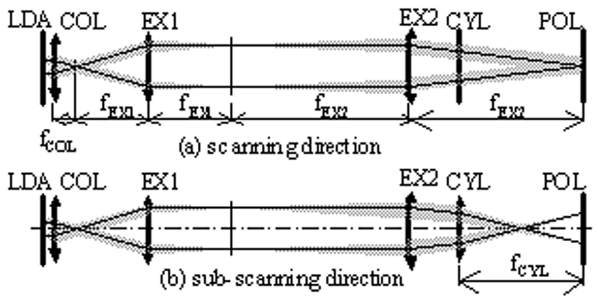


Figure 3. Configurations of optical elements.

Conversion of the Intervals of Scanning Lines

It is inevitable that the intervals of scanning lines on the photoconductor drum change according to the print-dot-density. If the number of the beam is unity, we can make them appropriate by merely optimizing the rotating speed of the polygonal mirror. On the other hand, if the number of the beams is plural, means of converting them are requisite.

For this purpose, we have to change the interval of light source Ps or the magnification ratio M, as it is clear from the Eq. (1). Some methods for changing the interval Ps have been introduced, but we considered that they would be required too much precision to be realized. So we tried to develop a method for changing the magnification ratio M, and designed a converting lens system that consisted of two spherical lenses. They are a positive and a negative lens, and the angular magnification is set to be 0.8 that corresponds to the ratio of print-dot-density (480/600). Even if the interval of the light sources in the sub-scanning direction is fixed, we can change the interval of scanning lines by means of inserting it into the optical axis, keeping these beams being focused on the photoconductor drum.

However, there is a problem to be solved. By inserting the converting lens system into the optical axis, the intersection of multiple beams in the scanning direction moves from the facet because of the variance of the angular magnification. It causes the area where beams strike the facet to be widening, as shown in Fig. 4.

The relationship between the excess of the facet and the scanning position, assuming that the number of beams is 4 and the required scanning area is 500mm, are shown in Fig. 5.

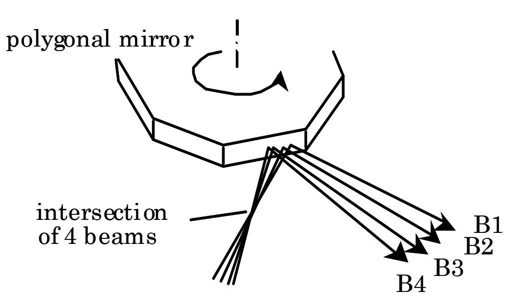


Figure 4. Intersection of multiple beams.

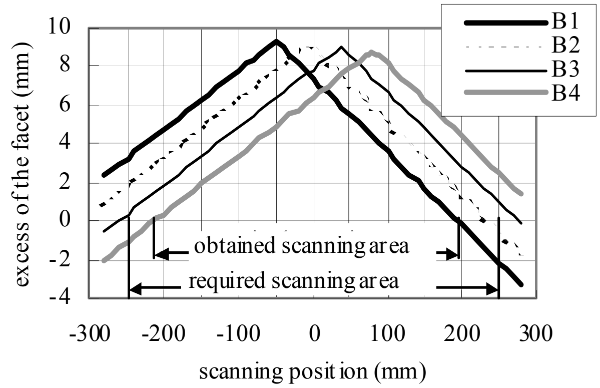


Figure 5. Scanning area for each beam when the converting lens system is inserted.

The negative value in the longitudinal axis means insufficient for scanning because of the truncation of the beam. Each beam can scan different area because of the movement mentioned above; accordingly the area we can get would be considerably reduced.

In order to correct the defect, we examined a new converting lens system consist of two cylindrical lenses and a spherical lens that are S1, S2 and S3 respectively. The configuration in the scanning direction is shown in Fig. 6(a), and that in the sub-scanning direction is shown in Fig. 6(b), where z is the distance between the focal plane of Lens EX1 and the principal plane of Lens S3, and $HH_{1,2}$ is the sum of the distance between two principal planes of Lens S1 and S2. The focal lengths of two cylindrical lenses are equal to that of the spherical lenses in the converting lens system developed before so as to maintain the magnification ratio in the sub-scanning direction. On the other hand, they have no power in the scanning direction so the intersection remains on the surface of the facet. The spherical lens is utilized to compensate the divergence caused by the distance $HH_{1,2}$. The function of the spherical lens in detail is indicated in the Fig. 7.

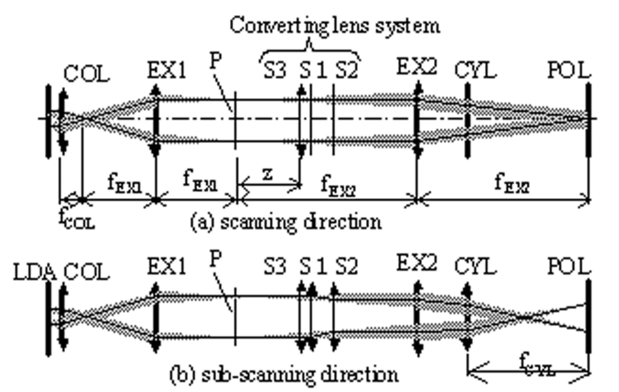


Figure 6. Configurations of optical elements with the converting lens system

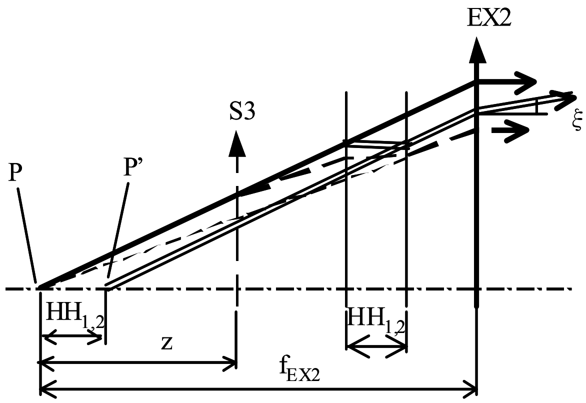


Figure 7. The function of the spherical lens S3.

The beam diverges from the front focal point of lens EX2 P is paralleled by the lens (solid line). If two cylindrical lenses of which the sum of the distance between two principal planes is $HH_{1,2}$ are inserted, the beam is shifted and diverges from the point P' (double line). As the object point P' is located closer than the front focal point P, the beam is not paralleled enough by the lens EX2, and travels in the direction of ξ. The beam is slightly converged by the lens S3, which has a positive power, and incidents to lens EX2 as if it diverged from the point P' (broken line). That is, lens S3 works as moving the object point from P' to P. We optimized the specifications of lens S3. For the treatment of ray tracing, matrix representation is useful, as is shown in Eqs. (2), (3), and (4),

$$\begin{bmatrix} h_a \\ u_a \end{bmatrix} = \begin{bmatrix} 1 & f_{EX2} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -1/f_{EX2} & 1 \end{bmatrix} \begin{bmatrix} 1 & Q \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -1/f_{S3} & 1 \end{bmatrix} \begin{bmatrix} 1 & z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ -1/f_{EX1} \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} h_c \\ u_c \end{bmatrix} = \begin{bmatrix} 1 & f_{EX2} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -1/f_{EX2} & 1 \end{bmatrix} \begin{bmatrix} 1 & Q \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -1/f_{S3} & 1 \end{bmatrix} \begin{bmatrix} 1 & z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad (3)$$

$$Q = f_{EX2} - (z + HH_3 + HH_{1,2}) \quad (4)$$

where h is the beam height, u is the beam direction respect to the optical axis, f_{EX2} is the focal length of lens EX2, f_{S3} is the focal length of lens S3, HH_3 is the distance between two principal planes of Lens S3, and the suffix 'a' and 'c' denotes the axial ray and the chief ray respectively. We set f_{EX1} = 160.3 mm, HH_3 = 0.7 mm, $HH_{1,2}$ = 2.7 mm, and the beam height at the principal plane of lens EX1 as unity.

We obtained the relationship between z, hc, and f_{S3}, under the condition of $u_a = 0$, shown in Fig. 8, and Fig. 9.

For the value of $1/f_{S3}$ represented in Fig. 8, and Fig. 9, hc is considerably small, which means all beams are incident to almost same position of the facet. However, z changes relatively larger; therefore, we determined f_{S3}, considering the limitation of the placement of lens S3. The specifications of the converting lens system are shown as Table1.

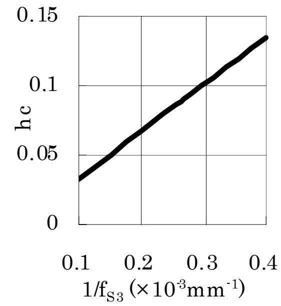


Figure 8. Beam height at the facet

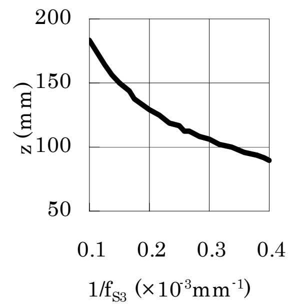


Figure 9. Position of lens S3

Table 1: Specifications of the Converting Lens System

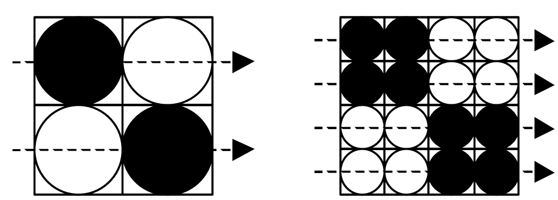
	Type	Focal length (mm)	Distance (mm)	HH (mm)
P	Focal plane	-	113.6	-
S3	Spherical lens	3.92×10^{3} $=1/0.26\times10^{-4}$	15.6	0.7
S1	Cylindrical lens	1.95×10^{2}	46.6	1.4
S2	Cylindrical lens	-2.93×10^{2}	156.9	1.3

Double Dots Double Scanning Method

There is another approach that could change the print-dot-density. An example of conventional dots arrangement with 240 dpi is shown in Fig. 10(a), and one with 480 dpi is shown in Fig. 10(b). A dot in 240 dpi can be formed by scanning the double dots in 480 dpi twice, considering 2 × 2 dots that are modulated alike as one dot. Therefore we can obtain the dot density 240 dpi with the intervals of scanning lines for 480 dpi.

Seven-Level Print Dot Density

A typical specifications for print-dot-density that we have been required are shown as Table 2.



(a) 240dpi (b) 480dpi

Figure 10. Arrangement of dots

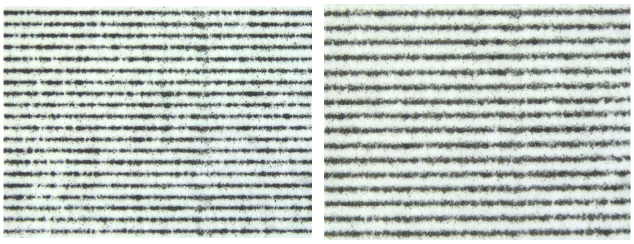
Table 2: Specifications for Various Dot-Density

dpi	600	480	343	320	300	267	240
P_D	42.3	52.9	74.1	79.4	84.7	95.2	106
RR	0.4	0.5	0.7	0.75	0.8	0.9	1.0
CLS	WO	W	WO	WO	WO	W	W
DD	WO	WO	W	W	W	W	W
Dev	0	0	-.17	-.08	0	-.13	0

dpi: print-dot-density, P_D: optimum intervals of the scanning lines (micro meter), RR: reduction ratio, Dev: deviations from P_0 (relative value), CLS: the converting lens system, DD: Double dots double scanning method, W: with, and WO: without.

The deviations are calculated in the case of the lines are formed with every three absences, which is seemed to be the severest condition. Four of all are theoretically zero, and the rest are also small enough in practical use from the previous experimental data.

Two of printing samples among those are shown in Fig. 11. The intervals look to be converted correctly.



(a) 600dpi (b) 480dpi

Figure 11. Printing samples

Conclusion

To achieve several different print-dot-density using multiple beams for printers, we developed a method for conversion of intervals of scanning lines. A lens system consists of two cylindrical lenses and a spherical lens is appeared to be effective. We obtain wide printing area regardless of whether the lens system is inserted into the optical axis or not. And by utilizing the double dots double scanning method, it is possible to design the optical system with seven-level print-dot-density.

Reference

1. K. Kataoka, Y. Shibayama, M. Ohuchi, and S. Yokokawa, "Laser printer optics with use of slant scanning of multiple beams" Appl.Opt. vol. 36, No.25, 6294-6307(1997)

Author Biography

Takeshi Mochizuki was born in Saitama-Pref., Japan in 1958. He received his BE and ME degrees from the university of Tsukuba in 1981 and 1983, respectively. He has been developing optical systems for laser beam printers, in Hitachi Koki Co., Ltd. from 1983, Hitachi Printing Solutions, Ltd. since 2002 and Ricoh Printing Systems, Ltd. since 2004. He is a member of OSJ and SPSTJ.