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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 two cylindrical lenses and a spherical lens, and designed a four-beam optical system with a converting function of seven levels in print dot density. © 2008 Society for Imaging Science and Technology.*
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INTRODUCTION

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

The unique problem of the multiple-beam scanning system is to efficiently convert intervals of scanning lines formed by multiple beams for various print sizes. First, we developed a converting lens system that consists of two spherical lenses, which convert the magnification ratio in the sub-scanning direction. However, the converting lens system by itself would make the printing area narrower. To compensate the narrowed printing area, we found that the addition of a spherical lens would be effective. In this article, 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 Figure 1. Multiple beams emitted from multiple light sources such as a laser diode array are fed to a rotating polygonal mirror. Then, the beams are deflected and focused on a photoconductor drum through scanning lenses, to obtain multiple scanning lines simultaneously. The interval of scanning lines P_D is given by

$$P_D = MP_S, \tag{1}$$

where M is the magnification ratio in the sub-scanning direction and P_S is the interval of the light sources in the sub-scanning direction. As regard as a general laser diode array, the period of the light sources P_0 is several tens times larger than the diameter of light sources D. Therefore the light sources are necessarily arranged in a slant angle γ with respect to the scanning direction[1] as shown in Figure 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 Figure 3(a), and in the sub-scanning direction is shown in Fig. 3(b), where the focal lengths 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 on each other not only in the sub-scanning direction but also in the scanning direction because of the slanted arrangement of the light sources. The lens EX1 and the lens EX2, which are both spherical lenses, are arranged in a telescopic configuration; they serve to expand the width of the parallel beams. The facet of the polygonal mirror is placed at the back focal plane of the lens EX2 so that all the parallel beams are incident upon nearly the same position of the facet. Accordingly,

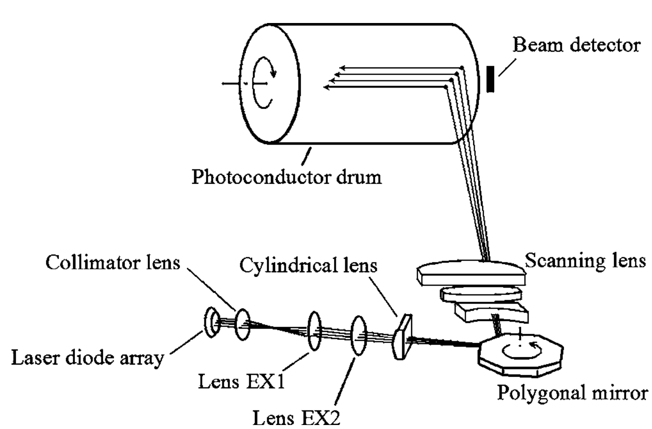

Figure 1. Configuration of optical system.

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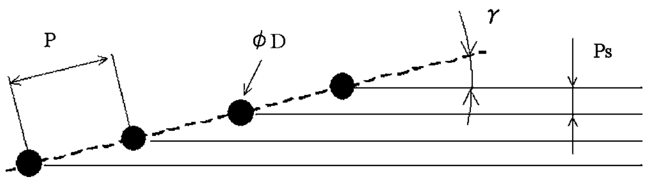


Figure 2. Arrangement of laser diode array.

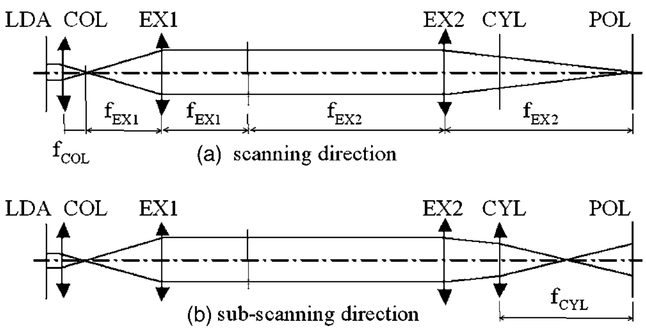


Figure 3. Configurations of optical elements.

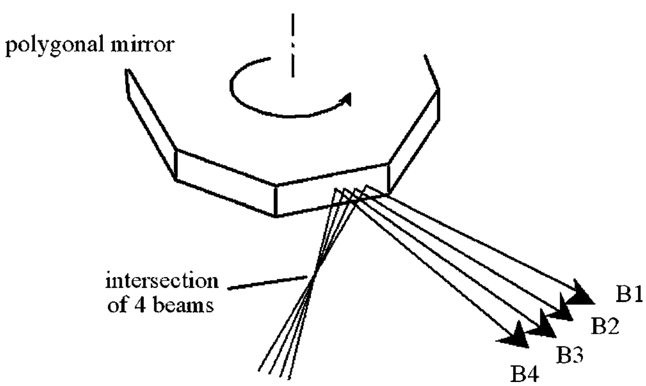


Figure 4. Intersection of multiple beams.

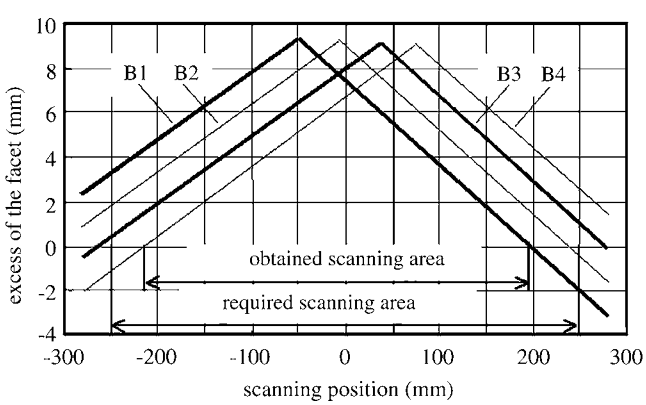


Figure 5. Scanning area for each beam when the converting lens system is inserted.

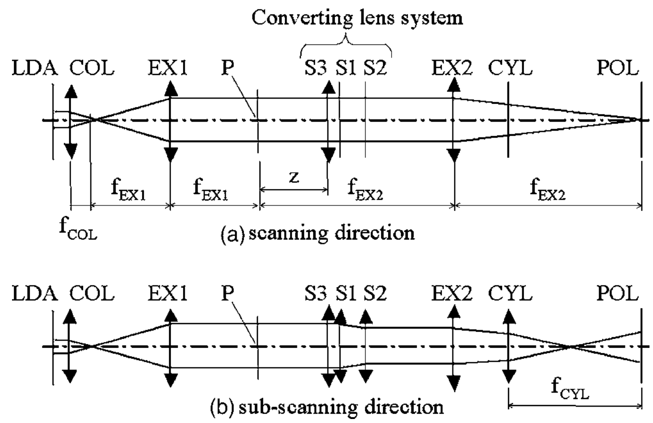


Figure 6. Configurations of optical elements with the converting lens system.

we do not have to make the facets larger even though 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.

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. For a single beam, we can make the intervals of scanning lines appropriate by merely optimizing the rotating speed of the polygonal mirror. On the other hand, for multiple beams, it is necessary to convert the intervals of scanning lines.

For this purpose, we have to change the interval of light source P_s or the magnification ratio M. Some methods for changing the interval P_s have been introduced;[2–4] however, the methods tend to require complicated structure or high precision in arrangement. Therefore, we developed a method for changing the magnification ratio M and designed a converting lens system that consists of two spherical lenses. The lenses in the two spherical lens system are a positive and a negative lens, and the angular magnification is set to be 0.8 which corresponds to the print dot density ratio, 480/600. Even if the interval of the light sources in the sub-scanning direction is fixed, we could change the interval of scanning lines by inserting the two spehrical lens system into the optical axis, keeping the beams being focused on the photoconductor drum. However, by inserting the two spherical lens system into the optical axis, the intersection of multiple beams in the scanning direction moves away from the facet because of the variance of the angular magnification in the scanning direction. The movement causes the area, where beams strike the facet, to be wide as shown in Figure 4.

The relationship between the excess of the facet and the scanning position, in the case where the number of beams is four and the required scanning area is 500 mm, is shown in Figure 5. The negative value on the longitudinal axis expresses scan inadequacy owing to truncation of the beam. Each beam could scan a different area because the intersec-

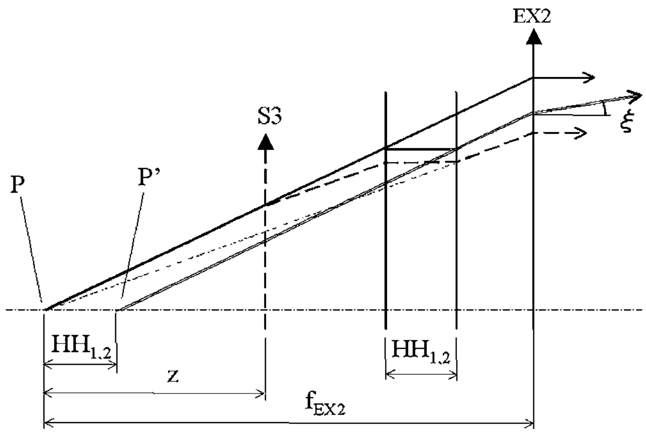


Figure 7. The function of the spherical lens S3.

tion of multiple beams moves away from the facet; accordingly the area we could obtain would be considerably reduced.

In order to correct the defect, we examined a new converting lens system consisting of two cylindrical lenses and a spherical lens that are S1, S2, and S3, respectively, as shown in Figure 6. The configuration in the scanning direction is shown in Fig. 6(a), and the configuration in the sub-scanning direction is shown in Fig. 6(b); where z is the distance between the focal plane of the lens EX1 and the principal plane of the lens S3, and $HH_{1,2}$ is the sum of the distance between the two principal planes of the lenses S1 and S2. The advantage of using two cylindrical lenses is that these two lenses have no power in the scanning direction so the intersection remains on the surface of the facet. For our new converting lens system, the two cylindrical lenses S1 and S2 are configured similarly to the conventional two spehrical lens system, which consequently maintains the magnification ratio in the sub-scanning direction.

The spherical lens S3 in the new converting lens system is utilized to compensate the divergence caused by the distance $HH_{1,2}$. The function of the spherical lens S3 in detail is indicated in the Figure 7.

The beam diverges from the point P, which is the front focal point of the lens EX2, and becomes parallel through the lens (solid line). If the two cylindrical lenses of which the sum of the distance between two principal planes is $HH_{1,2}$ are inserted, the beam shifts 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 sufficiently parallel at lens EX2, and travels in the direction ξ. The beam is converged slightly by lens S3, which has a positive power, and incident to the lens EX2 (bold broken line) as if it diverged from the point P' (broken line). The lens S3 moves the object point from P' to P. We optimized the specifications of the lens S3 using matrix representation shown in Eqs. (2)–(4)

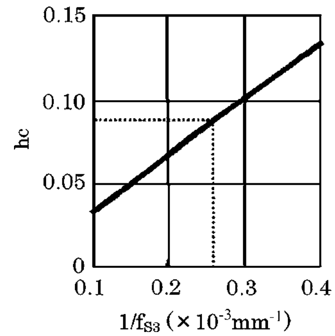


Figure 8. Beam height at the facet.

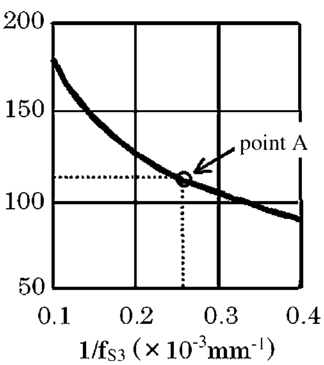


Figure 9. Position of the lens S3.

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

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

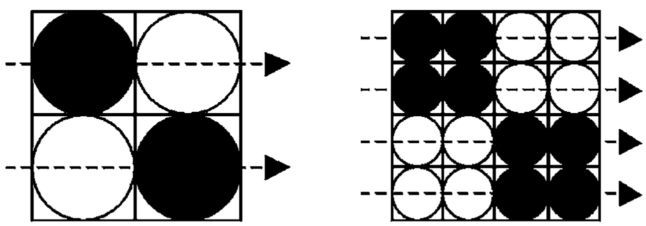
$$Q = f_{EX2} - (z + HH_3 + HH_{1,2}), \quad (4)$$

where HH_3 is the distance between two principal planes of the lens S3, and the suffixes "a" and "c" denote the axial ray and the chief ray, h is the beam height, u is the beam direction with respect to the optical axis, f_{EX2} is the focal length of the lens EX2, and f_{S3} is the focal length of the lens S3. For example, if $f_{EX1}=160.3$ mm, $f_{EX2}=336.7$ mm, $HH_3=0.7$ mm, $HH_{1,2}=2.7$ mm and the beam height at the principal plane of the lens EX1 is normalized, the relationships among z, hc, and f_{S3}, under the condition of $u_a=0$, are as shown in Figure 8 and Figure 9.

Within the range of $1/f_{S3}$ represented in Figs. 8 and 9, hc is much smaller than 1.0; in other words all beams are incident to almost same facet position. On the other hand, z changes significantly with the value of $1/f_{S3}$; therefore, we chose the point A in Fig. 9 where $1/f_{S3}=0.26\times10^{-3}$ mm^{-1}

Table I. 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} $=1/0.26\times10^{-3}$	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



(a) 240dpi (b) 480dpi

Figure 10. Arrangement of dots.

and $z=113.6$ mm in consideration of the limitation of the placement of the lens S3. The configurations of the lens S1 and the lens S2 were then set to correspond to the configuration of the conventional two spehrical lens system. Consequently, we obtained a representative specification of the converting lens system shown in Table I.

METHOD OF SCANNING DOUBLE DOTS TWICE

There is another approach that could change print dot density. The example of conventional dot arrangement with 240 dpi is shown in Figure 10(a), and with 480 dpi is shown in Fig. 10(b). A dot in the 240 dpi case could be formed by scanning the double dots in the 480 dpi image twice, i.e., 2×2 dots are modulated as a single dot. Therefore we could obtain the dot density 240 dpi with the scanning line intervals for 480 dpi.[5,6]

SEVEN-LEVEL PRINT DOT DENSITY

Typical specifications for print dot density are shown as Table II. The deviations from the optimum intervals are calculated for the case where the lines are formed with every third dot absent, which is the severest condition. In four cases out of seven in Table II, the deviations are theoretically zero; the rest are also small enough for practical use on the basis of previous experimental data.

Printing samples with 600 and 480 dpi are shown in Figure 11. The intervals are successfully converted.

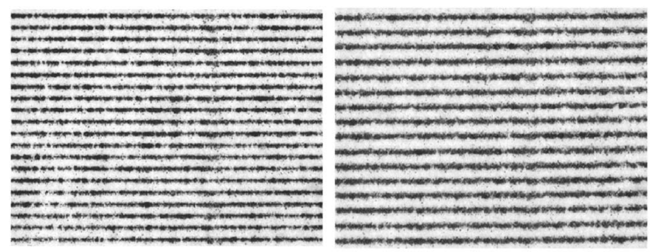
CONCLUSIONS

To achieve several different print dot densities using multiple beams for printers, we developed a method for converting intervals of scanning lines. Usage of the lens system which consists of two cylindrical lenses and one spherical lens is effective. We obtained a wide printing area regardless of whether the lens system was inserted into the optical axis or not. By utilizing a method of scanning double dots twice, we were able to design the optical system for seven-level print dot density.

Table II. Specifications for various dot densities.

Print dot density (dot per inch)	600	480	343	320	300	267	240
Optimum intervals P_D (μm)	42.3	52.9	74.1	79.4	84.7	95.2	106
Reduction ratio	0.4	0.5	0.7	0.75	0.8	0.9	1.0
Converting lens system	WO	W	WO	WO	WO	W	W
Method of scanning double dots twice	WO	WO	W	W	W	W	W
Maximum error of intervals (%)	0	0	17	8	0	13	0

W: with and WO: without



(a) 600dpi (b) 480dpi

Figure 11. Printing samples.

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