Multi-Beam Optical Scanning System with 20-channel Edge-emitting Laser Diode Array for Production Printing Applications

Yasuyuki Shibayama, Kazuhiro Akatsu, Takeshi Mochizuki and Junshin Sakamoto

Abstract

Ultra-high-speed laser printers have been used for production printing, and have recently been extended to on-demand printing where higher resolution printing with an offset press is required. Therefore, developing an optical scanning system that provides a higher scanning rate is necessary. A 20-channel edge emitting laser diode array emits high output power for the purpose of increasing the scanning rate. As the beams for scanning increase, their positional errors become critical. Therefore, higher resolution lenses, which are stable against thermal variation, are also required for the system.

An example of an optical scanning system using 20-channel edge emitting laser diode array and some optical techniques for higher resolution are introduced.

Introduction

In the field of production printing, ultra-high-speed continuous-feed laser printers have been used in heavy production for printing statements or invoices at government offices and companies throughout the world. Their high volume performance and high product reliability have been appreciated. In addition, a recent trend in printer application is moving from the said conventional uses to on-demand printing, such as direct mail and books, where higher resolution printing with an offset press is required [1].

To meet these demands, highly resolvable and stable image formation is indispensable for the first step in image formation of an optical system. There are several new technologies that are needed for this enhancement.

Requirements of scanning beam number

To obtain a high-speed printer with a higher resolution, increasing the scanning rate is inevitable. The relationship between the scan rate and the pixel element (PEL) time depends on the number of scanning beams, as shown in Fig. 1, where the PEL time denotes the modulation period for one pixel.

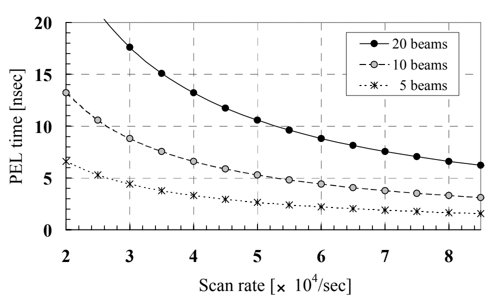


***Figure 1**. Relationship between scan rate and PEL time*

Supposing that the dot density is 1200 dpi is a mainstream in the field of a high-speed printer, and the process speed is 1.5 m/sec; the fastest class, the corresponding scan rate will be 7.1×10^4/sec. Generally speaking, a PEL time less than 5 nsec is beyond the critical limit of modulation. Therefore, 10 beams are still insufficient for this condition, and the required number of beams is 20 for this purpose.

Configuration of an optical scanning system

Figure 2 shows a configuration of an optical scanning system using a 20-channel light source. Only 5 out of 20 beams are depicted for easy recognition. The beams are first collimated through a collimator lens. Then, through another three lenses, the beams are expanded and directed to the same point on a facet of a polygon mirror in the scanning direction and then focused in the sub-scanning direction. The beams deflected by the polygon mirror travel through five scanning lenses and scan the surface of a photoconductor drum. 20 adjacent scanning lines can be obtained from one scanning.

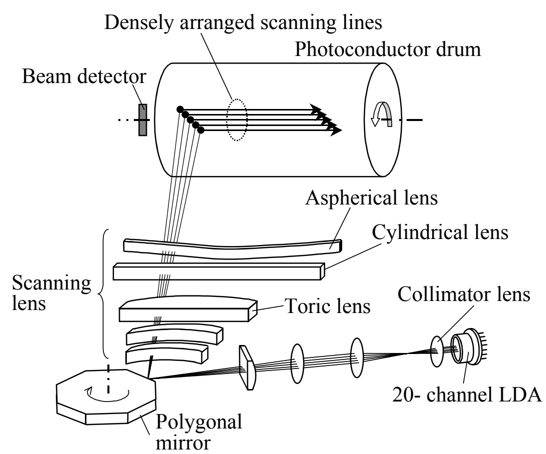
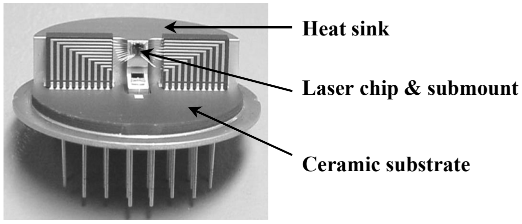


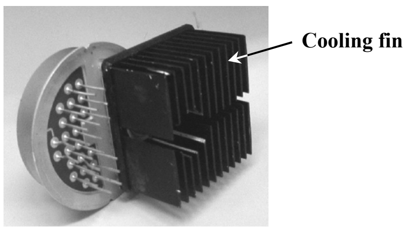
***Figure 2**. Configuration of optical scanning using 20-channel LDA*

Light source for 20-beam scanning

Figure 3 shows a 20-channel edge-emitting laser diode array (20-channel LDA) [2][3][4][5]. Table 1 shows the specifications of the laser diode array. The light-emitting points are highly integrated on one chip and provide a large output in a visible range. For the purpose of heat dissipation, the LDA chip is junction-down mounted on a ceramic submount, which is bonded to a heat sink. Then, the heat sink is projected to the rear, and a cooling fin is fixed for air-cooling.



(a)



(b)

Figure 3. Photograph of (a) inner structure and (b) package of 20-channel LDA

Table1 Specifications of 20-channel LDA

Lasing wavelength	Typical 658 nm Maximum 660 nm
Light-emitting points spacing	30±0.5 μm
Light-emitting points linearity	±0.075 μm
Optical output power	10 mW/ch
Threshold current	10~20 mA
Droop	<9 %/500 μsec (All channel emission)

The light-emitting points of the light source are disposed in a straight line and spaced at 30 μm, shown in Fig. 4. Though this spacing is considerably smaller than that in conventional high-output power lasers, it is still much larger than the diameter of the light-emitting points. This is why the light-emitting points are arranged at a slant angle to form scanning lines adjacent to each other on the drum surface, as shown in Fig. 2 [6].

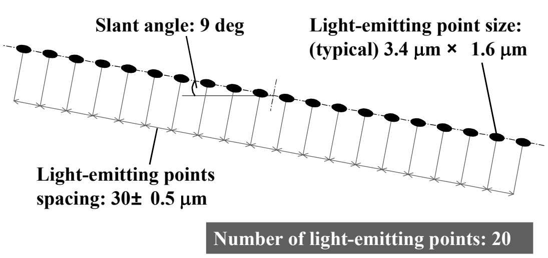


Figure 4. Arrangement of light-emitting points of 20-channel LDA

Control signals for multi-beam modulation

Control signals for laser modulation are shown in Fig. 5. As stated above, 20 light-emitting points are arranged at a finite angle to the scanning direction. For this reason, a beam detector that is located upstream of the printing area detects each beam independently and nearly periodically. Their special distances are compensated by controlling the delayed period consisting of a number of clock pulses.

The sample and hold method for laser power control is a common approach, however, it is quite difficult to control all beams for every scan due to the limitation of the non-printing period. In our optical system, controls for only four beams are performed at one scan, then controls for all beams are completed orderly after every five scans. Although the control frequency decreases for one beam, considering the causes of the variation in output power are the atmospheric environment and degradation of the laser device, it is still frequent enough for slow variation.

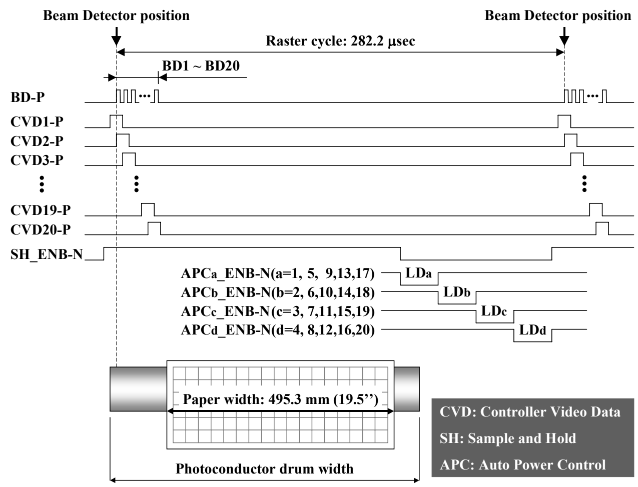


Figure 5. Control signals for laser modulation

Scanning lenses for multi-beam

A line spacing error may cause banding and critical degradation in print quality; therefore, our optical system is designed with special importance on uniformity of line spacing. The spacing on the drum is calculated by multiplying the spacing of the light-emitting points of the light source by a certain magnification ratio. Consequently, accurate placement of the light sources and a lowered constant magnification ratio are needed. A highly integrated 20-channel laser diode array and a lens system whose details are as follows are effective for this purpose. Even though a smaller magnification decreases transmittance because of the inevitably accompanied beam truncation, a considerably small magnification, such as 7, can be obtained by taking advantage of the sufficient output power of the edge-emitting laser diode. Moreover, this small magnification provides a large arrangement angle for the light emitting points; therefore, line spacing error is not easily affected by the angular error of the arrangement. The line spacing is in linear proportion to the magnification as stated, so not only a small but also a constant magnification over the scanning area is required [4].

In our optical system, scanning lenses are divided into two groups. Scan linearity and focusing characteristics in the scanning direction are largely performed with the first group, which is placed upstream. Meanwhile, magnification ratio and focusing characteristics in the sub-scanning direction are largely performed with the second group. Furthermore, the total refractive power is dispersed to the two groups appropriately. The reasoning is as follows.

First reason is to obtain a lowered magnification as mentioned above. Figure 6 depicts a simplified configuration of scanning lenses where each group is reduced to one lens. The ratio of ai (the optical path length from the deflection point to a principal point) to bi (the optical path length from the principal point to the photoconductor drum), which performs the magnification, is designed to be a certain value at every scanning angle [7]. As an example of being on the optical axis, the ratio Ha to Hb, which denote the distance from the principal plane to the toric lens and to the aspherical lens, respectively, is obtained from the relationship between the refractive power of two lenses, Ψa and Ψb.

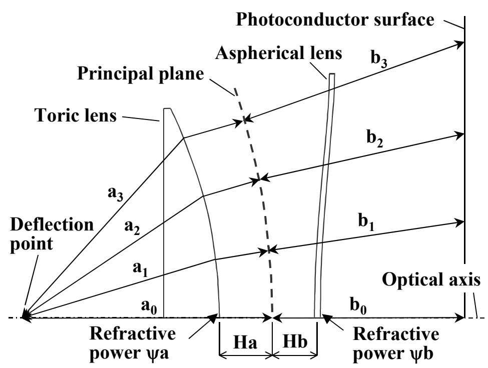


***Figure 6**. Magnification of scanning lenses*

Another reason relates to machining accuracy. A toric lens is commonly used in the first group because each effective power in the scanning direction and sub-scanning direction can be set independently. However, it is more difficult to make toric lenses than spherical or cylindrical lenses; therefore, variations of the radius in the sub-scanning direction are expected to arise.

A positional radial error in the sub-scanning direction generates a defocus in the corresponding portion in the scanning area; however, adjustment of any element has little effect on the partial defocus. Optimization of the provided power of the toric lens is an effective measure for the defocus.

Figure 7 shows the relationship between the power of the toric lens and the defocus caused by a radial error of the lens.

The horizontal axis represents the focal length of the toric lens in the sub-scanning direction ($1/\Psi_{Tor}$) normalized by the total focal length of the scanning lens in the scanning direction ($f_{F\theta}$). The vertical axis represents the normalized defocus ($\Delta Z/f_{F\theta}$) caused by a 0.02% radial error in the sub-scanning direction. A negative correlation can be seen. In other words, the low power of the toric lens desensitizes the defocus to the radial error. In our optical system, a long cylindrical lens is disposed in the second group, and it shares a certain amount of the total required power in the sub-scanning direction. However, if the second group consists of only a cylindrical lens, the ratio of ai to bi is difficult to keep constant at every scanning angle because of the lack of variable parameters. For this reason, another long lens made of plastic, which has a rotationally asymmetric aspherical surface, is placed downstream from the cylindrical lens.

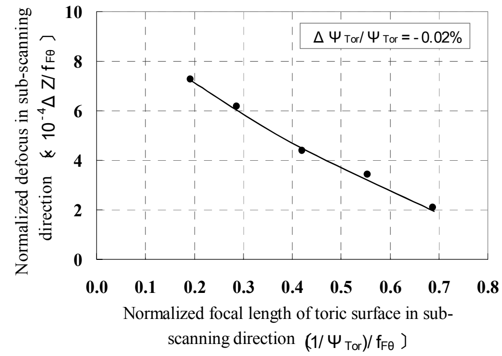


***Figure 7**. Relationship between power of toric lens and expected defocus*

Plastic materials generally have quite large changes in their refractive index, and cause large defocus. In our optical system, the cylindrical lens, which can be easily made from glass, provides the majority of total power, and the plastic aspherical lens provides less power. In addition, the aspherical lens is designed to have a slight negative power and produces relatively more positive power at a higher temperature. Therefore, the aspherical lens acts as a compensator for the decrease in the total power caused by the increase in the wavelength at a higher temperature condition. As a whole, the summation of the power of these two lenses is almost maintained despite the temperature. Consequently, the variations in the defocus and the magnification ratio are reduced to practically agreeable values.

Figure 8 shows the relationship between the scanning position and the magnification ratio at different temperatures. In this figure, three temperature conditions are assumed, namely, room temperature, 13K greater than room temperature, and 17K less than room temperature. The magnification ratio reduced to 0.4% at 30K. This variation corresponds to 3.8% of the period of scanning lines, so it is estimated to be negligible for practical use.

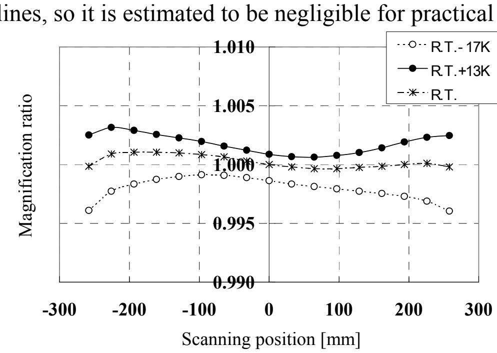


***Figure 8**. Magnification ratio*

Collimator lens for multi-beam

If the number of light sources is one or only a few, the light sources are situated near the optical axis of the collimator lens. Therefore, a collimator lens with a small image circle, where aberrations are compensated to an acceptable extent, can be used. If a collimator lens with a small image circle is used with a 20-

channel LDA, the field curvature, which is characteristic of the collimator lens, causes a relative focus position errors between the 20 beams correspond to the distance from the optical axis. This may bring about an agreeable unevenness of the spot size.

Although eliminating the field curvature of the collimator lens shows some effect, the field curvature is designed to be at an appropriate value so as to compensate for the total effect on the focus position errors in our optical system.

Figure 9 shows the field curvature of the collimator lens. In the scanning direction, there is a certain value of negative curvature. On the other hand, in the sub-scanning direction, there is very little curvature because the 20 beams situated at a relatively small angle to the horizontal line shown in Figure 2 did not generate considerable displacement in this direction.

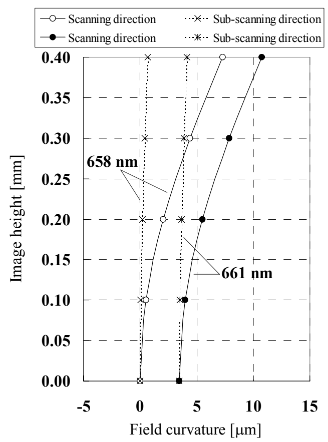


Figure 9. Field curvature of collimator lens

Optical characteristics of the system

Field curvatures of our optical system are shown in Figs. 10 and 11. Figures 10 and 11 show the field curvature in the scanning direction and in the sub-scanning direction, respectively. Three typical beams that are placed on the axis and at the both ends are considered; moreover, three temperature conditions are assumed as stated above. Although the residual field curvature in the sub-scanning direction looks relatively large, it is about one half of the focal depth.

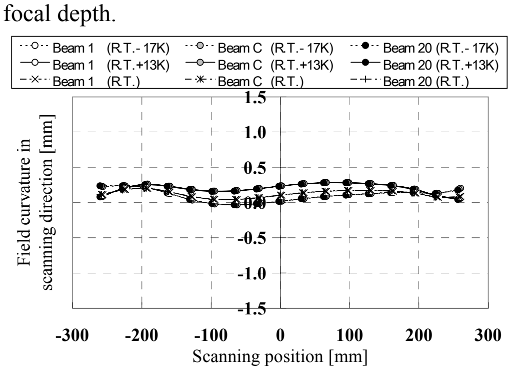


Figure 10. Field curvature in scanning direction

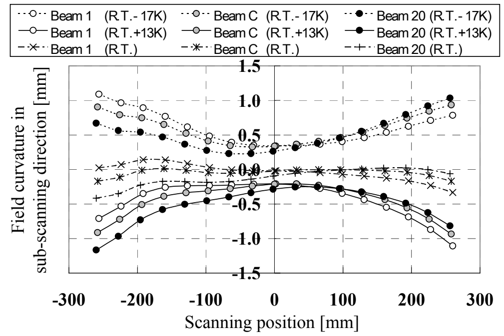


Figure 11. Field curvature in sub-scanning direction

Conclusion

A multi-beam optical scanning system and technologies for production printing were introduced. For a high-speed printer with a higher resolution, we adopted a 20-channel edge emitting laser diode array with high-output power and accurate placement of the light-emitting points and developed a corresponding control system for laser modulation. In addition, we designed scanning and the collimator lenses for the 20-beam optical scanning system, which is stable against thermal variation.

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Author Biography

Yasuyuki Shibayama was born in Ibaraki-Pref., Japan in 1967. He received his BS degrees in 1990. He has been developing optical systems for laser beam printers, at Hitachi Koki Co., Ltd. from 1990, Hitachi Printing Solutions, Ltd. since 2002 and Ricoh Printing Systems, Ltd. since 2004. He is a member of OSJ.