A Technical Overview of Optical Unit for Tandem Color Laser Printer

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Abstract

We propounded a four-photoconductor tandem system to meet the demand for colorization and high-speed performance of copiers and printers [1]. *Since then, we have developed optical units for the system, to cope with some problems typically found in color machines, such as the flexibility of the optical configuration and the reduction of displacements among four color dots. The optical design that we are to introduce here has some essential features to deal with some of the difficulties referred to above.*

To facilitate the optical configuration, we employ singlet scanning lenses for each color in the optical unit. And we apportion refractive powers between two surfaces of the scanning lens effectively, to reduce wave front turbulence. Next, to reduce displacements among four color dots in sub-scanning direction, we set the bow of each color scanning line to the same side, by locating a pair of two-piled scanning lenses symmetrically to the deflecting device and flipping one of the pair vertically. In addition, we corrected displacements among four color dots by employing the rotating structures for light source units.

Introduction

In the recent printer market, the switchover from monochrome machines to color machines has become a major trend.

There are several approaches to develop color machines, and any of these approaches basically depend on the number of photoconductors. Full color printers sequentially process separate images in four colors, typically magenta, cyan, yellow and black. Considering subtractive primaries, black can be made from mixing equal amount of magenta, cyan and yellow. However the generated black is inferior to pure black in high contrast quality, so usually pure black is used without mixing.

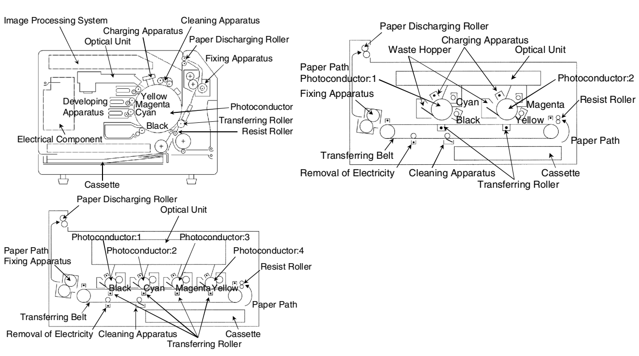

***Figure 1**. Basic configurations of full color printers*

Figure.1 shows basic configurations of full color printers with one, two and four photoconductors [2] [3]. Specifically the type with four photoconductors aligned in parallel is called a *four-photoconductor tandem system*.

To describe one of optical characteristic, we define *color displacements* as displacements among four color dots on the photoconductors. The number of photoconductors is associated closely with print speed, manufacturing cost and the difficulties of reducing color displacements. Particularly in color printers, reducing color displacements is a serious problem because the array accuracy of each color dot is a key factor to re-create original images. When the number of photoconductors is only one, the photoconductor must be rotated four times to produce four color images. As a result, the print speed gets slower. Meanwhile, when the number of photoconductors is four, the print speed is four times as fast as only one photoconductor. But the manufacturing cost gets higher and the color displacements are prone to occur more. It is necessary to produce higher resolution to enhance image quality. So a four-photoconductor tandem system is the best solution because it can maintain high resolution without losing print speed. Therefore we must consider adequately how to reduce manufacturing cost of the tandem machines and prevent color displacements. This paper describes the improvement of some of the difficulties stated above with an optical unit such as one of printer modules.

Optical Unit for A Four-Photoconductor Tandem System

The four-photoconductor tandem system requires four scanning optical systems corresponding to each photoconductor. There are several approaches to configure four scanning optical systems.

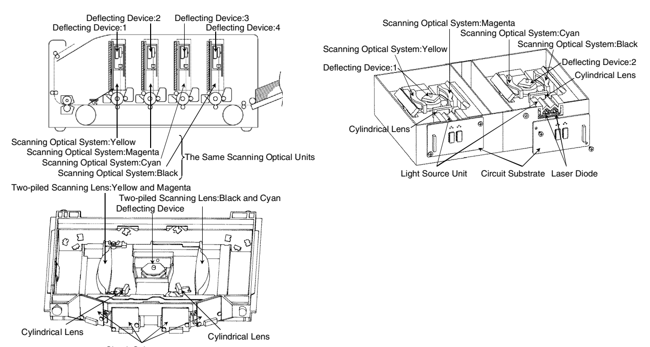

***Figure 2**. Configurations of four scanning optical systems*

The simplest way is to align four identical optical units, which are used in monochrome printers, set side-by-side. But this approach uses four deflecting devices in a machine, and tends to be more expensive for the manufacture. Therefore we have developed a new optical system that can produce four color images with one single deflecting device in a machine. This type of system has been achieved by piling up two scanning lenses and locating a pair of the two-piled lenses symmetrically to the deflecting device.

Disadvantage

The worst disadvantage of this type of system is that the optical configuration becomes complicated. Generally it is preferred that the size of the optical unit is smaller and the distance between the unit and photoconductors is shorter to minimize the size of the printer. So we usually add an ingenuity to fold the light path properly by inserting several mirrors between scanning lenses and photoconductors. Therefore, the optical configuration of this system is apt to be rather complicated.

In addition, a scanning optical system generally consists of more than two lenses to hold light spot size on the photoconductor stably. The color machines equip a total of eight lenses in the cramped optical unit, and it constricts the downsizing of the optical unit. We need to stop the deterioration of the light spot size while facilitating the optical configuration by composing each scanning optical system with a single lens.

Solutions of Some Problems

The problems to be solved about the new optical unit are summarized as follows:

1. We need to achieve the effective reduction of wave front turbulence with one single scanning lens and to downsize of the optical unit.
2. We need to reduce color displacements, especially in sub-scanning direction.

The solutions of these problems are discussed below.

Reducing Wave Front Turbulence

To reduce wave front turbulence with one single scanning lens, we must apportion refractive powers between two surfaces of the scanning lens effectively.

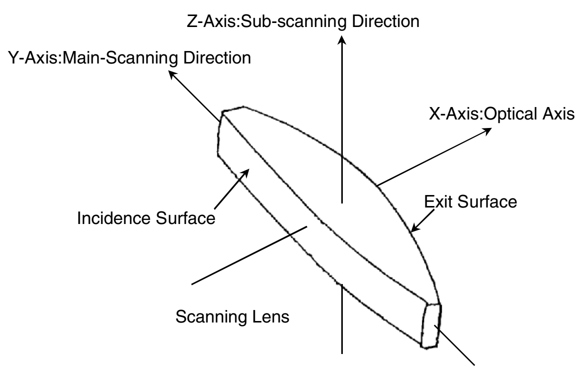

***Figure 3**. Coordinate axes*

We define the coordinates as shown in Figure 3. X-axis is set along the optical axis of the scanning lens. Y- and Z-axis are also referred to as the main-scanning and sub-scanning directions respectively. The cross sectional shape of the scanning lens along the main-scanning direction determines the optical characteristics on the photoconductor along Y-axis, such as focal positions in the cross-section field and scanning linearity. The scanning linearity is equivalent to the uniformity of velocity of a light spot scanned from an end to another end on the photoconductor.

Similarly in sub-scanning direction, the cross sectional shape determines the characteristics along Z-axis, such as focal positions in the cross-section field and lateral magnification.

In addition, reducing wave front turbulence is critical to the stability of the light spot size, and we must apportion refractive powers properly between the incidence surface and the exit surface of the scanning lens [4]. Typically the meniscus shape is adopted as the cross sectional shape of the scanning lens in both main-scanning and sub-scanning direction to obtain some well-corrected optical characteristics except wave front turbulence. But in the case of the meniscus shape, one of surfaces is logically concave and the other is convex with larger refractive power. A large refractive power is apt to cause wave front turbulence.

Therefore we dared to adopt the biconvex shape to the cross sectional shape of the scanning lens, apportioned refractive powers between two surfaces of the lens effectively, and made it possible to reduce the wave front turbulence. Besides, *curved axial toroidal surfaces* [5] [6] were applied to both surfaces to maintain some optical characteristics such as the focal positions, the scanning linearity and the lateral magnification at high performance.

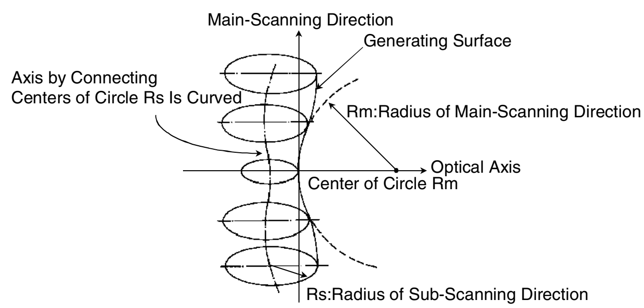

***Figure 4**. Curved axial toroidal surface*

Curved axial toroidal surface is shaped by producing the cross sectional shape along the main-scanning direction in an aspherical form which is defined with high order polynomial, and by varying the radius on the cross sectional shape along the sub-scanning direction as a function of Y as shown in Figure.4.

As the surface like this toroidal determines the radius of the cross sectional shape along the sub-scanning direction independently from the cross sectional shape along the main-scanning direction, it is able to stabilize light spot size anywhere on the photoconductor. Figure 5 shows the scanning lens we have designed [7].

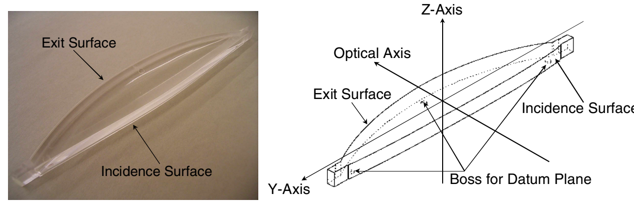

***Figure 5**. Scanning lens*

By-product

An unexpected by-product is produced by shaping the cross sectional shape of the scanning lens along both main-scanning direction and sub-scanning direction as the biconvex shape.

In the new optical unit that we have approached, a pair of two-piled scanning lenses is located symmetrically to the deflecting device. All of the light flux that enters a scanning lens is not always transmitted and a certain part of the light flux is reflected. So the optical unit tends to produce undesirable stray light because the light flux that is reflected at the incidence surfaces of one two-piled scanning lens that enters the other and is focused onto the photoconductors.

The biconvex shaped scanning lens diffuses the light flux that is reflects at the incidence surfaces, and the stray light does not cause any harmful ghost images on the photoconductors.

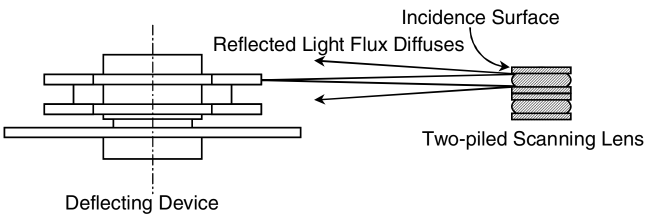

***Figure 6**. Light flux that is reflected at the incidence surfaces*

Reducing Color Displacements

Color displacements have harmful influences on image quality of color machines. Though they occur by various causes, this paper describes how to reduce them considerably in the optical unit. Color displacements can be broken down into two components along the main-scanning direction and sub-scanning direction. Color displacements along the main-scanning direction can be corrected electrically, so this paper describes the method to reduce displacements along the sub-scanning direction.

Color displacements along the sub-scanning direction chiefly consist of the shift and the bow of each color scanning line on photoconductors. Each scanning optical system in the optical unit corresponds to their respective photoconductors as shown in Figure 7 [8]. Two mirrors are inserted into each scanning optical system in the optical unit.

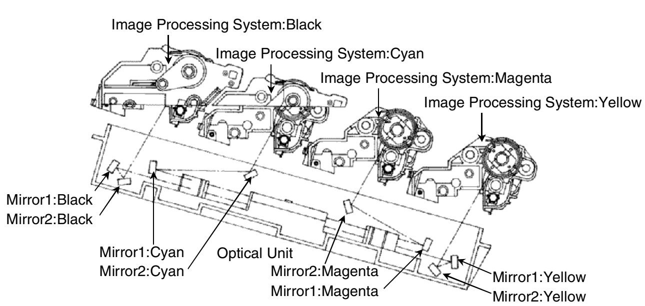

***Figure 7**. Layout of scanning optical systems*

The scanning lens gets bent by means of molding process, and a warpage of the lens induces the bow of the scanning line on the photoconductor. In mass production of scanning lenses, all warpages are prone to be uniformly concave as shown in Figure 8 [9].

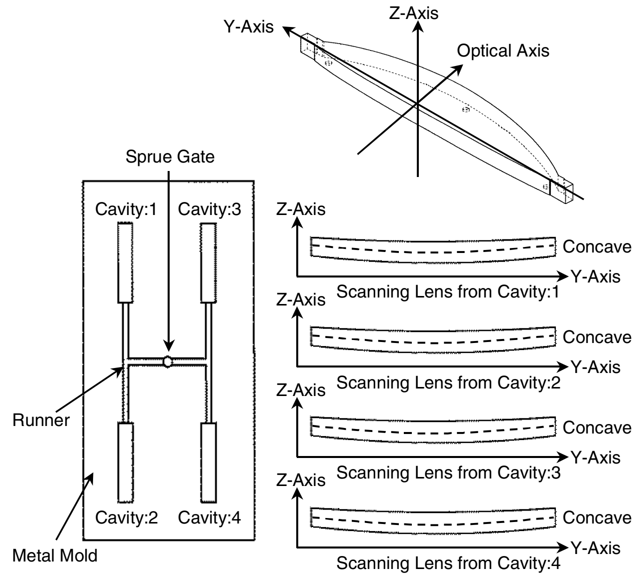

***Figure 8**. Warpage of the lens*

If these scanning lenses are applied to the optical unit, the bow of magenta scanning line overlaps with the bow of yellow line, and cyan overlaps black. When we intend to reduce the color displacements, we do not need to consider the bows of each color scanning line. It is important to make each color scanning line overlap correctly. So the next thing we must consider is to have the scanning lines of yellow and magenta overlapped with the ones of black and cyan fittingly. We have succeeded in setting the bow of each color scanning line to the same side, by locating a pair of two-piled scanning lenses symmetrically to the deflecting device and flipping one of the pair vertically [10] [11].

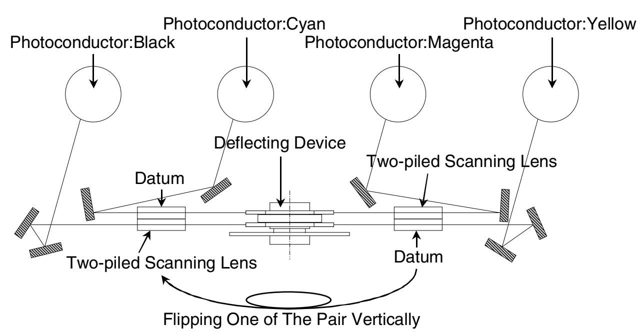

***Figure 9**. Locating a pair of two-piled scanning lenses symmetrically to the deflecting device and flipping one of the pair vertically*

Rotating Structures for Light Source Units

In addition, the rotating structures have been employed onto each light source unit to correct the shift of each color scanning line along the sub-scanning direction [12].

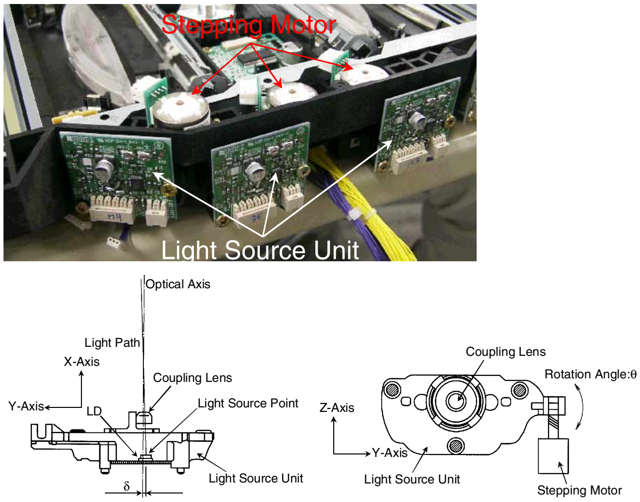

***Figure 10**. Rotating structures for light source units*

A light source is moved a few fractions δ from the optical axis of a coupling lens in the light source unit as shown in Figure 10. By doing so, the rotation of the light source unit around the axis generates substantial separation of the light source from the axis in sub-scanning direction.

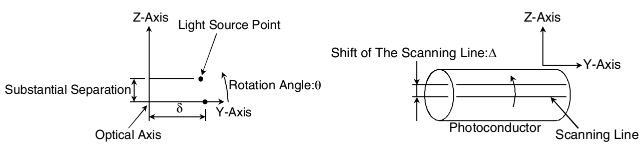

***Figure 11**. Principle of correcting the shift of each color scanning line*

There is a relation between the rotation angle θ of the light source unit and the shift Δ of the scanning line through the lateral magnification β of the optical system in sub-scanning direction, as given in Equation.1.

$$\delta \times \tan\theta \times \beta = \Delta \qquad (1)$$

Therefore we can correct the shift of each color scanning line on the respective photoconductor along the sub-scanning direction by rotating each light source unit around each axis.

The measurement result is shown in Figure.12.

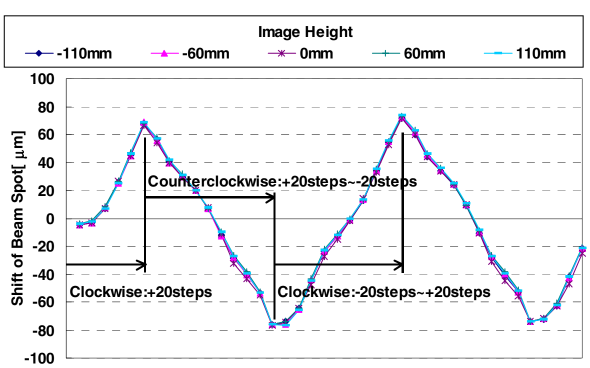

***Figure 12**. Measurement result*

The shift Δ is approximately proportional to the rotation angle θ. If we can detect color displacements along the sub-scanning direction, the rotation angles indispensable for correction can be calculated subsequently.

Conventionally, the color displacements could be corrected electrically only by an integral multiple of the interval between the scanning lines which is determined by resolution or *dpi*. But the rotating structures enable displacements to be diminished by a fraction of less than the interval.

Conclusions

The new optical unit that we have approached has several characteristics as follows:

1. It is adequate to reduce manufacturing cost of the machines due to employing only one single deflecting device in it.
2. It has accomplished the facilitation of the optical configuration due to employing singlet scanning lenses for each color in it.
3. The reduction of wave front turbulence has been enabled by apportioning refractive powers between two surfaces of the scanning lens effectively in it.
4. By setting the bow of each color scanning line to the same side, the reduction of color displacements in sub-scanning direction is actualized due to as follows:
   a. Locating a pair of two-piled scanning lenses symmetrically to the deflecting device
   b. Flipping one of the pair vertically
   c. Employing the rotating structures for light source units.

Therefore, the optical unit is most appropriate for the four-photoconductor tandem system and might be adopted into many color machines in the near future.

References

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Author Biography

In 1995, I completed Chuo University department of science and engineering and joined RICOH CO., LTD. Thereafter I have engaged in design of a scanning optical system. I belong to Imaging Engine Development Division now.