Image Banding Based on Opto-Mechanics Considering Laser Scanning Unit in Printing Systems

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Abstract

Consumer's product selection measures are being shifted from the units' operational performance to overall performance. High quality image that required "no banding, good color alignment, etc." which used to be important evaluation indices, now became vital performance factors. To satisfy customer's needs about image quality, development of evaluation tools for measurement of image arrangement or banding is urgently needed and each company's own up-to-date special tools and standards are used in manufacturing goods. One of the major image quality issues is known as banding which is related to the fluctuations of the internal printer components. Accumulated errors from instability of controlling belts or tolerance of gears operating in photographic and fusing systems make thick band characteristic which is low frequency banding. This paper describes the phenomenon of high frequency banding from Laser Scanning Unit (LSU) which causes thin banding characteristic. As printers' trend move towards smaller size, color tandem type of LSU is becoming more compact than it was. Image banding occurred due to opto-mechanic positions, characteristics of optic parts (lens, mirrors, etc.) and beam path in LSU. Image banding evaluation analysis with some cases are compared and discussed on experimental and analytic results.

Introduction

Banding is one of the most undesirable print artifacts that limit print quality in the electro photographic printer technologies. Banding is perceived by the human visual system as achromatic variations or both achromatic and chromatic variations in the paper process direction. With laser printers, banding results from non-uniform line spacing which is primarily caused by fluctuations in angular velocity of the organic photoconductor drum.

Because of the negative effects of banding on printer quality, there has been considerable research devoted to reducing banding. Throughout the stages of the printer development life cycle, it is necessary that printer engineers can frequently measure the principal banding frequencies exhibited by their developing printer prototypes, and based on this information, modify the printer design to reduce the banding artifacts.

The laser optical system is one of key unit in laser beam printer (LBP) and the achievements in design and manufacturing of the optical system highly contributed to the current popularization of LBP. Moreover, the optical performance of the laser optical system becomes increasingly important because high-speed, high quality image and small size which depends mostly on the optical system is demanded from market. LSU is a typical device for imaging by the beam scanning. As shown in Figure 1, the laser light from the laser diode is collimated and focused on the polygon scanner mirror. The scanner mirror reflects incident light and scans it onto the photosensitive drum. The scanning lens linearly focusing the light onto the photosensitive drum, that is, the drum will be imaging plane of the laser spot. The laser spot on the drum make voltage difference and make a latent image.

According to this paper, the opto-mechanic banding characteristic of LSU which generated by a optic path and structural vibration is presented by experiment and analytic method.

Problem statement

Printer set's banding score and Fast Fourier Transform (FFT) frequency characteristics are measured with useful SEC tool that can analyze banding frequencies exhibited by our color laser printers by SEC banding check test page. At the beginning of developing new print set model, almost components don not have stable dimensions uniformities in each part of samples. Hence, image evaluation analysis results many banding problems including both low frequency and high frequency, and they are represented by many peaks in image frequency domain from FFT analyze tool. Printers have many kinematical relations between a pair of gears and motors which are in driving and rotating OPC drums, development systems, paper transmission belt and polygon motor in LSU system. As each motors and gears have their own rotating speed and teeth characteristics, fft analysis results can be matched from each peak to each banding length easily. Also, all dynamic parts must be listed by driving (gear) table of a print set. Banding length (mm) in image can be represented by numerical formula as like process speed (mm/s) and rpm of special peak as following,

$$\text{Length in image} = \text{Process speed} \times 60/\text{Rpm} \quad (1)$$

Rpm means a revolution per minute and it is specific speed which is solved. Fig.2 shows FFT analysis example plot of the banding peaks in frequency domain from tools.

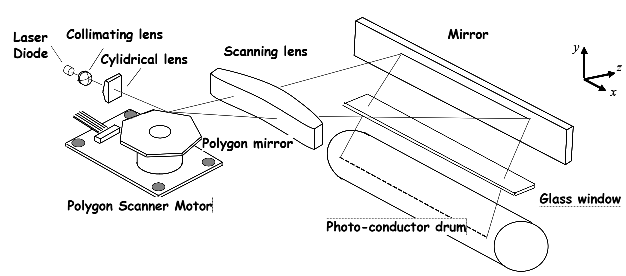


Figure 1. *Schematic of Laser Scanning Unit*

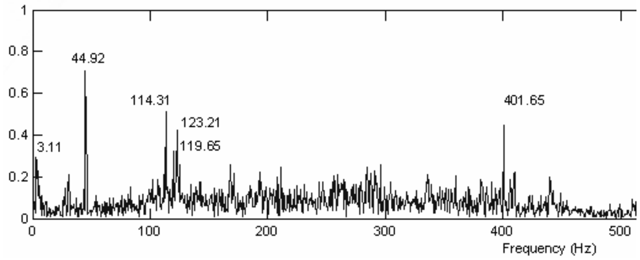


Figure 2. The Image evaluation FFT analysis result

Some peaks are very high so that users can recognize that image is not fine as they print their specific images. As it is represented by equation (1), higher rpm (frequency) makes short banding length. It means that number of banding repetition in a print image is more frequently than long banding length. Assuming A4 size is 210mm × 297mm and problematic banding length is 10mm, the page has more 20 banding lines. Frequency intensity which users feeling is different as following who they are, but adaptable frequency will be very offend to users. But specific frequency is different as printer system specification and driving table of print set informs engineers about almost frequency characteristics of operating system.

Bandings in LSU system

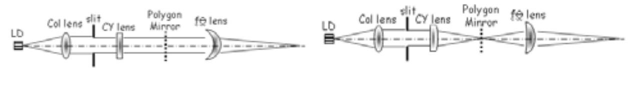
Score and FFT frequency characteristics of the print set's bandings are measured by SEC banding check test page with SEC tools that can analyze banding frequencies exhibited by our color laser printers. In LSU system there are kinds of high frequency bandings that have less than 1mm length. The Polygon motor is rotating about 30,000rpm ~ 40,000rpm in LSU; as rpm represents to frequency ranges, speeds are 500Hz ~ 670Hz.

LSU bandings can be generated by three major factors. It relates to the error motion or the vibration of scanning part. First factor is from the polygon motor's dynamic vibration characteristics-Pyramidal angle error including polygonal mirror facet, and second one is vibration of at least one of parts on the optical path shown in Fig. 3. In the components on the optical path, the polygon motor directly affects to LSU banding as the polygon mirror is mounted on the motor. As it is expressed in Fig.3 (b), beam of process direction is focused on the polygon mirror facet. As polygon mirror is not vertical angle by beam, last focusing point will be different with predicting. Scanning direction is also important for bandings.

Table 1. Divided angle of polygon mirror samples

No.(6F30)		Divided angle(")					
Facet/dia	n	D-1	D-2	D-3	D-4	D-5	D-6
#01	se_1	3.0	-9.8	1.8	-0.3	-5.3	11
#02	se_2	14.5	1.2	-13.6	1.5	1.8	-5.3
#03	se_3	0.6	8.0	-6.8	3.0	3.6	-8.3

Third one is by optic path design. As printers' trends move towards small size, color tandem type of LSU is needed to more compact and small size. So beam path use more reflecting methods using many mirrors to compact path. But, sometimes, beam path is not 2-Dimension.



(a) (b)

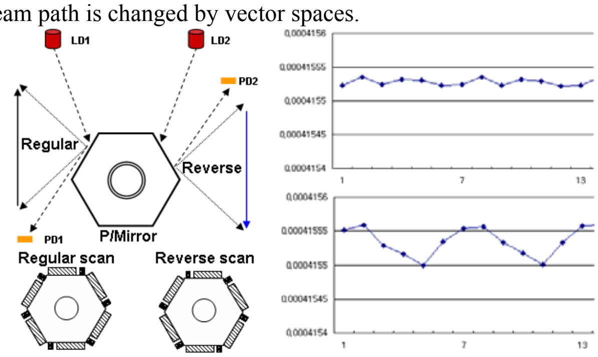
Figure 3 .Lay path in scanning (a) and process direction (b)

Using 2 more mirrors with mixed angle effect, 3-D twisted space path is occurred. The twist path can make some errors because the dimension is not fine numbers.

As shown in Table 1, divided angles of 6 facet 30 outer diameter polygon mirror samples effect to errors from facet to facet.

Bandings from Optic misalignment

Optical path in LSU is very various and depends on what optical system is used. As following the optical system, total beam path size and effective angle is changed. The market demand for high-speed performance of a color laser beam printer created a tandem-type color printers which have four organic photoconductive (OPC) drums to develop four colors (Cyan, Magenta, Yellow, and Black). While the conventional system with one drum uses four cycle process to create a full color image, the tandem can produce the image just with one cycle process. In spite of its efficiency and high speed, it produces a problem of color registration which did not occur in the one drum system. Informing registration algorithm C,M,Y and K color's standard video time, checking horizontal synchronization signal(H_Sync.) at the first in LSU on print. H_sync.'s shaking phenomenon come from various errors like laser diode defect, positioning angle errors, beam path misalignment, etc. H_Sync. shake can affect to bandings and its effect is different as following what half toning algorithm is used to each color. As printers' trend move towards smaller size, color tandem type of LSU is becoming more compact than it was. Image banding occurred due to opto-mechanic positions, characteristics of optic parts (lenses and mirrors) and beam path. This tandem LSU used second reflecting mirror for compacting its size. Beam detecting path doesn't pass through f-theta lens as following fig.5. Compensating beam focus to scanning direction in front of photo diode (PD) sensor, beam detecting (BD) lens is needed. These reflecting mirrors for beam detection make double angle system and finally vectors of beam have spatial axis(x, y ,and z) as the beam path is changed by vector spaces.



(a) (b)

Figure 4. Tandem LSU scanning (a), Polygon mirror divided angle effect (b)

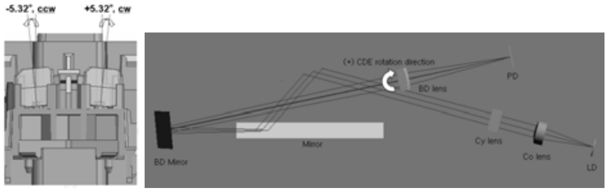


***Figure 5**. BD lens and PD sensor Alignment and Simulation results (Cove-V)*

Fig.1 shows the beam vector element considered with three components in 3-space and the magnitude of a vector.

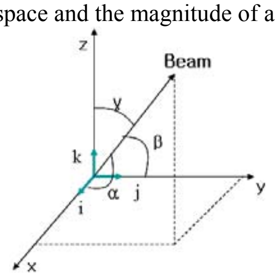


***Figure 6**. Direction angles of Beam in 3-space*

$$a = a_1 i + a_2 j + a_3 k \tag{2}$$

It can be written in terms of the dot product:

$$\|a\| = \sqrt{{a_1}^2 + {a_2}^2 + {a_3}^2} \tag{3}$$

The angles α ,β , and γ between beam and the unit vectors i , j, and k, respectively, are called direction angles of beam. Angle between two vectors is as follows;

$$\cos\theta = \frac{a_1 b_1 + a_2 b_2 + a_3 b_3}{\|a\|\|b\|} \tag{4}$$

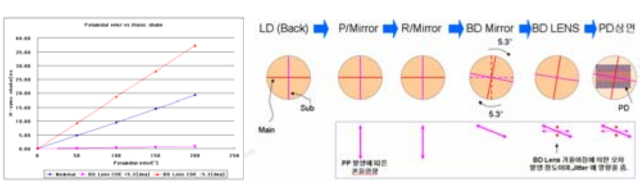
Which simplify to

$$\cos\alpha = \frac{a_1}{\|a\|}, \cos\beta = \frac{a_2}{\|a\|}, \cos\gamma = \frac{a_3}{\|a\|} \tag{5}$$

Direction cosines of beam are cosα ,cosβ , and cosγ , since the magnitude is 1, it follows from the last equation that

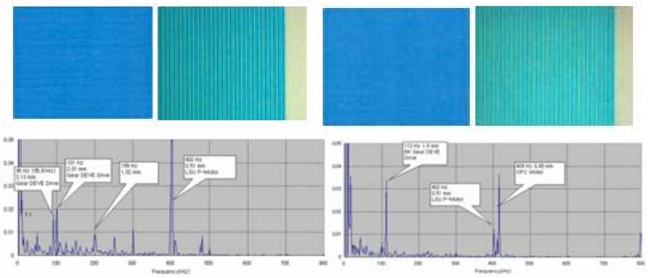
$$\cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1 \tag{6}$$

Using commercial s/w tool code-V, twisted beam path angle can be acquired easily. As shown in Fig.5. BD lens's angle was calculated to 5.32°. Comparing PAE with H_Sync., Shake in considering BD lens angle, 5.32° angle is smallest case for H_sync. shake value in fig. 7 (a).



(a) (b)

***Figure 7**.H_sync. shake analysis considering BD angles(a), path (b)*



(a) (b)

***Figure 8**. Comparison of enhancement before (a) and after (b)*

In main and sub factors of beams, process direction factors affect to scan direction factors (H_sync. shake) as optics parts is misalignment from LD to target focused. Each case considering BD and PD angles is shown in table 2 and4. The case of BD/PD +5.3 is smallest H_sync. shake. Results of changing angles of optical path and part angle (BD lens) are shown in fig. 8. LSU banding peak is reduced and real print image show good quality.

Table 2. Existence vs. no existence vs BD lenses

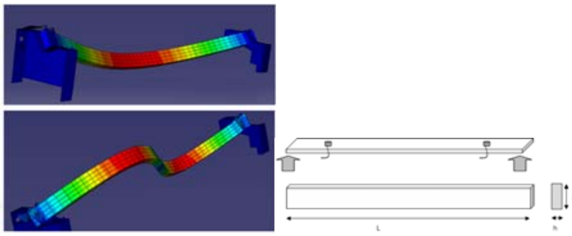
number	BD lens	no BD lens	remarks
Set #1	43	67.4	ns
Set #2	44.3	63.8	
Set #3	47.4	68.3	
Set #4	37.2	38.6	
Set #5	45.7	62	

Table 3. Pyramidal errors in case of BD lens angles

Pyramidal Error["]	Original	BD Lens +5.3[deg]	PD +5.3[deg]	BD/PD +5.3[deg]
0	0.00	0.00	0.00	0.00
50	4.76	0.17	4.59	0.00
100	9.57	0.39	9.23	0.09
150	14.42	0.61	13.90	0.13
200	19.28	0.87	18.54	0.26

Vibration characteristics of components

The vibration of LSU or any mechanical parts in laser beam printer could be amplified by structural vibration characteristics. To find the resonant frequency in LSU in terms of structural vibration, the acquisition of Frequency Response Function (FRF) of concerned parts is required under the actual boundary condition. The FRF's for important parts of any LSU can be acquired experimentally and CAE analysis. The input force from an impact hammer is applied to the same actual vibration source point, and outputs of acceleration at each concerned point are acquired. Table 4. shows the FRF results of some components in LSU; 1st f-theta lens, 2nd f-theta lens 1st reflecting mirror, and 2nd reflecting mirror. Problem banding length is 1.1mm and it can be conversed by relation of equation (1); 147Hz.



(a) (b)

***Figure 9** .CAE analysis of reflecting mirror (Abacus)(a) and test setup (b)*

Table 4. Pyramidal errors in case of BD lens angles

Part	Size	Weight	Natural Freq.	Remarks
Reflect Mirror	R/M-a	20.85g	450~460Hz	Size:a, Weight:b
	R/M-b	26.24g	340~350Hz	S:1.25a,W:1.26b
	R/M-c	42.8g	1st)141~145Hz 2nd)500Hz	S:1.7a,W:2.0b
f-theta lens	f-th-a	-	~600Hz	
	f-th-b	-	~300Hz	

3rd mirror was very close to 147Hz and analytic and CAE analysis was compared with experimental results. Simply experimental setup and simulation model with commercial program: Abacus shows in fig. 9. And comparison results are in table 5.

Table 5. Comparisons of test results

Experiment	Analysis	Theory	Remarks
140 ~ 145Hz	157Hz	141Hz	

From EULER equation for beams' solution, the natural frequencies of vibration is found by

$$w_1 = 22.37\sqrt{\frac{EI}{ml_4}} \tag{7}$$

And,

$$I = \frac{1}{12}bh^3 \qquad m = m/l \tag{8}$$

Where h is height of reflect mirror, b is width of reflect mirror, and M is weight.

Table 6. Comparisons of analytic results

w n	2014.87	1/s	320.6	Hz	fix-fix
	888.95	1/s	141.4	Hz	simple-simple
E	75000000000	Pa			
m	0.142666667	Kg/m			
M	0.0428	Kg			
L/b	0.3/ 0.012	m			
I	1.25E-10	m^4			*h: 0.005m

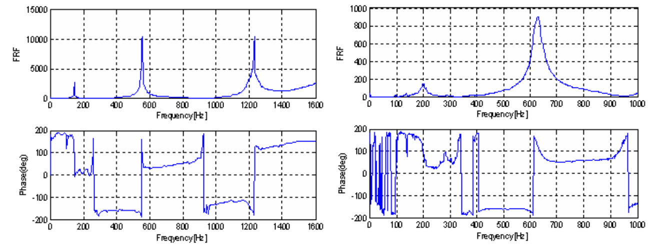
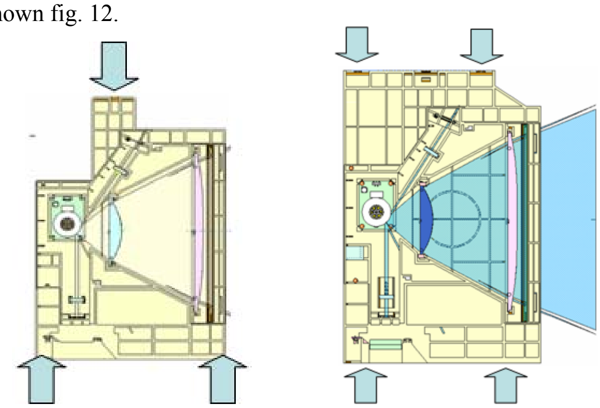


***Figure 10**. Comparison of enhancement before and after*

Table. 6 shows fix-fix and simple-simple support cases results of analytic. For natural frequency tuning, some assembly is added and finally FRF results shows in fig. 10: 50~60Hz frequency was shifted and the banding is disappeared.

Fixing characteristics of LSU

LSU have many components (lens, f-theta lens, etc.), but it is also a component in a print set. As it is fixed on the set, there are many cases for fixing type from LSU to set. LSU can be composed to close to vertical angle or upside direction angle. Almost 3 or 4 fixing type is used between LSU frames and set as following what kind of placement type of set inside is. From beginning design step, those concepts are decided and it can be modified before real production of print. As this case is occurred on develop step, fix type can be changed from 3 fix to 4 fix types. Banding frequency is 153Hz and finally problematic frequency is disappeared as shown fig. 12.



(a) (b)

***Figure 11**. Comparison of LSU fixing condition 3 fix(a) vs. 4 fix(b)*

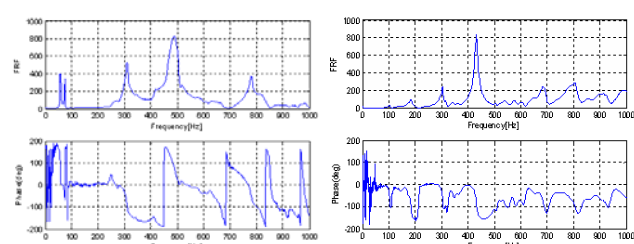


***Figure 12**. Comparison of enhancement before and after*

Conclusion

In this paper, Image banding occurred due to opto-mechanic positions, characteristics of optic parts (lens, mirrors, etc.) and beam path in LSU. Image banding evaluation analysis with some cases are compared and discussed on experimental and analytic results.

Process direction factors affect to scan direction factors (H_sync. shake) as optics parts is misalignment from LD to target focused. Each case of BD and PD angles is considered. The case of BD/PD +5.3 is smallest H_sync. shake. LSU banding peak is reduced and real print image show good quality.

With results Fix-fix and simple-simple support cases of analytic, natural frequency tuning is done. Finally some assembly is added and FRF results are like that 10: 50~60Hz frequency was shifted and the banding is disappeared.

Considering fixing point of LSU from 3 fix to 4 fix types, problematic banding frequency -153Hz was tuned and finally problematic frequency is disappeared.

Experimental results indicate that the proposed evaluation model is stable and yields high value of correlation.

Acknowledgements

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Author Biography

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