Banding Reduction in Electrophotographic Printer

Je-Hwan You, Hyeong-Chae Kim and Sang-Yong Han
Digital Printing Division, Samsung Electronics Co., Ltd.
Suwon City, Korea

Abstract

The Banding is an image artifact that appears as light and dark bands periodically across a page. Banding can be classified into two categories: fine and rough ones.

Fine banding artifact could be caused by the periodic vibration or motion of optical devices on the optical path with the excitation frequency of the polygon mirror motor. The periodic vibration is mainly related to excitation force due to an imbalance of the rotor part of polygon mirror motor or the structural weakness of laser scanning unit. The periodic motion is mainly caused by pyramidal errors of the polygon mirror motor.

Rough banding artifact in printed images could be caused by the inaccurate motion or vibration of the OPC part or the fusing part driven by main driving unit. Printed image patterns have several frequencies, which can be obtained from the position of dots in a specific pattern of printed image and Fast Fourier Transform (FFT) result of the position data. The identified frequencies can be confirmed by referring to the tooth frequencies of the parts on the gearing table. This paper proposes a secure way to identify the causes of banding from FFT of the measured position data of dots in a specific pattern of printed images. The experiment was conducted to verify the identified causes of bandings.

Introduction

One of the major factors related to printed image quality of Laser Beam Printer (LBP) is a pitch error between scanned lines. The pitch error in electro-photographic printer is caused by the vibration or error motion of scanning or scanned part, which means Laser Scanning Unit (LSU) or Organic Photo-Conductive (OPC) as shown in Fig. 1. The vibration of scanning or scanned part is closely related to structural dynamics. The output of vibration can be expressed as the excitation force of vibration source multiplied by the unique frequency response of the system. The pyramidal error of polygon mirror or the vibration, which is generated by a large excitation force or structural weakness of LSU, causes the pitch error due to error motion. A pitch error caused by LSU is shown in Fig. 2. It shows the differences between LSU banding and no banding. They are the printed images generated in 2 by 2 patterns. This pattern can be used for the identification of the related frequencies. Most of pitch errors are visible in this pattern because the size of pitch error is larger than 0.5mm. If a printed image is produced at a smaller pattern, say 1 by 1 pattern, a pitch error is too small to recognize with bare eyes even if the measuring system could detect the pitch error. The frequencies related to pitch error could be identified by the FFT analysis of pitch error. The frequencies can be also found in the gearing table of the printer tested. The fact that a minute pitch error could be caused by not only LSU but also any other parts is experimentally verified in this paper. A certain pitch error pattern is described by a kind of beat phenomenon. The case of a microscopic pitch error generated by a structural weakness is introduced in this paper.

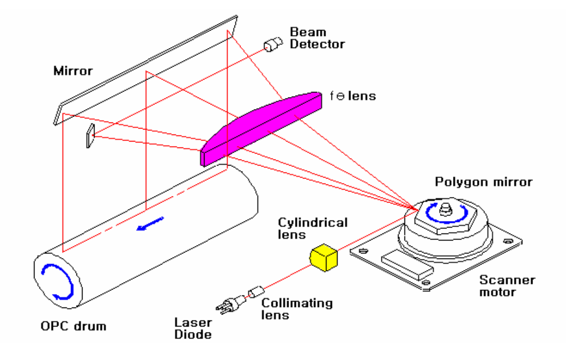
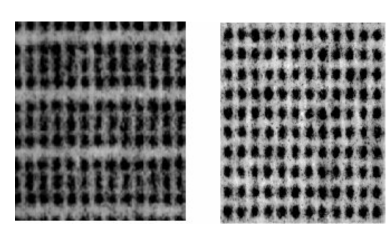


Figure 1. Laser Scanning Unit & OPC



(a) LSU banding *(b) No banding*

Figure 2. Banding caused by LSU

LSU Banding

A typical LSU banding in 2 by 2 patterns is shown in Fig. 3. As noticed in Fig. 3, LSU banding appears in the period of 2 revolutions of polygon mirror that has 6 facets; a periodic artifact of a period of 12 scanned lines in 2 by 2 pattern. This periodic phenomenon can be explained with motional frequency; LSU banding appears exactly in the half frequency of the rotation frequency of polygon mirror.

LSU banding can be generated by two major causes. It relates to the error motion or the vibration of scanning part. One is pyramidal error of rotating polygon mirror shown in Fig. 4(a), and the other is the vibration of at least one of parts on the optical path(Laser Diode → Collimating lens → Cylindrical lens → Polygon mirror → fΘ lens → Reflecting mirror → OPC drum) shown in Fig. 4(b).

The pyramidal error is the cause of being able to generate the pitch error even if there is no vibration in any part of LSU. Under general design specification, optical system must satisfy the pitch error of less than 5µm on the OPC in case the adjacent pyramidal error of rotating polygon mirror is 100 seconds. It means that if the pyramidal error is larger than the given specification, LSU banding could appear even if there is no mechanical vibration.

Among parts on the optical path, the polygon mirror motor directly affects on LSU banding because the polygon mirror is mounted on the motor. It has also a small amount of imbalance, and the imbalance is the vibration source with the excitation force proportional to the amount of unbalance. The unbalance of polygon mirror motor can be simply described with the static amount, which is the same as the vector sum of the unbalance of upper and lower parts of rotor. The excitation force can be expressed by equation (1).

$$F = mr\omega^2 , \qquad (1)$$

where 'mr' is the amount of unbalance, 'ω' is the angular velocity.

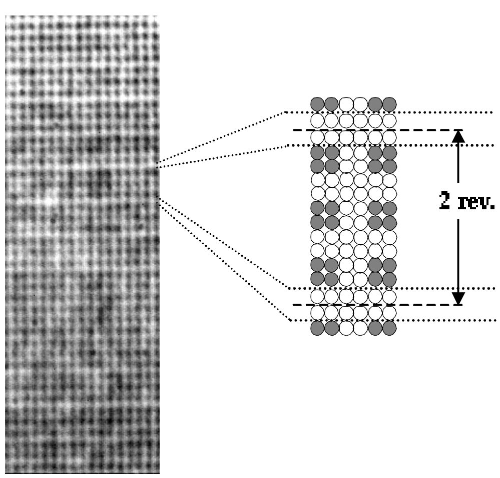
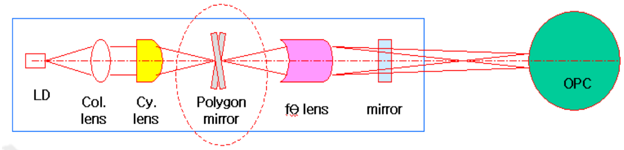
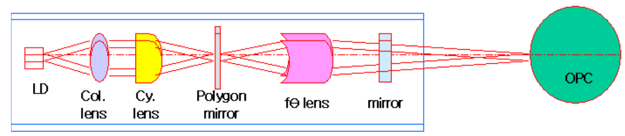


Figure 3. Analysis of Banding caused by LSU



(a) Pitch error due to pyramidal error of polygon mirror



(b) Pitch error due to the vibration of LSU

Figure 4. Analysis of Banding caused by scanning part (LSU)

The excitation force is generated in the same frequency with the rotation frequency of polygon mirror, and is one of the major source of vibration as well as the cause of the LSU banding due to vibration. The output of vibration X(f) can be expressed in the product between the excitation force F(f) of vibration source and the unique frequency response H(f) of the system as shown in equation (2).

$$X(f) = H(f) \cdot F(f) \qquad (2)$$

This means that even if the excitation force F(f) is small, but if the frequency response at the specific frequency is large, than the vibration could be large. Therefore, the vibration problem should be considered as the problem related to not only excitation force but also the frequency response of the object.

For example, the left one of Fig. 2 is the printed image that has a LSU banding, which is caused by the structural weakness of a specific part in LSU. The experiment of getting FRF (Frequency Response Function)'s of concerned parts in LSU was conducted, and finally the fact that the FRF of the reflecting mirror is relatively larger than those of other parts was found. So, the thickness of the reflecting mirror changed thicker, and then the LSU banding disappeared.

Fine Banding Similar to LSU Banding

The fine banding similar to LSU banding shown in Fig. 5, but this type of fine banding is different from LSU banding.

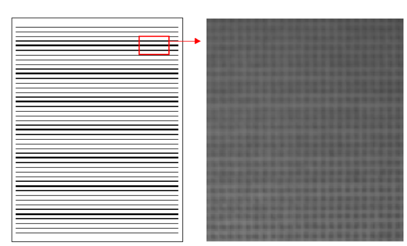


Figure 5. Fine banding similar to LSU banding

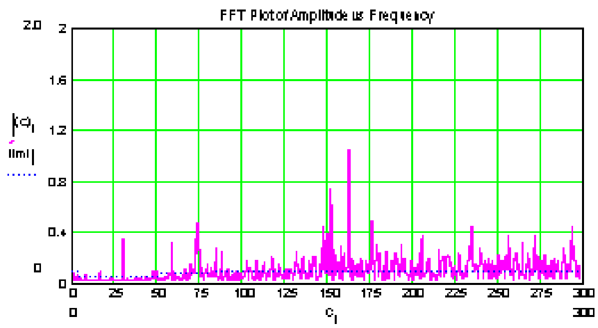


Figure 6. FFT result for the printed image shown in Fig. 5

Table 1. Relevant Frequencies on Gearing Table

Freq. on FFT (Hz)	Item & tooth freq. on gearing table		pitch	Remark
	Item	tooth freq. (Hz)		
73,5	GEAR-FUSER	36,73	1,213mm	Heat roller
147		36,73	0,606mm	
80,9	GEAR-DRV,DEV GEAR-RDCN AGITATOR GEAR-DRV DRSR	80,90	1,114mm	Dev. roller
160		80,90	0,557mm	
175,6	polygon motor	351,3 rps	0,508mm	LSU

According to the FFT result for the printed image shown in Fig. 5, the dominant frequency is not the frequency related to LSU banding as shown in Fig. 6. If this banding were LSU banding, the dominant frequency would be exactly the same as the half frequency(about 175.6 Hz) of the rotation frequency(351.3 Hz) of polygon mirror which rotates in 21,082 rpm. However, the dominant frequencies are about 160 or 147Hz. Among these, the frequency component of about 160 Hz is harmonic component of tooth frequency of parts in development unit. As found in Table 1, the pitch error induced by the frequency component of about 160Hz is 0.557mm, which is similar to the pitch error of LSU banding, 0.508mm. It looks like LSU banding, but isn't exactly regular as LSU banding. It is because this fine banding appears at each 13 scanned lines, while LSU banding appears at each 12 scanned lines that is exactly relevant to 2 revolutions of polygon mirror.

On the other hand, this kind of banding repeats to appear and disappear in the low frequency of about 15Hz across the entire page. This can be described with beat phenomenon. That is to say, in this case the beat frequency is about 15Hz, which is the gap between 175.6 and 160Hz. The other beat could be also generated by the frequency components of 160 and 147Hz.

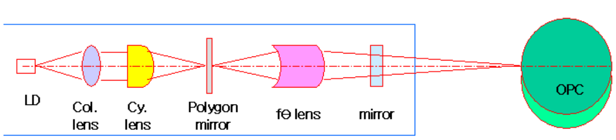


Figure 7. Analysis of Banding caused by scanned part (OPC)

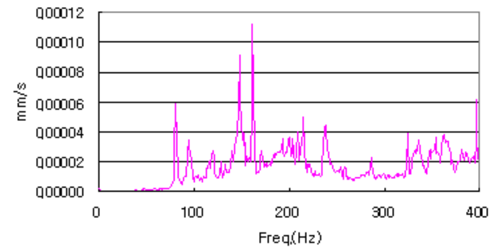


Figure 8. FFT result for vibration velocity of OPC part

The existence of dominant frequency components was verified experimentally through measuring the vibration velocity of OPC part as shown in Fig. 7. The FFT result for vibration velocity of OPC part is as shown in Fig. 8. The fact that the dominant frequency components are 160 and 147Hz was confirmed.

To reduce this type of banding, the mechanism of old-ham coupling was applied to a driving unit connected to development parts. Finally, the above fine banding was reduced.

LSU Banding Due to Structural Weakness

The vibration of LSU or any mechanical parts in laser beam printer could be amplified by structural weakness. To find the weak part in LSU in terms of vibration, the acquisition of FRF of concerned parts is required under the actual boundary condition. The FRF's for important parts of any LSU can be acquired experimentally as shown in Fig. 9.

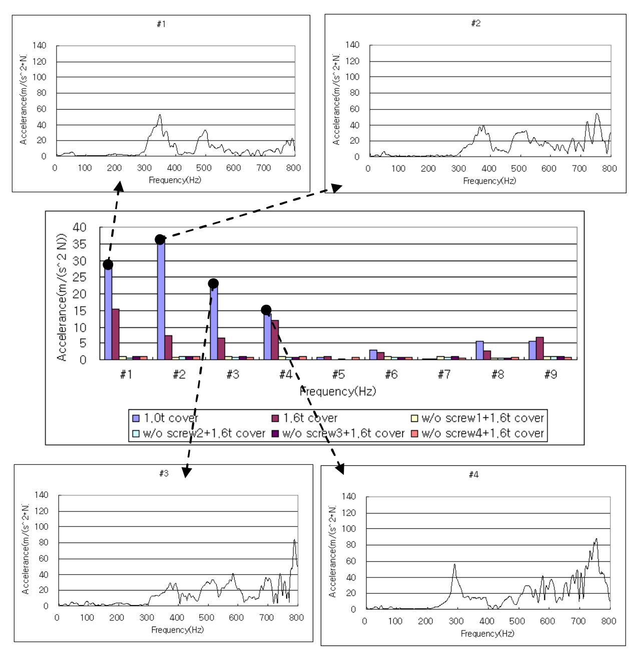


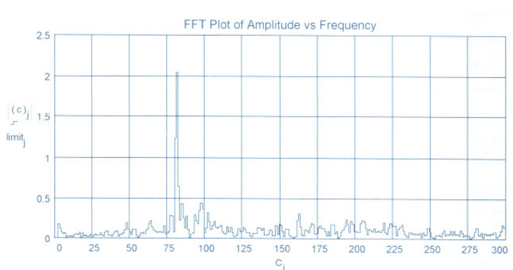
Figure 9. FRF(accelerance) of parts in LSU (at 367Hz)

The input force from an impact hammer is applied to the same actual vibration source point, and the outputs of acceleration at each concerned point is acquired. Finally, the accelerance (=acceleration/force) that is a kind of FRF can be acquired at each concerned points. Fig. 9 shows the accelerances at 9 important points with respect to frequency. In this case, rotating speed is 22,000rpm, so it means that the excitation frequency is 367Hz. Therefore, we can get the value of accelerance at the concerned frequency of 367Hz from FRF results at 9 points. The central one in Fig. 9 shows the comparison between the magnitudes of accelerance at the same frequency of 367Hz for 9 points. According to this comparison, the 4 points (#1,2,3,4) out of 9 concerned parts were very sensitive to the thickness of the LSU cover frame directly connected to set main frame. Finally, the thickness of LSU cover frame was determined based on the above FRF results to reduce the structure borne vibration.

Rough Banding

The rough banding artifact in printed images could be caused by the motion inaccuracy or vibration of the OPC part or the fusing part driven by main driving unit. Fig. 10(a) is an example of rough banding induced by OPC part. The pitch of banding is about 1.1~1.2mm, which can be considered as OPC banding according to Table 1. As you can see in Fig. 10(c), the dominant frequency component is about 80Hz, which is the same as the relevant frequency in Table 1. The rough bandings related to OPC or fuser are induced by the error of alignment, tolerance, and motion inaccuracy relevant to parts in OPC or fuser. Therefore, modifying the relevant parts can reduce this kind of rough banding.

(a) OPC banding *(b) Fuser banding*



(c) FFT result for pitch error of OPC banding

Figure 10. Examples of rough banding

Conclusion

In this paper, the classification and analysis of various bandings was conducted, and the way of reduction for each banding was described in the view of system dynamics.

LSU banding appears in every two revolutions of the 6-facets polygon mirror in 2 by 2 pattern. It means a periodic artifact of a period of 12 scanned lines in 2 by 2 pattern. In other words, LSU banding appears exactly in the half frequency of the rotation frequency of polygon mirror in the case of a 6 facets polygon mirror.

LSU banding induced by structural weakness of LSU was presented. The way of improving the dynamic characteristics of LSU by using the identification and modification of frequency response of the system was proposed in order to reduce the structural weakness of LSU.

Fine banding similar to LSU banding was also presented. This kind of banding could appear in case the frequency close to half of the rotational frequency exists in the system. Therefore, this sort of frequency must be avoided to remove fine banding similar to LSU banding.

References

1. Michael T.S. Ewe, Jim M. Grice, George T.-C. Chiu and Jan P. Allebach, "Banding Reduction in Electrophotographic Process Using Piezoelectric Actuated Laser Beam Deflection Device", IS&T's NIP16, pp.276-280, 2000
2. Guo-Yan Lin, Jimmy M.Grice, Jan P. Allebach, and George Chiu, "Banding Artifact Reduction in Electrophotographic Printers by Using Pulse Width Modulation", IS&T's NIP16, pp.281-286, 2000
3. Cheng-Lun Chen, George T.-C.Chiu and Jan P. Allebach, "Banding Artifact Reduction in Electrophotographic Process Using OPC Drum Velocity Control", IS&T's NIP17, pp.60-66, 2001
4. Wencheng Wu, Edul N.Dalal, and D.Rene Rasmussen, " Perceptibility of Non-sinusoidal Bands", IS&T's NIP18, pp.462-466, 2002
5. Yousun Bang, Zygunt Pizlo, and Jan P. Allebach, "Discrimination Based Banding Assessment", IS&T's NIP19, pp.745-750, 2003

Biography

Je-Hwan You received his BS, MS, and Ph.D degrees from Yonsei University, Seoul, Korea in respectively 1992, 1994, and 1999. He was a visiting scholar supported by KOSEF(Korea Science and Engineering Foundation) at Northwestern University, IL, US. in 2000.

Since 2001 he has worked for Samsung. Before joining Samsung, he researched on various types of magnetic bearings, including superconducting bearing. His current research interest focuses on the tribological problems and image quality related to especially polygon mirror motor as well as mechanical parts in LBP.