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Examination of Spur Marks Found on Inkjet-printed Documents*

ABSTRACT: In this paper, we propose the examination of spur mark evidence on inkjet-printed documents. Spur marks are tool marks created by the spur gears in the paper conveyance system of many inkjet printers. The relationship between printouts and printers were investigated by comparing the spur marks found on printed documents with reference spur marks sampled from known printers. The comparison was based on two characteristics of spur marks: pitch and mutual distance. These characteristics extracted the geometric features of spur marks and provided information on the type of spur gears and their location in the paper conveyance system. The spur marks on a printout matched the reference spur marks within three percent of the measured values. Spur marks were considered to be effective class characteristics to identify certain brands of inkjet printers since spur gears are used in many types of these machines.

KEYWORDS: forensic science, questioned documents, printers, inkjet printers, class characteristics, spur gears, spur marks, pitch, mutual distance

Examination of inkjet printers is becoming more prevalent in the field of forensic document examination. Fraudulent documents such as counterfeited banknotes, securities, passports, traveler's checks and driver's licenses are being created worldwide with computers and peripherals due to technological improvements. This technology is also used to illegally manufacture documents such as fake wills, contracts and receipts that may be used to perpetrate financial crimes.

Inkjet printers are popular image output devices for computers (1). Over 74 million were sold worldwide in 2002 (2). The quality of inkjet printers has significantly improved, and the costs associated with purchasing and printing have decreased. The advancement of inkjet printers has also enabled criminals to produce quality counterfeits with little effort and cost. In 2001, over 5,000 inkjet-printed counterfeit banknotes were examined at the National Research Institute of Police Science, Japan (3).

Previous studies have focused primarily on the chemical examination of inkjet inks using thin layer chromatography (4,5), infrared reflectance/luminescence properties (4), and spectral reflectance properties in the visible wavelength region (6).

However, physical defects on documents are also effective tools for forensic examination. Tool marks have been widely used in forensic science to link known and suspect items, and to identify suspect items that created the markings (7). One of the advantages of tool mark analysis is the stability of physical markings against environmental disturbances after indentation. In the field of document examination, tool marks have been applied extensively to examine photocopiers (8–10), typewriters (11–13) and label makers (14). A recent case report demonstrated visualization techniques using an electrostatic detection device to reveal the latent physical markings by printers and copiers on documents (15). Corroboration of chemical and physical evidence may be helpful to forensic scientists in order to isolate a family or group of suspect printers.

This paper investigates the feasibility of identifying spur marks created on documents produced by inkjet printers. The authors propose a method of making physical measurements of spur marks to link questioned documents with suspect inkjet printers.

Theory

Spur Gears of Inkjet Printers

The spur gears are the mechanism for holding the paper in place as it passes through an inkjet printer (16). They ensure that the print media is kept flat to prevent the cockling of paper caused by the moisture of the ink. If the print media is not kept flat, the quality of printing is diminished because ink droplets are not placed accurately. In some cases, print media is destroyed by becoming caught on the print head.

Spur gears are an important design feature for many models of inkjet printers. In this study, we have examined 118 models of inkjet printers by 8 manufacturers listed in Table 1. In this table, models were classified according to the existence of spur gears that have rubber rollers. Table 2 lists the number of models examined and the number of models with spur gears. Of the 118 models of inkjet printers, spur gears were used in 93 (78.8%) produced by 7 manufacturers. However, 25 models by 5 manufacturers had no spur gears. The prevalence of spur gears depended on the manufacturer. The ratio of Hewlett-Packard and NEC printer models with spur gears was 30.4% and 45.5%, respectively. In contrast, all of the models by Canon, Epson, and Ricoh, and over 90% of the models by Lexmark, and Fujitsu had spur gears.

In non-inkjet printers, rubber rollers are usually used to hold the print media in place, as well as reducing the occurrence of significant defects in the substrate. However, these rubber mechanisms are sometimes not practical to use in inkjet printers since ink does not immediately dry as a document passes through the paper

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TABLE 1—*Spur gears in 118 models of inkjet printers by eight manufacturers.*

Class	Manufacturer	Model
With spur gears	Canon	BJC-410J, BJC-420J, BJC-400J, BJC-455J, BJC-210J, BJC-240J, BJC-250J, BJC-430J, BJC-430J Bk, BJC-430J Lite, BJC-430J DLite, BJC-440J, BJC-465J, BJC-35v, BJC-35v II, BJC-80v, BJC-50v. BJC-600J, BJC-600S, BJC-610JW, BJC-620JW, BJC-680J, BJC-700J, BJC-800J, BJC-820J, BJC-880J, BJC-5500J, BJF800
	Seiko EPSON	MJ-700V2C, MJ-900C, MJ-910C, MJ-500C, MJ-510C, MJ-510CS2, MJ-520C, MJ-800C, MJ-810C, MJ-830C, MJ-830CS2, MJ-930C, PM–600C, PM-700C, PM-750C, PM-800C, MJ-3000C, MJ-3000CU, MJ-5000C, MJ-5100C, MJ-6000C, MJ-8000C, PM-2000C, PM-5000C
	Hewlett-Packard	DJ1120C, DJ340, DW320, DW310, DJ300J, DJ1200C, DJ1200C/PS
	Lexmark	1000,1000B, 1020, 2030, 2050, 2050B, 2070, 5000, 5000B, 5700, 5770, 7000, 7200, 7200B
	Ricoh	CJ720/A2, CJ720II, CJ720/A2II, IPSiO JET 300
	NEC	PR-J4000, PC-PR101/J100L, PC-PR101/J110R, PC-PR101/J110, PC-PR101/J80L
	Fujitsu	VS-120, VS-150, VS-180, XJ-330, XJ-300, XJS-400, XJ-600, XJ- 610, XJ-700, IA-3000, XJ-800
With no spur gears	Hewlett-Packard	DJ720C, DJ850C, DJ694C, DW694C, DW680C, DW660C, DW600, DW540, DJ560J, DJ505J, DJ500J, DW560C, DW550C, DWC, DW, PhotoSmart
	Lexmark	150C
	NEC	PC-PR101/J180, PC-PR101/J200, PC-PR101/J300, PR-J220, PC- PR101/J400, PR-J320
	Fujitsu	XJ-500
	Oki data	Picnica MICROLINE JET 300

TABLE 2—*Spur gear statistical information reported by manufacturers.*

Manufacture	Number of Models Examined	Number of Models with Spur Gears	Number of Models with no Spur Gears	Percentage of Models with Spur Gears
Canon	28	28	0	100.0
Seiko EPSON	24	24	0	100.0
Hewlett-Packard	23	7	16	30.4
Lexmark	15	14	1	93.3
Ricoh	4	4	0	100.0
NEC	11	5	6	45.5
Fujitsu	12	11	1	91.7
Oki data	1	0	1	0.0
Total	118	93	25	78.8

conveyance system. Smearing of the ink may occur when contact is made with the conventional rubber rollers. By utilizing spur gears, the area of contact is limited to the tips of the gear teeth.

Figure 1 shows an example of the paper conveyance system of an inkjet printer with spur gears. This is the top view of the paper conveyance system in an EPSON PM-750C inkjet printer. Spur gears are located in front of the print heads and run over the top of the document. Figure 2 shows an example of a spur gear. This is the side view of a metal spur gear found in an EPSON PM-750C inkjet printer. Spur gears are classified into two types based on their composition: metal and plastic. A large number of spur gears are made of metal. The diameter of most spur gears is approximately 10 mm and the number of teeth ranges from 16 to 64. As shown in Fig. 3, most of the spur gears are coupled with plastic holders. Each spur gear is supported by a shaft and holders in the printer mechanism.

Figure 4 depicts the rubber rollers that are sometimes found under some of the spur gears. This is a view of the paper conveyance system from the side of the paper outlet of an EPSON PM-750C inkjet printer. As the media passes through, it is supported between the spur gears and the rubber rollers; however, at the point where the spur gear is not paired with a rubber roller, the print media only makes contact as it moves toward the gear.

Spur Marks of Inkjet Printers

Spur marks are the indented marks found on documents that result from the spur gears. Figure 5 is a diagram of the indentation

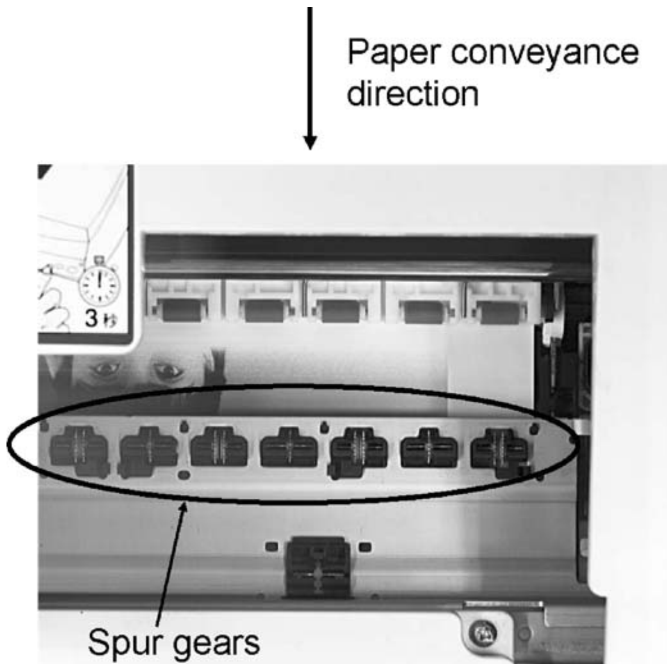

FIG. 1—*Overview of the paper conveyance system of an EPSON PM-750C inkjet printer.*

process of spur marks. During the printing process, print media is softened due to the moisture of the ink. Thereafter, each spur gear makes contact with the print media at its tips. By contacting spur gears with softened print media, the fiber and coated materials of the print media is damaged to the extent that the original shape is not retrieved. This is not elastic deformation, but rather plastic deformation. The deformation is fixed as the print media is dried. Accordingly, small dents remain on the print media after the printing process. However, in the areas without printing ink, spur marks are impressed resulting in plastic deformation when the pressure between spur gears and print media is high. As the print media are conveyed toward the paper outlet, each spur gear rotates, and its tips makes contact with print media resulting in consecutive impression marks formed on the print media. Spur marks by an individual gear in a single line are referred to as a spur mark line.

Figure 6 is an example of two spur mark lines by an Epson PM-750C printer. Each spur mark is indicated by a circle, and

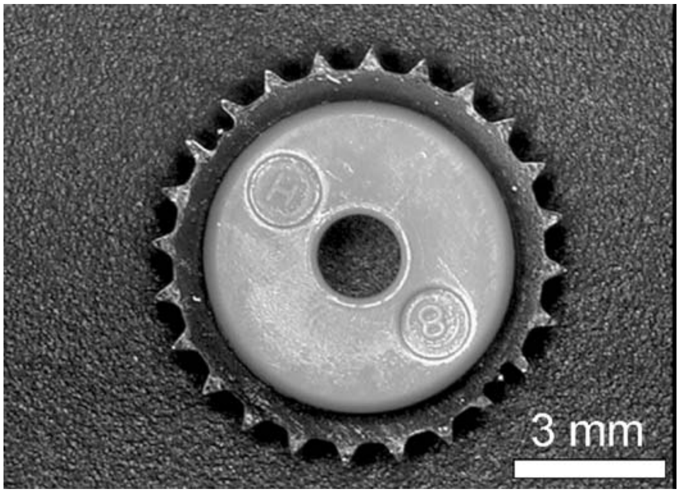

FIG. 2—*Side view of a metal spur gear.*

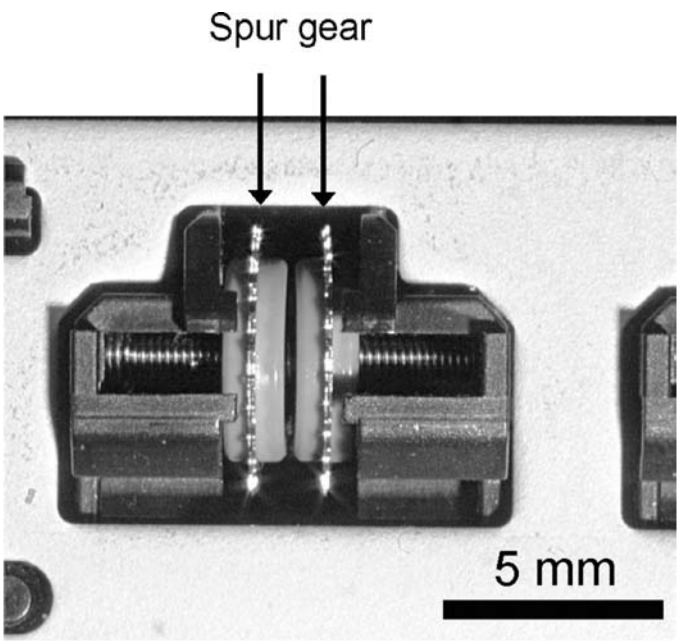

FIG. 3—*A set of spur gears supported by shafts and holders on the same metal plate.*

the spur lines are represented as dashed lines. The spur lines are a set of similar "bumps" at constant intervals. Spur lines formed in the same printing process should be parallel. The direction of spur mark lines is parallel to the paper conveyance direction (sub-scanning direction) and perpendicular to the direction of movement of the print head (main-scanning direction).

Figure 7 shows a spur mark that is visualized at magnifications ×320 as a small wedge shaped dent in the substrate with oblique lighting. The shape of the spur mark generally reflects the shape of the tips on the spur gear. The spur marks are larger, deeper, and sharper than the bumps and dents that originally existed on the paper. The authors observed at least one line of spur marks on hardcopies of 90 models (96.8%) of inkjet printers with spur gears listed in Table 1.

Spur marks are clearly impressed when the pressure between spur gear and print media is high. We found that the spur gears with rubber rollers under them make distinct spur marks except for the part of extremely low ink dot area coverage such as the highlight

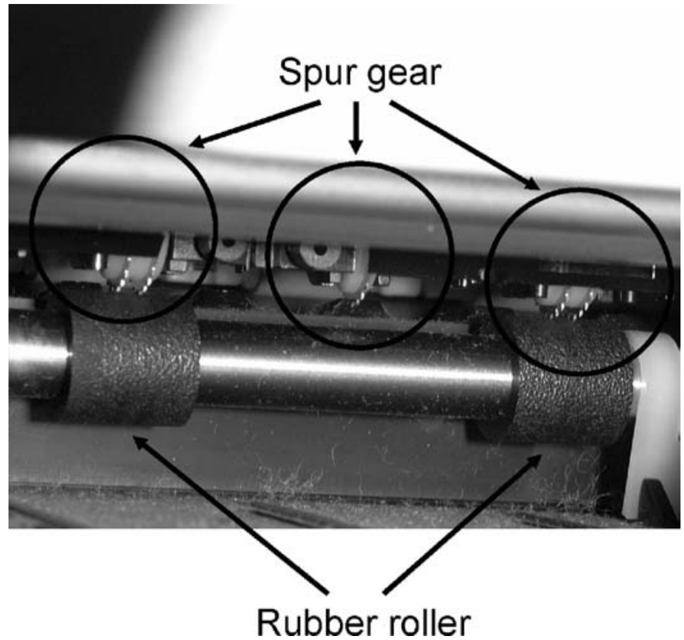

FIG. 4—*Spur gears and rubber rollers observed from the paper outlet.*

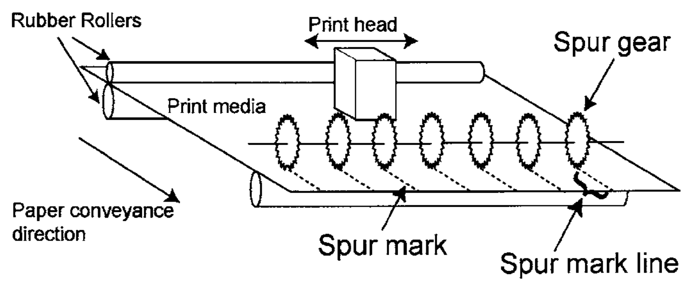

FIG. 5—*Schematic diagram of the process of impressing spur marks.*

of an image and the portion without ink droplets. The spur gears with rubber rollers induce sufficient pressure to impress distinct spur marks. For the case of spur gears without rubber rollers, spur marks were occasionally impressed when print media happened to contact with spur gears at the part of high ink dot area coverage. The spur gears made of plastics seldom impress spur marks.

Spur marks are also impressed where ink dot area coverage is high. As the ink dot area coverage is increased, the surface of print media is soft and easily deformed due to the moisture of inks. Therefore, cases when the spur marks are formed in the process of printing, the distinctness of spur marks does have a correlation with the ink dot area coverage.

Spur Mark Comparison Method (SCM)

The spur marks found on questioned documents and the spur gears of suspect printers can be compared to determine if they are associated. The examination is referred to as the Spur mark Comparison Method (SCM). Figure 8 is a basic outline of the SCM. However, direct comparison of spur gears and spur marks can sometimes be difficult due to the limitations of rooms in the paper conveyance system. Therefore, a comparison is performed between reference spur marks sampled from the suspect printer and the spur marks on the questioned document. This type of examination is commonly utilized in the field of tool mark identification (7). If geometrical features between the spur gears and the spur

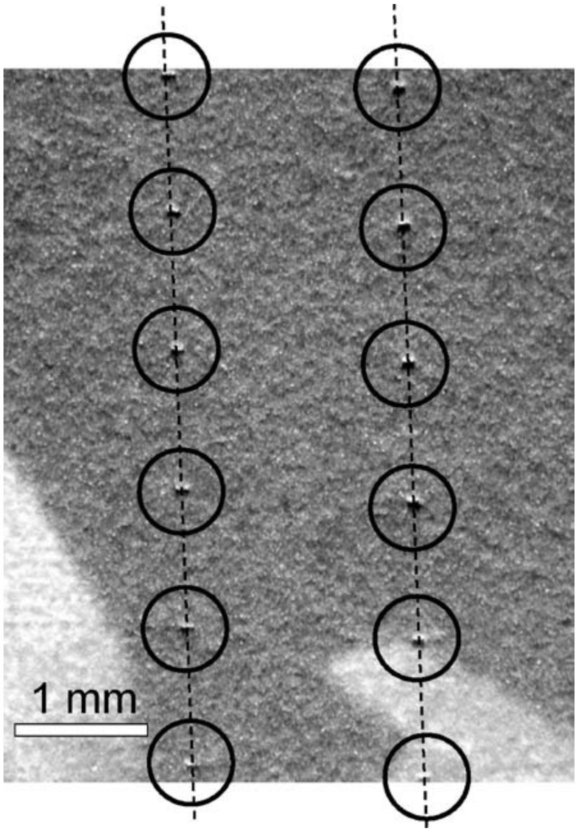

FIG. 6—*Spur marks and spur mark lines. Each spur mark is indicated by a circle, and spur mark lines are shown as dashed lines.*

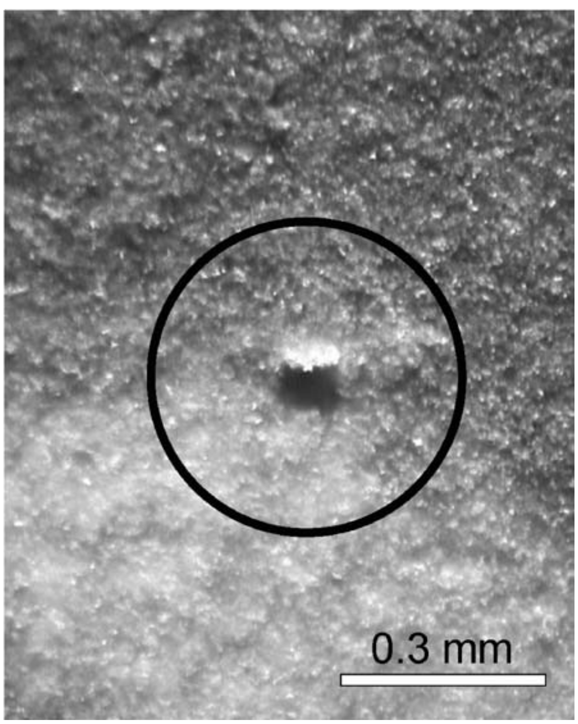

FIG. 7—*Enlarged image of a spur mark.*

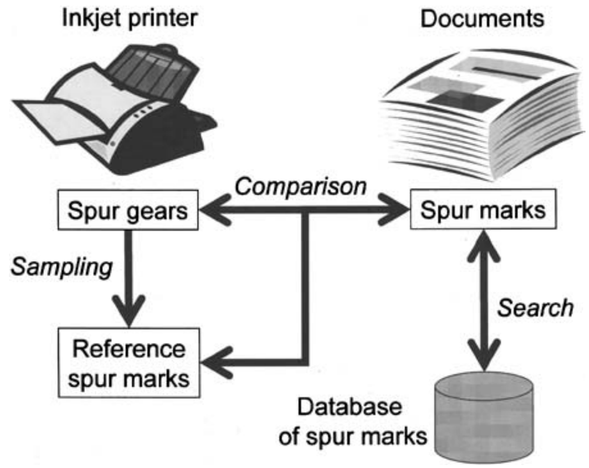

FIG. 8—*Spur mark Comparison Method (SCM).*

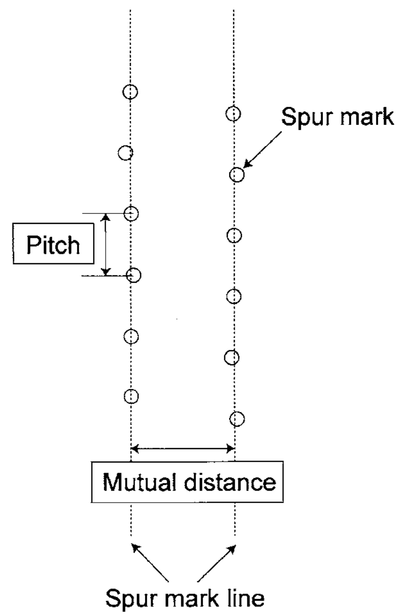

FIG. 9—*Pitch and mutual distance. White circles represent spur marks, and the dashed lines represent spur mark lines.*

marks do not agree, it is assumed there is no relationship between them. Identification of the individual inkjet printer is achieved in cases when the peculiar features existed in spur marks, such as defects, deficiencies or distortions on the tip of the spur gears. These features provide strong evidence when making an identification of the individual inkjet printer from which the document was printed. However, features of spur marks are generally common in a group of models making them class characteristics. Therefore, the SCM usually identifies a group of models. By constructing a database of spur gears used in various models of printers, a group of inkjet printers can be potentially identified by comparing characteristics of spur marks.

We introduce two characteristics, pitch and mutual distance, to represent the geometrical features of spur marks. Figure 9 illustrates these two characteristics. Pitch is the distance between adjacent spur marks in an individual spur mark line. Within one spur mark line, the interval between spur marks is constant. The interval corresponds to the pitch along the addendum circle of a spur gear, which is the length of an arc between two adjacent teeth in the circumscribed circle connecting each tip of the teeth of a spur gear. Pitch is determined by the gear diameter and the number of teeth that represents the type of spur gear. Mutual distance represents the proximity between adjacent spur mark lines and corresponds to the proximity between spur gears in the main scanning direction.

Mutual distance also indicates the relative location of the spur gears in the paper conveyance system.

SCM should be performed based on the "natural" spur marks that were impressed in the process of printing. If a criminal knows that forensic scientists utilize spur marks for the analysis of inkjet-printed documents, they may intentionally impress spur marks before or after the printing process for the purpose of feinting. Sometimes spur marks are impressed accidentally, but the natural spur marks are distinguishable because their distinctness correlates with the ink dot area coverage. If spur marks are impressed before or after the process of printing, the distinctness is almost constant regardless of ink dot area coverage.

Materials and Methods

The printers used for experimental demonstration were two printers of different models and manufactures: Printer A (Seiko Epson, PM-750C) and Printer B (Canon, BJF 800). One printout was created from each printer on a matte coated paper of A4 size (Seiko Epson, A4MJSP1). The image data for printing was a printer standard test pattern (Japan Electronic Industry Development Association, JEIDA-46-1996, J8_600.bmp), which is a bitmap image of 4252 by 5598 pixels at 600 dpi. The print size was 180 × 237 mm without magnification or reduction.

Reference spur marks from each printer were sampled on a pressure measurement sheet (Fujifilm, Prescale MS mono-sheet) attached to a sheet of plain copy paper. The sheet was fed through the paper conveyance system without printing an image. The color of the paper changes to magenta in areas in which pressure is induced, and the density of the color indicates the magnitude of pressure. Reference spur marks were digitized at 600 dpi using a flatbed scanner. The image contrast was enhanced using the level correction function in a photo retouch software package (Adobe, Photoshop 6.0).

Spur marks on the printout were visualized by oblique lighting from an incandescent light source. The incident angle of the light used was 70°. Spur marks were observed using a microscope at magnifications from ×56 to ×320. The locations of spur mark lines were recorded in an image data file, which was used for printing samples.

Thereafter, the pitch and mutual distance of spur marks was measured using a glass scale. Pitch (p) was calculated as the average pitch within a spur mark line, based on the assumption that the pitch is constant, as follows:

$$p = \frac{l}{m} \qquad (1)$$

where l is the distance between two spur marks, and m is the number of spur marks occurring over distance l. The length l was measured to three significant digits with a glass scale having 0.1 mm gradations. By setting l to be longer than 10.0 mm, the pitch (p) was calculated to an accuracy of 0.01 mm.

For the mutual distance, in cases where the measurement target was shorter than 10.0 mm, a measurement was performed to an accuracy of 0.1 mm using the same scale. For cases where the mutual distance was larger than 10.0 mm, a measurement was performed using a steel scale having a 0.5 mm interval.

The spur marks on the printout and the reference specimens were compared. First, the two spur marks were observed on a computer monitor by split-screen image, and then the authors examined the correspondence between the two sets of spur marks. The values for pitch and mutual distance were also compared. The differences between spur marks and spur gears were evaluated quantitatively.

Results and Discussion

Case 1—Printer A

Figure 10 shows the arrangement of spur gears in Printer A. Spur gears are supported by two axes: Axis 1 and Axis 2, both of which are perpendicular to the paper conveyance direction. There are 20 metal spur gears on Axis 1 and one plastic spur gear on Axis 2. Axis 1 has seven sets of spur gears adjacent to each other as shown

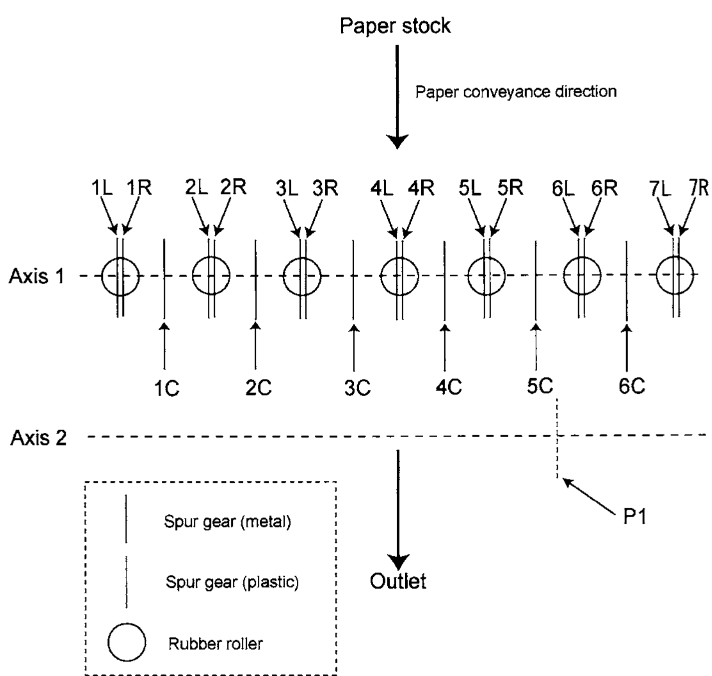

FIG. 10—*Location of spur gears and mechanical parts in the paper conveyance system of the Epson PM-750C.*

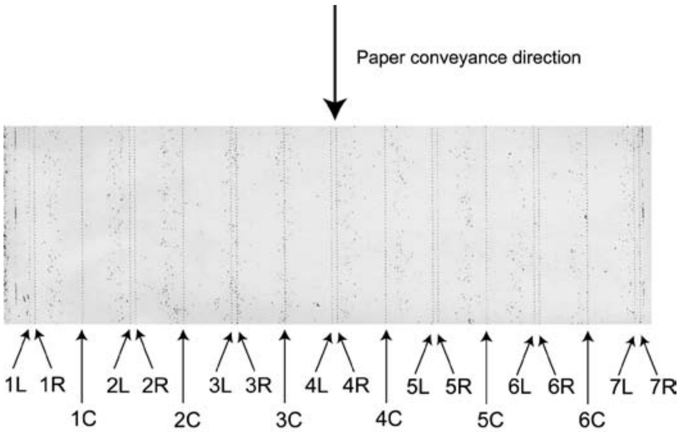

FIG. 11—*Spur marks of the Epson PM-750C printer sampled on a pressure measurement sheet.*

in Fig. 3. Double spur gears are labeled from 1 to 7, with the left and right gears denoted by L and R respectively. There are rubber rollers under the double spur gears. There are also seven single spur gears denoted by C and each is located between two sets of double spur gears. There are no rubber rollers under the single spur gears. In addition, on Axis 2, there is one plastic spur gear with no rubber roller beneath.

Figure 11 shows reference spur marks sampled from the printer. There were 20 spur mark lines corresponding to metal spur gears; however, no spur mark line was observed for the plastic spur gear. Each spur mark line was named after the corresponding spur gears as shown in Fig. 11. Within a spur mark line, spur marks occurred at a constant interval, and they were continuous without the absence of spur marks. The distinctness and density of reference spur marks was approximately constant. Therefore, the authors assumed that there was no absence of teeth in the spur gears and no slippage of the spur gears in the paper conveyance process. The pressure was considered to be approximately constant within a spur mark line. There were no differences in the distinctness or density between reference spur marks by the spur gears with rubber rollers and those without.

Figure 12 shows the locations of ten spur mark lines on the printout, which are represented by the thick lines A1 to E2 shown in the figure. Spur mark lines were not continuous, and the distinctness was related to the total area coverage of the document. Spur marks were not observed in low-coverage areas, such as image highlight or margins without half-tone dots.

Figure 13 shows the results of a graphical comparison between the spur marks on the printout and the reference specimens. The spur mark lines from A1 to E2 on the printout showed correlation with the spur mark lines from 2L to 6L and from 2R to 6R of the reference specimens. However, the spur mark lines were not observed to correlate with the spur gears without rubber rollers (from 1C to 6C and P1) or with some of the spur gears with rubber rollers (1L, 1R, 7L and 7R).

Table 3 shows the numerical comparison of pitch between the corresponding spur marks shown in Fig. 13. The difference was less than 0.01 mm, which is less then the accuracy of the measurement.

Table 4 lists the results for mutual distance. For the mutual distance of a set of spur gears adjacent to one another, in four out of five cases there was perfect agreement. The remaining case had a deviation of 0.1 mm. However, this is the minimum unit of the measurement and is less than 1% of the measured mutual distance. For the mutual distance between different units of spur gears, three

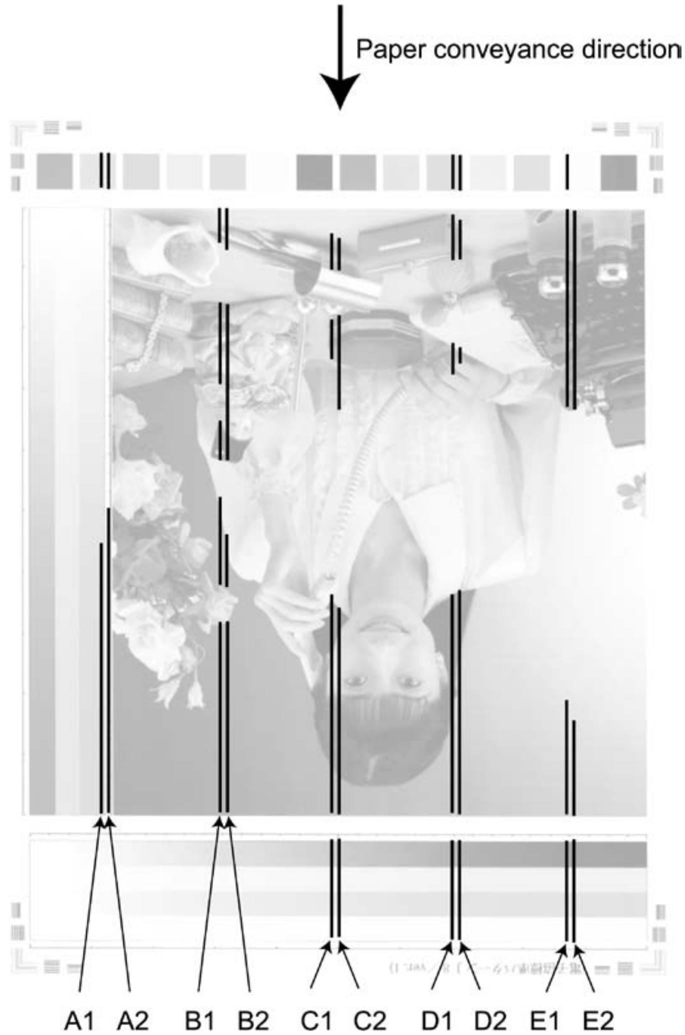

FIG. 12—*Location of spur mark lines on printout, represented as thick lines denoted from A1 to E2.*

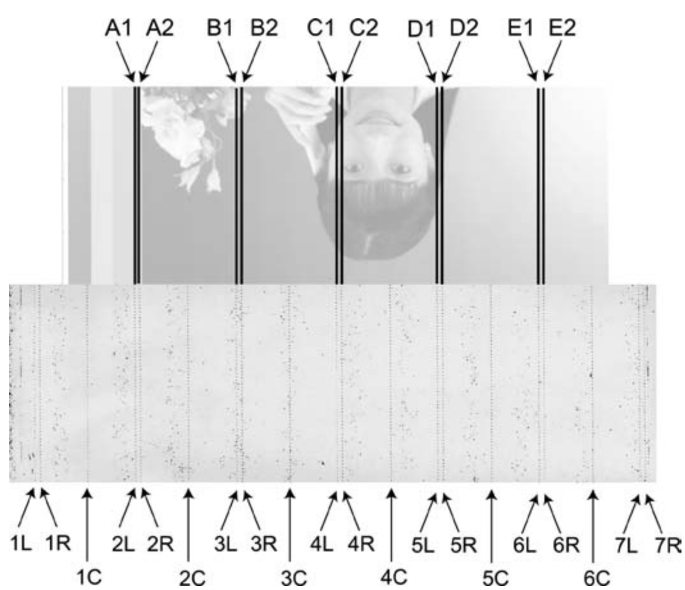

FIG. 13—*Graphical comparison between the spur marks on a printout (upper) and on a pressure measurement sheet (lower) for the Epson PM-750C printer.*

TABLE 3—*Comparison of pitch between the spur marks on the printout and on a pressure measurement sheet for the Epson PM-750C printer. The notation <0.01 indicates differences of less than 0.01 mm.*

Printer (Reference Spur Marks)		Printout		
Spur Mark Line	Pitch (mm)	Spur Mark Line	Pitch (mm)	Difference (mm)
1L	1.04	(Not detected)		
1R	1.04	(Not detected)		
2L	1.04	A1	1.04	<0.01
2R	1.04	A2	1.04	<0.01
3L	1.04	B1	1.04	<0.01
3R	1.04	B2	1.04	<0.01
4L	1.04	C1	1.04	<0.01
4R	1.04	C2	1.04	<0.01
5L	1.04	D1	1.04	<0.01
5R	1.04	D2	1.04	<0.01
6L	1.04	E1	1.04	<0.01
6R	1.04	E2	1.04	<0.01
7L	1.05	(Not detected)		
7R	1.04	(Not detected)		

TABLE 4—*Comparison of mutual distance between the spur marks on the printout and on a pressure measurement sheet for the Epson PM-750C printer. The notations <0.1 and <0.5 indicate differences of less than 0.1 mm and 0.5 mm, respectively.*

Printer (Reference Spur Marks)		Printout		
Section	Mutual Distance (mm)	Section	Mutual Distance (mm)	Difference (mm)
1L–1R	1.9	(Not detected)		
1L–2L	32.5	(Not detected)		
2L–2R	1.8	A1–A2	1.8	<0.1
2L–3L	32.5	A1–B1	32.5	<0.5
3L–3R	1.8	B1–B2	1.7	0.1
3L–4L	32.5	B1–C1	32.5	<0.5
4L–4R	1.8	C1–C2	1.8	<0.1
4L–5L	32.0	C1–D1	33.0	1.0
5L–5R	1.8	D1–D2	1.8	<0.1
5L–6L	32.5	D1–E1	32.5	<0.5
6L–6R	1.8	E1–E2	1.8	<0.1
6L–7L	32.5	(Not detected)		
7L–7R	1.9	(Not detected)		

cases out of four matched perfectly. The remaining case showed a deviation of 0.5 mm, which is only 1.5% of the measured value and is the minimum unit of the measurement.

Case 2—Printer 2

Figure 14 shows the arrangement of spur gears in Printer B. Spur gears are supported by four axes: from "Axis 1" to "Axis 4". Each axis is perpendicular to the paper conveyance direction. There are 20 metal spur gears on Axis 1 and five metal spur gears on each axis from Axis 2 to Axis 4. Spur gears were labeled as shown in Fig. 14. On Axis 1, there were 10 sets of spur gears adjacent to each other. Such double spur gears were named from 1–1 to 1–10. The left and right gears of the double spur gears are denoted L and R, respectively. There are five single spur gears on each axis from Axis 2 to Axis 4, as denoted by 2-2C to 4-9C in Fig. 14. The spur gears on Axis 2 and Axis 3 are located above the surface of the print media, and do not come into contact with the print media unless extreme cockling of the paper occurs. Rubber rollers are only present on Axis 1 and Axis 4.

There were 25 spur mark lines corresponding to metal spur gears. However, those for spur gears without rubber rollers were not observed. Each spur mark line was named after the corresponding spur gear, as shown in Fig. 15. Within a spur mark line, spur marks occurred at a constant interval, and the spur mark line was continuous without the absence of spur marks. The distinctness and density of reference spur marks was almost constant. Therefore, we assumed that there were no absences of teeth in the spur gears and that no slippage of the spur gears occurred in the paper conveyance process. The pressure was considered to be approximately constant within a spur mark line. There were no differences in the distinctness or density between each reference spur mark line.

Figure 16 shows the location of spur mark lines on the printout. There were 16 lines of spur marks. The location of each spur mark line is represented by a thick line, labeled from A1 to H1, in this figure. Spur mark lines were not continuous, and this distinctness was related to the total area coverage of the document. Spur marks were not observed in the low-coverage areas, such as image highlight or margins without half-tone dots.

Table 5 shows the numerical comparison of pitch between the corresponding spur marks of the reference spur gears and those

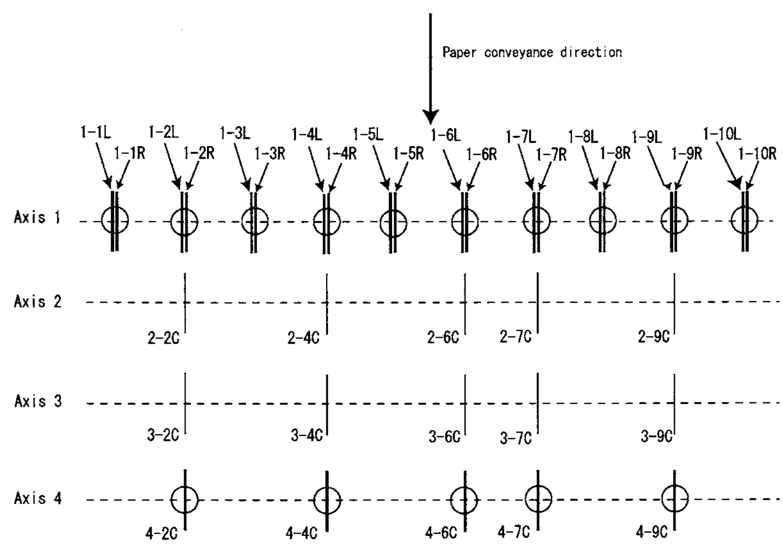

FIG. 14—*Location of spur gears and mechanical parts in the paper conveyance system of the Canon BJF800.*

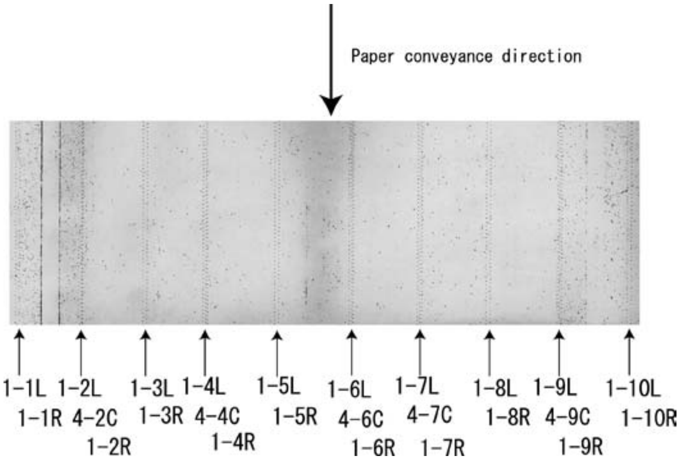

FIG. 15—*Spur marks of the Canon BJF800 printer sampled on a pressure measurement sheet.*

FIG. 16—*Graphical comparison between the spur marks on a printout (upper) and on a pressure measurement sheet (lower) for the Canon BJF800 printer.*

on the printout. By graphical comparison, nine spur mark lines corresponding to the reference spur mark lines 1-1L, 1-1R, 4-2C, 1-2R, 1-8R, 4-9C, 1-9R, 1-10L and 1-10R were not observed. The pitch showed a perfect match except for spur mark line A1 that had a deviation of only 0.01 mm.

Table 6 shows the result of mutual distance. The mutual distance within double spur gears matched perfectly. For mutual distance between different sets of spur gears, three out of six cases matched

TABLE 5—*Comparison of pitch between the spur marks on the printout and on pressure measurement sheet for the Canon BJF800 printer. The notation <0.01 indicates differences of less than 0.01 mm.*

Printer (Reference Spur Marks)		Printout		
Spur Gear	Pitch (mm)	Spur Mark	Pitch (mm)	Difference (mm)
1–1L	1.29	(Not detected)		
1–1R	1.29	(Not detected)		
1–2L	1.29	A1	1.28	0.01
4–2C	1.29	(Not detected)		
1–2R	1.29	(Not detected)		
1–3L	1.29	B1	1.29	<0.01
1–3R	1.29	B2	1.29	<0.01
1–4L	1.29	C1	1.29	<0.01
4–4C	1.29	C2	1.29	<0.01
1–4R	1.29	C3	1.29	<0.01
1–5L	1.29	D1	1.29	<0.01
1–5R	1.29	D2	1.29	<0.01
1–6L	1.29	E1	1.29	<0.01
4–6C	1.29	E2	1.29	<0.01
1–6R	1.29	E3	1.29	<0.01
1–7L	1.29	F1	1.29	<0.01
4–7C	1.29	F2	1.29	<0.01
1–7R	1.29	F3	1.29	<0.01
1–8L	1.29	G1	1.29	<0.01
1–8R	1.29	(Not detected)		
1–9L	1.29	H1	1.29	<0.01
4–9C	1.29	(Not detected)		
1–9R	1.29	(Not detected)		
1–10L	1.29	(Not detected)		
1–10R	1.29	(Not detected)		

TABLE 6—*Comparison of mutual distance between the spur marks on the printout and on a pressure measurement sheet for the Canon BJF800 printer. The notations <0.1 and <0.5 indicate differences of less than 0.1 mm and 0.5 mm, respectively.*

Printer (Reference Spur Marks)		Printout		
Section	Mutual Distance (mm)	Section	Mutual Distance (mm)	Difference (mm)
1–1L–1–1R	1.2	(Not detected)		
1–1L–1–2L	23.5	(Not detected)		
1–2L–4–2C	0.6	(Not detected)		
1–2L–1–2R	1.2	(Not detected)		
1–2L–1–3L	23.5	A1–B1	23.5	<0.5
1–3L–1–3R	1.2	B1–B2	1.2	<0.1
1–3L–1–4L	22.5	B1–C1	23.0	0.5
1–4L–4–4C	0.7	C1–C2	0.6	0.1
1–4L–1–4R	1.2	C1–C3	1.2	<0.1
1–4L–1–5L	24.5	C1–D1	24.0	0.5
1–5L–1–5R	1.2	D1–D2	1.2	<0.1
1–5L–1–6L	23.5	D1–E1	23.5	<0.5
1–6L–4–6C	0.5	E1–E2	0.6	0.1
1–6L–1–6R	1.2	E1–E3	1.2	<0.1
1–6L–1–7L	22.5	E1–F1	22.5	<0.5
1–7L–4–7C	0.6	F1–F2	0.7	0.1
1–7L–1–7R	1.2	F1–F3	1.2	<0.1
1–7L–1–8L	23.5	F1–G1	24.0	0.5
1–8L–1–8R	1.2	(Not detected)		
1–8L–1–9L	23.5	G1–H1	23.0	0.5
1–9L–4–9C	0.6	(Not detected)		
1–9L–1–9R	1.2	(Not detected)		
1–9L–1–10L	23.5	(Not detected)		
1–10L–1–10R	1.2	(Not detected)		

perfectly. The remaining three cases had deviations of 0.5 mm. However, this is only approximately 2% of the measured value and is the minimum unit of measurement.

The spur marks on the documents of inkjet printers matched with the reference spur marks sampled from the printer, within deviations of 2% of the measured values. For Printer B, the deviations were large in sections C1-C2, E1-E2 and F1-F2, compared with the measured distances. The primary reason for this is considered to be the meandering of the print media during the paper conveyance process. As show in Fig. 14, spur mark lines C1, E1 and F1 were impressed by the spur gears on Axis 1. However C2, E2 and F2 were impressed by those on Axis 4. If the paper moved 0.1 mm laterally in the paper conveyance process between Axis 1 and Axis 4, the mutual distance deviated by 0.1 mm. The lateral movement of 0.1 mm is not so extraordinary since the fact that the distance between Axis 1 and Axis 4 is several centimeters. As shown by this example, it is important to judge the deviation of mutual distance while considering the mechanical structures of the paper conveyance system.

Conclusion

In this paper, the authors proposed an examination of spur marks found on inkjet-printed documents using the Spur mark Comparison Method (SCM). The relationship between a printout and printer was examined by comparing spur marks that are physically impressed on a document. Characteristics of spur marks, pitch and mutual distance were used to extract the geometrical features of spur marks. These characteristics provided information on the mechanical structures of the paper conveyance system. Spur marks on documents produced by two different inkjet printers have matched with reference spur marks from two suspect printers. There was only a 3% deviation in the measured values. Deviations in mutual distances were interpreted as having originated due to paper conveyance meander.

The SCM are considered to be an effective examination method for inkjet printer evidence since spur gears are present in most printers. In future studies, class identification of inkjet printers will be achieved by constructing a database of spur gears. By corroborating chemical and other physical evidence, forensic scientists may be able to isolate families or groups of suspect printers.

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