Miniaturization of Dot Pattern by Metal Forming for Direct Marking of 2D Barcode Symbols

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Abstract

To create information delivering ability on metal surfaces by microforming, a direct marking system of 2D bar code symbols (Data Matrix) on a metal plate as surface microcavities using a dot impact forming machine is developed via symbol images. Miniaturization of dot pattern was further enabled by introducing an x-y microstage to reduce the pitch of dots from 119μm to 30 μm, resulting in 2D symbols at 840 DPI with successful rapid decoding by a PC-based optical system compatible with direct marking.

1. Introduction

Micro-metalforming has been developed during the last ten to fifteen years intensively to find its superiority on other processing mainly for efficiency in mass-production [1]-[3]. However, intelligent and less speedy way of application can be another acceptable direction of development. One of those applications can be found among abilities of surface microgeometry formed on metal surfaces. It is expected that such properly defined arrays of surface asperities can deliver information inherent to the parts on which the surface asperities are formed. This enables metallic parts to play the role of durable, high temperature resistant, chemically stable media for information transmission. This idea can be realized through direct marking of two dimensional bar codes, among which Data Matrix [4] and QR Code [5] are popular. Specifically their symbol patterns are composed of orthogonal arrays of white and black square cells, which can be replaced by circular dots if appropriate decoding software is used. This feature is suitable for direct marking of 2D bar codes on metal surfaces. Data Matrix is used in the present study, however, similar availability is confirmed for QR Code as well [6].
Currently available methods of direct marking include micro-drilling, dot impacting (=micro-metalforming) and laser marking. Micro-drilling and dot impacting are usually used in a semi-micro range (order of 0.X mm)[7]. Though laser marking is microscopic (order of 10 μm), the apparatus is expensive and the geometry of the marking has some problems. The methods of information acquisition, common among those marking are acquiring grey scale images of dotted patterns using appropriate lighting, a macro-lens and an image sensor, and then these images are processed and decoded into text.
The author studied forming of surface micro-geometry by coining [8] [9] and special rolling [10] and confirmed that microcavities with diameter of some tens of micron can be formed without serious problems because of secure contact between tool and workpiece during indentation. In the present paper microforming ability of metal sheets are fully utilized by sequential micro-dot impacting and the ability of information delivery of the formed surface cavities.
In the previous paper [6], the author constructed a laboratory system of encoding arbitrary text into 2D barcode symbols of Data Matrix and QR Code, marking of 2D barcodes by a dot impact pin in terms of progressive micro-metalforming and successful and speedy image acquisition and decoding by a CCD sensor with PC-based direct marking decoding software. In the previous experiments dotting was made in both x and y directions at a fixed pitch of 119 μm (210 DPI) because of the performance of the dotting machine. In the present paper, for realizing higher density marking and decoding system, a computer controlled micro x-y stage is introduced. Finally direct marking of 16 times higher density at a pitch of 30 μm, that is 840 DPI marking, was achieved and successfully decoded by the current system. The limitation of further miniaturization is discussed.

2. Basic experimental method [6]

2.1 Microforming process and equipment

The experimental procedure is shown in Fig. 1. Information expressed by characters or numerals are encoded to Data Matrix by a commercial software to obtain symbol images in a BMP file format. The images are imported to a so-called "metal printer" (Metaza MPX60) in a manner that one dot corresponds to one cell of the 2D barcode image. The metal printer makes arrays of dots at a pitch of 119 μm at an average speed of 65 cell/s including black cells (no dots) and feeding time. The tested specimen material is an austenitic stainless steel SUS304 of 1.47 mm thickness (MVH: 217.1) and the surface is mirror-finished to have a clear image of symbols. The head of dot impact pin made from tungsten carbide has a cone shape with a cone angle of 90 degrees and a rounded head of about 10 μm diameter. The impact force is adjustable to obtain cavity diameter of 29 to 65 μm for the current tested specimen.

2.2 Measurement and decoding

Fig. 2 shows a measuring system of direct marked 2D bar code. The image of the dotted pattern is acquired by a CCD camera with a macro-zoom lens and close-up lenses. This system totally zooms up actual 1mm to 16.7 to 96.6 pixels in the VGA monitor at a working distance of 138mm. Lighting direction is slanted by 50 degrees from sample plane normal. Under this lighting, as schematically shown in the expanded figure of Fig. 2, the original plane surface looks dark and the surface cavities formed by a dot impact pin look bright, because of optical geometry to cause normal reflection at the rounded bottom. However, of course, a reverse image is also obtainable in terms of image processing software.
The speed of shutter was fixed at 1/60 s. The samples were placed normally to the optical axis. Image acquisition and decoding was repeated automatically as soon as one cycle is completed to check the repeatability and average time of decoding.

3. Experimental results

3.1 Simple example

Fig. 3 shows a barcode symbol of "International Conference on Precision Engineering" in Data Matrix (ECC200) (a) and the corresponding dot pattern image (b) obtained from a dotted stainless steel sample by the optical system shown in Fig. 2. It has 28x28 cells including quiet zone of 1 cell width around its square. A Data Matrix symbol has a characteristic L shape at the left and bottom sides and altenating black and white cells on the top and right sides to detect the size, location and rotation of the symbol.

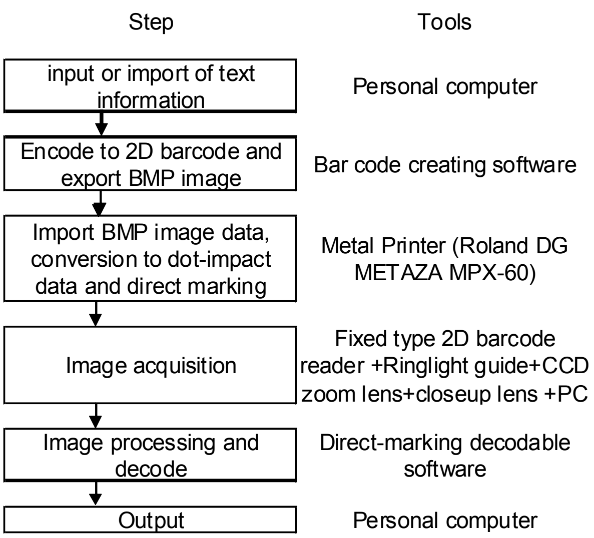


Fig. 1. Experimental procedure and the related tools [6].

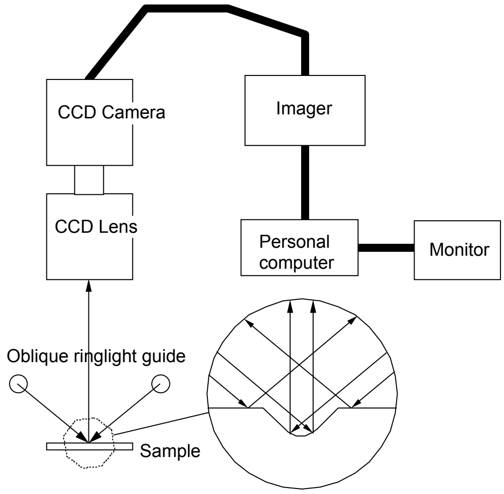
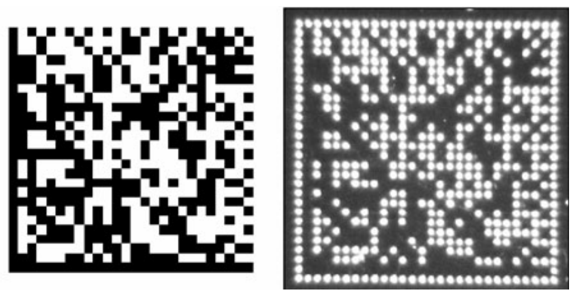


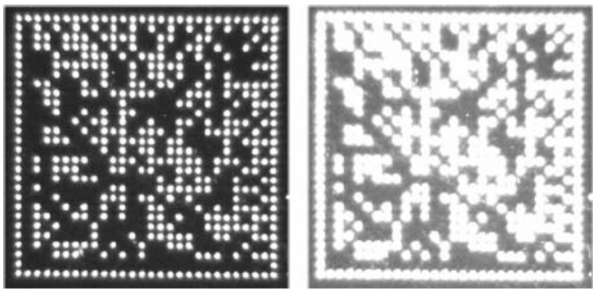
Fig. 2. System of measuring direct marked 2D bar-code symbols [6].



(a) (b)

Fig. 3. Data Matrix Symbol of "International Conference on Precision Engineering" (a) and the corresponding decodable dot pattern image (b) obtained by the optical system shown in Fig. 2. Dot pitch: 119μm. 28x28 cells including quiet zone. Global size: 3.30 mm. Marking time: 24s.

The image Fig. 3 (b) varies with variation of diameter of the dotted cavities and/or illumination. An increase in diameter of the dotted cavities results in a slight increase in the enlarged white marks in the acquired image. However, an increase in illumination overrides the effect of cavity diameter. Fig. 3(b) is the darkest limit of the image that can be decoded with 100% success. **Fig. 4(a)** shows an even darker example that can not be decoded at all and Fig. 4 (b) shows bright limit that can be decoded with 100% success. Figs. 3 and 4 show that the decodable range of illumination is wide.
Apart from the optical system shown in Fig.2, for laboratory purposes, one can decode Data Matrix ECC200 symbols in the following manner: acquire an original image (for example as in **Fig. 5(a)**) using a normal flat-bed scanner with high resolution of 3200 DPI or higher and then apply "dilate" filter a few times by an image processing software to transform the image into Fig. 5 (b). Finally, the image Fig. 5 (b) can be decoded by a conventional (=direct-marking incompatible) decoding software. However, in this method decoding is sensitive to the degree of dilation of the images.



(a) (b)

Fig. 4. Variation of the images by illumination. (a) An undecodable dark image. (b) Bright limit image decodable with 100% success. Dot pitch: 119μm. Size: 3.30 mm.

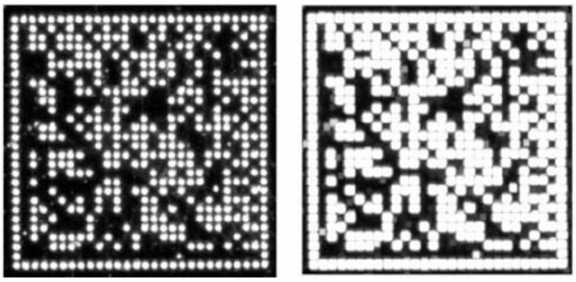


Fig. 5. An image taken by a flat-bed scanner (a) and the dilated image (b) that is decodable by normal software. The same marking as in Figs. 3 and 4.

3.2 Further miniaturization - 4 times high density dots

The used machine produces dots at a fixed pitch of 119μm presumably for simplicity of the machine mechanism and for the high rate of marking. To realize further miniaturization, a computer-controlled x-y stage was introduced. For example, to produce dots at a pitch of 60 μm, the original orthogonal dots are decomposed into 4 overlapping groups of dots as shown in **Fig. 6** as 11, 12, 21 and 22. Each group is marked at a normal pitch of 119μm but with or without a shift of the sample at 60 μm in x-y axes made by the motion of the x-y stage among the groups. The final overlapping pattern of dots is shown at the bottom figure as “composite”, where the distance of the neighbouring dots is 60 μm.

Fig. 7 shows an example of dots at a 60 μm pitch that is of 4 times-high density compared to Fig. 3(b).

3.3 Extreme miniaturization - 16 times high density dots

The above technique is naturally extended to 16 times high density dots, where the pitch of dots is 30 μm and the dotting pattern is decomposed into 16 partial patterns. **Fig. 8** shows an example of 16 times high-density dots that were decodable by the current measuring system.

The 16 times high density dots is useful if the text capacity is large. **Fig. 9 (a)** shows such an example of Data Matrix Symbol of 436 characters including spaces taken from the topics of the 11th ICPE as follows: “Topics of the conference include, but are not limited to, the following:

Advanced Manufacturing Systems
Ultra-Precision Machining and Micro Machining
Nanotechnology for Fabrication and Measurement
Rapid Prototyping and Production Technology
New Materials and Advanced Processes
Computer Aided Production Engineering
Manufacturing Process Control
Planning and Scheduling for Production
CAD/CAE/CAM”. The cell size is 76x76 including quiet zone of 2 cell width. Fig. 9(b) shows the corresponding decodable dots of the 16 times high-density. The global size of the dots is 2.28 mm while the size of original dots at a pitch of 119 μm is 9.04 mm. The marking was achieved in 94 s for the original dots and the decoding of this pattern takes for 0.30 to 0.35 s irrespective of marking density.

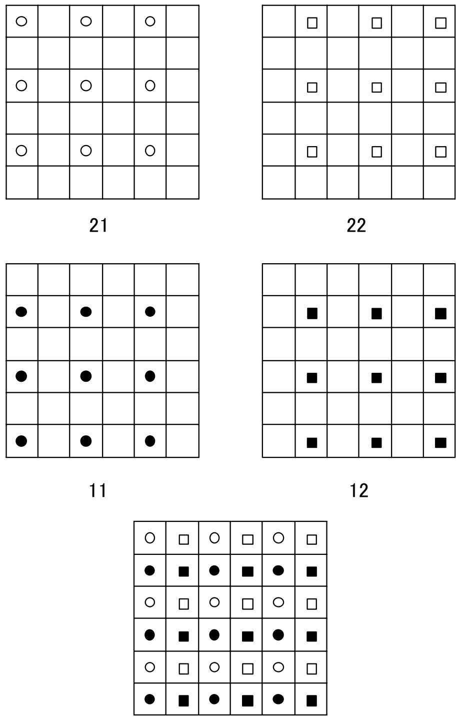
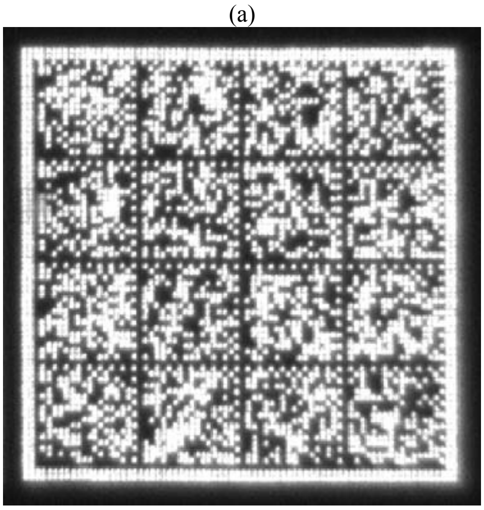


Fig. 6. Method of decomposition of orthogonal symbols into 4 groups and integration of the dots.

Fig. 7. Dots of 4 times high density compared with Fig.3 (b). Dot pitch: 60 μm. Size: 1.66 mm.

Fig. 8. Dots of 16 times high density compared with Fig.3 (b). Dot pitch: 30 μm. Size: 0.83 mm.

(a)



(b)

Fig. 9. An example of large symbol. (a) Data Matrix symbol of 436 characters taken from Topics of the 11th ICPE. 72 x72 cells. (b) Dots of 16 times high-density compared with Fig. 3 (b). Dot pitch: 30 μm. Size: 2.28 mm.

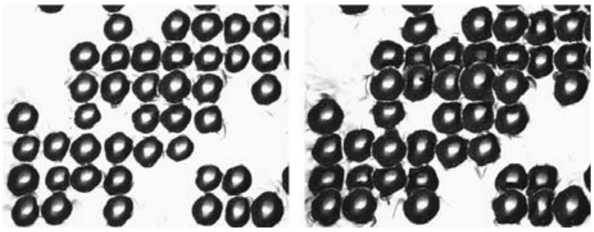
4. Discussion

4.1 Optical requirements to decode symbols

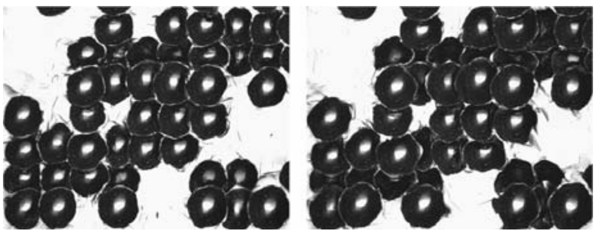
As the dot pitch decreases, requirements to the optical system become severe. Under the current optical system, where both the height of ring light and the intensity of the light are adjustable, the limiting optical condition seems to be magnification of the total optical system. For example, with 16times high-density dots at a pitch of 30 μm, magnification of 71.2 pixel/mm or higher was required. This corresponds to 2.14 pixel/cell. At this limiting condition, the alignment of CCD camera, illumination, and so on were severe and at 96.6 pixel/mm (=2.9 pixel/cell) they became moderate.

4.2 Dot size requirements

If the dot pitch is fixed, for example, at 30 μm, an important limiting condition of dot size (=diameter) is imposed. In the present system, dot size can be fairly small comparing with the cell size: dot size of 28.5 μm at a dot pitch of 119 μm, *i.e.*, 24% in diameter and 4.5% in area, was quite decodable if the illumination is slightly increased. However, in the case of small cell size, dot size must be smaller than a certain value. Fig. 10 shows scanning laser micrograph of decodable dots (a), (b) and undecodable dots (c), (d). Dotted cavities are rather independent and undeformed in Fig. 10 (a) and (b), while dots are severely interfered by the neighbouring dots in Fig. 10 (c) and (d). The limiting condition of decoding depends whether the central bright area of each dot (rounded bottom) is maintained or destroyed by the neighbouring (subsequent) dots. For example, in Figs. 10 (a) to (d), the second row from the top is formed at the initial stage of marking and is the most vulnerable to the subsequent dots (upper and lower). So in Fig. 10 (c) and (d) central bright area of the second row vanished. Judging from Fig. 10, the decodable limiting size of free dots is about 36 μm when the dot pitch (=cell size) is 30μm. It means that the dot diameter slightly larger than the dot pitch is allowed. With the impact force lower than that in Fig. 10 (a), the dots diameter get unstable presumably because of reduced normal stress and of a scatter in deforming resistance of crystallographic grains based on preferred orientation. In order to decrease the diameter of dots further, the rounded bottom should be reduced in size though it is fixed at about ten μm in the current machine.



(a) d=29.9 μm. (b) d=36.0 μm.



(c) d=39.7 μm. (d) d=43.1 μm.

Fig. 10. Effect of dot size on decoding. Dot pitch: 30 μm. d: average diameter of free dots. (a) and (b): decodable. (c) and (d): undecodable. Scanning Laser Micrograph.

5. Conclusion

To create information delivering ability on metal surfaces in a micro scale, patterns of 2D bar codes are micro-formed using a dot-impact metal printer, and the pattern was successfully decoded by a direct-marking compatible measuring system. Though the dot pitch is originally fixed at 119 μm depending on the machine performance, an additional x-y stage under the sample enabled to make a 16 times high-density dots at a pitch of 30 μm (840 DPI), resulting in successful decoding. The limitation of miniaturization is found with interference of dots to destroy neighbouring dots to vanish central rounded bottom. For this reason, the dot size should be below 120% of dot pitch. Optical magnification should be also as high as about 2.5 pixels / cell for stable decoding.

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