MOIRE PATTERNS IN ELECTRONIC ENGRAVING FOR GRAVURE

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Abstract: Electromechanically driven diamond stylus engraving machines have largely replaced etching methods in the imaging of gravure cylinders. As a consequence, traditional screen angling methods to minimize moire and color shifts in gravure printing cannot be utilized. The pseudo screen angling techniques currently being used on electromechanical engravers are reviewed in this paper. Finally it is shown that if the pitch of the engraving head when advanced along the cylinder axis can be controlled, the moire pattern can be made very small and undetectable.

Introduction

This paper discusses moire patterns that are generated in color page printing. The color page is printed by using four (4) screened pictures, one for each of the following colors; Cyan, Magenta, Yellow and Black. From these pictures, four offset plates or four gravure cylinders are generated. In the press the four pictures are printed one on top of the other. The result is a reproduction of the original copy.

Since the pictures are screened, slight angular errors can result in extensive patterns (moire patterns) that diminish the reproduction quality. To avoid these patterns the pictures are screened so that the screens are at large angles with each other. This creates small undetectable moire patterns.

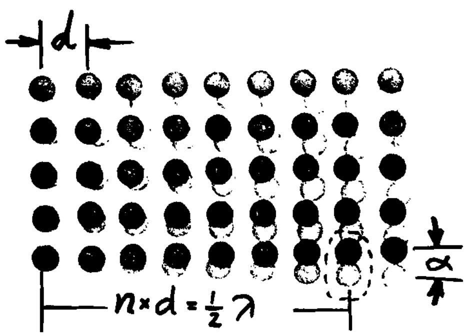

Figure 1 shows one screen and one line of a super-imposed screen at an angle

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While screen angling is readily accomplished when screened films are used with carbon tissue or other etching methods, it is not so simple when continuous tone unscreened films are scanned for the HelioKlischograph or other electronic engravers which cut dots or cells around the circumference of a gravure cylinder.

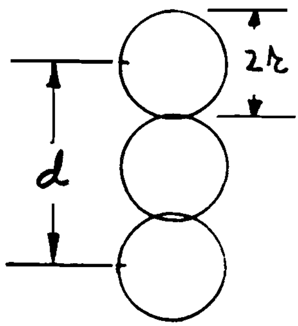


Fig. 2

Figure 2 is a magnified view of the dotted area in Figure 1.

Moire Patterns — Definitions, Parameters and Screen Ruling

For the moire patterns to be undetectable λ must be very small. Let us calculate this parameter. Looking at Figure 3, it can be seen that the pattern is composed of large squares. λ is the number of dots on one side of the square. The sides of the squares are created when the dot of the angled screen falls exactly between two dots of the basic (unangled) screen. Referring to Figure 1 we can describe this situation where the superimposed dot falls exactly between two dots of the basic screen with the following equation:

1) $$\sin \alpha = \frac{d/2}{n \times d} = \frac{1}{2n}$$

2) $$\lambda = 2n = \frac{1}{\sin \alpha}$$

It can be seen that for λ to be small α must be large.

In offset printing with film, $\alpha = 15°$. We can calculate

$$\lambda = \frac{1}{\sin 15°} = \frac{1}{0.259} = 3.86 \approx 4$$

This means that the pattern's squares will be 4 dots wide. This is considered an undetectable pattern.

It can be seen that the square size is determined by the number of dots, not by their size or screen ruling. This means that if we take screen

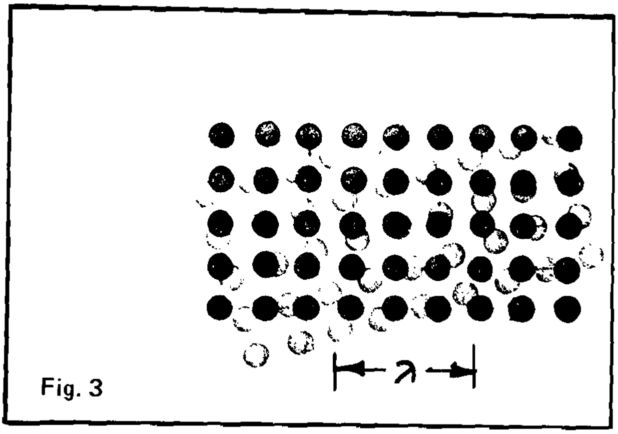


Figure 3 Moire pattern

ruling of 150 lines per inch at 15° where d is 170 μm, the square will be 4 x 170 μm by 4 x 170 μm. However, if we take a screen with 200 line per inch d is 127 μm and the square will be 4 x 127 μm by 4 x 127 μm. The second square is smaller and less detectable. If all the other parameters are unchanged the higher the screen ruling the smaller will be the moire squares. In fact, the selection of the screen ruling is mainly determined by the moire patterns. When moire patterns should be small, high screen ruling is required.

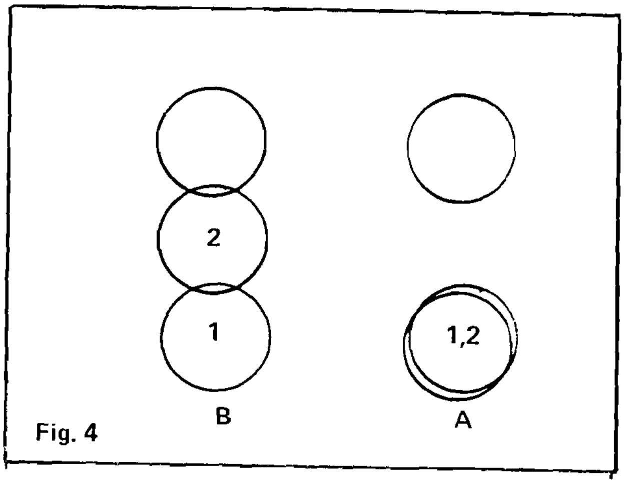


Figure 4 Dot positions

Table 1

d =	screen spacing
r =	dot radius
α =	angle between the super-imposed screens
a =	dot area = πr^2
s =	screen pixel area = d^2
Ri=	dot reflectivity (paper reflectivity = 1)
A =	Absorption = 1—R
D =	Density = —log R
λ =	moire pattern wavelength

Contrast Due to Moire Patterns

Referring to Figure 4 and Table 1 we can now define the contrast.

The reflection when the dots are super-imposed (See Figure 4A) is :

3) $R_{SI} = (S - a) \times 1 + a R_1 \times R_2$

Where R_1 and R_2 are the reflectivities of each dot respectively, R_{SI} is the total super-imposed reflectance and 1 is the reflectivity of the paper.

Figure 4B shows the other extreme or the moire pattern square side situation

4) $R_{ss} = (S - 2a) \times 1 + a R_1 + a R_2$

The contrast is one minus the ratio between these two situations

5) $$\text{Contrast} = 1 - \frac{(S - 2a) + a R_1 + a R_2}{(S - a) + a (R_1 \times R_2)}$$

If the dots are completely opaque (black dots) $R_1 = R_2 = 0$ then equation 5 turns into:

6) $$\text{Contrast} = 1 - \frac{S - 2a}{S - a}$$

The contrast will be maximum or equal to one when $S - 2a \rightarrow 0$

$S \rightarrow 2a \qquad a \approx \frac{S}{2}$

This means: $\pi r^2 = \frac{d^2}{2} \qquad r = \frac{d}{\sqrt{2\pi}} = \frac{d}{2.5}$

However, this result considers the dot to be circular only.

If 2.5 r = d, the dots will overlap and the contrast will be less than 1.

In Appendix A we calculated it to be 0.814 and indeed the highest contrast is when d = 2.5

Color Changes and Moire Patterns

When two colored screens are angled and moire patterns are generated these patterns will mainly be seen as color patterns. The combined color will not be constant. The moire patterns and color changes occur because of the same reasons that patterns are generated with two black dotted angled screens. The main difference is in the reflectance characteristics. The black dots have very low reflectance R 0. The colored dots have Vectors reflectances.

Referring to J.A.C. Yule's book (see reference) page 161, we see the following table (which was completed for this report):

	R Density	G Density	B Density	R Reflectivity	G Reflectivity	B Reflectivity
C	1.20	0.37	0.17	0.06	0.42	0.67
M	0.11	1.09	0.56	0.77	0.08	0.27
Y	0.01	0.06	0.96	0.98	0.87	0.11
CM	1.33	1.44	0.67	0.046	0.036	0.213
MY	0.11	1.22	1.61	0.77	0.060	0.024
CY	1.29	0.43	1.19	0.051	0.371	0.064
CMY	1.31	1.53	1.66	0.049	0.029	0.022

Density Reflectance

Properties of Y.C.M. Inks

From this table it is evident that each ink can be referred to as a vector with 3 elements; R, G, B either density or reflectance. When mathematical operations are performed, these inks should be treated as Vectors.

As an example, we can check the CM row. This row was measured, not calculated, but we can see that if we add the red densities of the C and the M we get the red density of the CM (adding densities is equivalent to multiplying reflectances).

Using equation (5), the contrast can be calculated, but what is more important are the values of the divider and dividend. One can see that the three elements of the ink vector are not the same when the dots are super-imposed or when they are separate. This difference is the color difference.

The exact calculations are given in Appendix B for the specific ink in the above mentioned table.

Let us calculate the contrast for ideal inks.

If Rc, Rm, Ry are the reflectance vectors and $S - 2a = 0$ we get:

$Rx = (R,G,B)$ $Rc = (0,1,1)$ $Rm = (1,0,1)$

$Ry = (1,1,0)$ $R_{paper} = (1,1,1)$

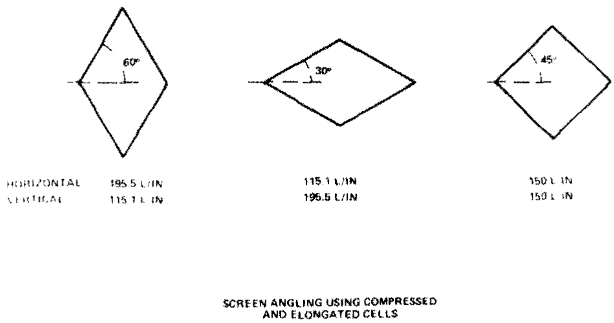
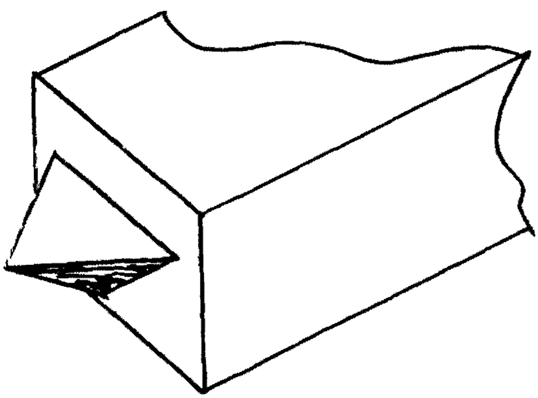


Figure 5 Compressed elongated and regular cell shapes



HELIO STYLUS SHAPE

Figure 6 Helio stylus shape

$$\text{Contrast }(M,Y) = 1 - \frac{0.5\,(R_M + R_Y)}{0.5\,R_{paper} + 0.5\,(R_M \times R_Y)} =$$

$$1 - \frac{0.5\,(1,0,1) + 0.5\,(1,1,0)}{0.5\,(1,1,1) + 0.5\,(1,0,0)}$$

$$\text{Contrast }(M,Y) = 1 - \frac{(1,0.5,0.5)}{(1,0.5,0.5)}$$

We can see that the divider and dividend are equal, meaning that there will be no color change due to the patterns and the contrast is zero. This means that there will be no pattern effect.

In Appendix B the calculations are done for practical inks and the pattern effect is significant.

Angling with Electromechanical Engravers

Currently, when using the HelioKlischograph (by Hell) or the model B600 engraver (by Ohio Electronic Engravers Inc.) the angling is done by compressing and elongating the cells on the engraver. Figure 5 demonstrates the cell shape as a result of these operations. It can be seen that the regular line of cells (45°) will be rotated 15° relative to the 30° (compressed) and the 60° (elongated) line of cells. This should be enough to eliminate the Moire patterns, or rather to diminish the patterns beyond the visible size.

Although theoretically this is a good solution the practical implementation is not so easy. Referring to Figure 5 it can be seen that the compressed cell is horizontally wider and vertically shorter. This is accomplished by slowing the rotation speed of the cylinder while maintaining the sinusoidal frequency of the sylus actuator. However to obtain the wide shape the stylus has to penetrate deeper. The shape of the stylus, Figure 6, makes it harder to accomplish this compression and some operators have relaxed the compression somewhat so that the engraving will be smooth and stylus life will be reasonable. This of course reduces the angle and increases the pattern size.

The elongated cells are easier to engrave. The cylinder speed is increased and the stylus penetration decreased. Again density consideration must assure the same cell volume. The face areas of the cells in Figure 5 are almost identical. The elongated cell, due to the decreased penetration, has smaller volume which calls for slightly higher penetration to compensate.

These three engraving patterns are used for yellow, cyan and magenta. The key is engraved in a regular pattern but at a higher screen ruling which means that the engraving time is longer.

In conclusion, although this method is theoretically correct, in practice there are problems. The engraving operators have learned to deal with most of the problems by deviating slightly from the required compression and elongation proportions. These deviations can result in a faulty cylinder, or diminished print quality. In the next section a suggestion is presented in which the engraving method does not require any compromise.

Angling with Electronic Engraving — Suggestion

For electronic engraving where the engravers are located along a line parallel to the cylinder axis, grid angles should preferably have angles as follows. The basis grid is angles at : 0^o, two grids can be angled at plus and minus α_1, where : $\alpha_1 = \arctan\frac{1}{2} = 26.56^o$ and the fourth grid will be angled at $\alpha_2 = 45^o$

According to equation 2) $\lambda = \dfrac{1}{\text{Sin}\,\alpha}$

we will get: $\lambda_1 = \dfrac{1}{\text{Sin}\alpha_1}$; $\text{Sin}\alpha_1 = 0.447$; $\lambda_1 = 2.23$

$$\lambda_2 = \frac{1}{\text{Sin}\alpha_2}; \quad \text{Sin}\alpha_2 = 0.707 \quad ; \lambda_2 = 1.414$$

It can be seen that the moire squares will be very small. In fact they will be smaller than the 15^o angled screens.

Referring to former sections of this paper it seems that if we select $\alpha = 0$ Black, $\alpha = \alpha_1$ Yellow, $\alpha = \alpha_2$ Cyan and $\alpha = -\alpha_1$ Magenta, we will get the minimum moire effects with the inks as specified. For better inks the results will be better.

The engraving heads will have to be driven differently than in the present engravers. The horizontal and vertical stepping increment will vary for the various angles.

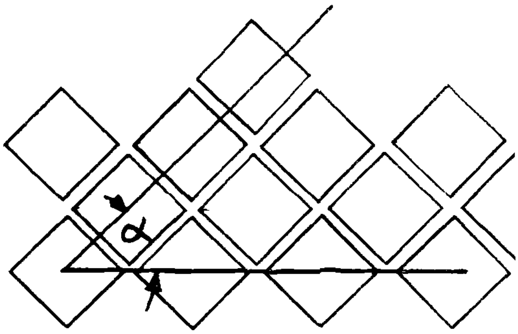


FIG. 7. α = 45°

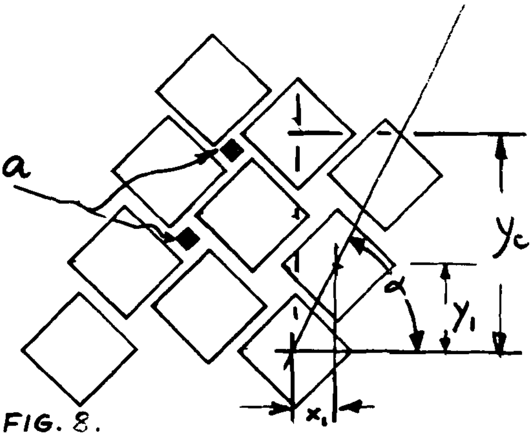
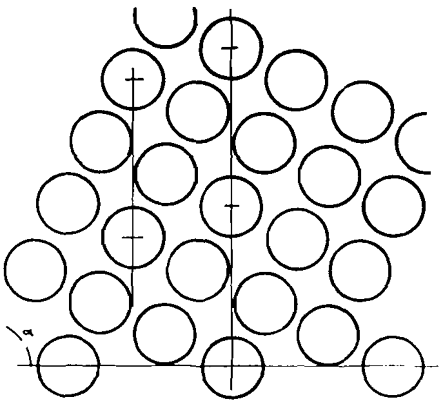


FIG. 8.

Figures 7 and 8 demonstrate the idea for the HelioKlischograph. Figure 9 demonstrates the idea for a laser engraver. Figure 7 is the regular Helio engraving. Figure 8 describes a way to generate an angle of $+\alpha$($-\alpha$ can be achieved also). The angle $(90-\alpha) = 26.5^{\circ}$ was selected at random. The distance between two consecutive cells is very large, in this case $2.5 \times y_1$. This may cause a problem when driving the diamond stylus. If the stylus has to be continuously vibrated, the vibration amplitude will have to be larger and the initial distance between the stylus and the cylinder will have to be larger.

The major disadvantage of this method is that some areas (a) cannot be reached by the engraver. In the case of 26.5° for center to center distance of 170 μm (150 lines per inch) and 25 μm post width, the unreachable area is about 12%. However, since the "unreachable" area provides a strong post the width of the post between the cells can be reduced by 4 um (to 21 μm) and the density can be maintained to within 7%.

Figure 9 shows the angling effect when a circular laser beam is used. Here cell depth can be controlled to compensate for unreachable area.



SCREEN ANGLING USING CONTROLLED HORIZONTAL PITCH AND VERTICAL SPACING

Figure 9 Screen angling using a laser engraver

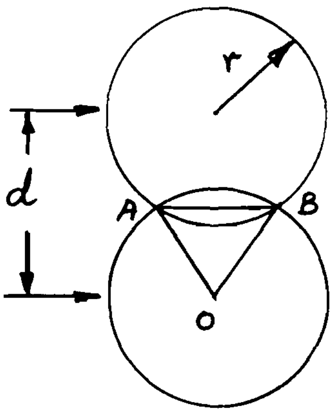


FIG. 10.

Figure 10 Overlapping Dots (See Appendix A)

Summary

This report reviews the parameters affecting moire pattern generation. A suggested solution for electronic engravers (i.e., HelioKlischograph, Ohio Electronic Engravers or other engravers driven by computers) was described. The work for this report was done as a part of the design of the GRI Laser Engraver.

Appendix A

Contrast Calculation with Circular Black Dots

Let us define the following (See Figure 10)

SEC = Section OAB area
TRI = Triangle OAB area
OVLP = overlapping area

1) $$\frac{SEC}{\pi r^2} = \frac{\alpha\,(rad)}{2\pi}$$

2) $$SEC = \frac{\alpha \pi r^2}{2\pi} = \frac{r^2}{2}\alpha\,(rad)$$

3) $$TRI = r\cos\frac{\alpha}{2} \times r\sin\frac{\alpha}{2} = \frac{r^2}{2}\sin\alpha$$

4) $$OVLP = (SEC - TRI) \times 2 = r^2(\alpha(rad) - \sin\alpha)$$

5) $$d = 4r \times \cos\alpha/2$$

6) $$Contrast = 1 - \frac{(S - 2a)}{(s - a)} =$$

$$1 - \frac{2rd - 2(\pi r^2 - OVLP)}{2rd - \pi r^2}$$

7) $$Contrast = 1 - \frac{2rd - 2r^2(\pi - \alpha rad + \sin\alpha)}{2rd - 2\frac{\pi}{2}r^2}$$

8) $$Contrast = 1 - \frac{d - r(\pi - \alpha rad + \sin\alpha)}{d - \frac{\pi}{2}r}$$

If we substitute 2.5 r = d into the equations we get:

9) $\cos \alpha/2 = \frac{2.5}{4}$ (see 5) above) $\frac{1}{2}\alpha = 51.31^{\circ}$

$\alpha = 102.63^{\circ}$ α rad = 1.79

10) $OVLP = r^2 (1.79 - 0.975) = 0.815 \times r^2$

$\underline{S - 2a} = 2\,rd - 2\,r^2 (\pi - 0.815) =$

$2\,r^2 (2.5 - \pi + 0.815) = \underline{0.173 \times 2\,r^2}$

$\underline{S - a} = 2\,rd - \pi r^2 = 2\,r^2 (2.5 - \frac{\pi}{2}) = \underline{2\,r^2 \times 0.93}$

11) $\text{Contrast} = 1 - \frac{S - 2a}{S - a} = 1 - \frac{0.173}{0.93} =$

$1 - 0.186 = \underline{\underline{0.814}}$

—and from other calculations this was found to be the largest contrast although it is less than 1.

Appendix B

Color Changes Due to Moire Patterns

Referring to equation 5)

$$\text{Contrast} = 1 - \frac{(S - 2a) + a\,R_1 + a\,R_2}{(S - a) + a\,R_1\,R_2}$$

If S = 2 a a/S = 0.5 we get:

1) $$\text{Contrast} = 1 - \frac{0.5\,(R_1 + R_2)}{0.5\,R_{paper} + 0.5\,R_1 \times R_2} =$$

$$1 - \frac{0.5\,(R_1 + R_2)}{0.5\,(R_{paper} + R_1 \times R_2)}$$

R_{paper} was introduced here as a vector with good reflectance in the Red, Green and Blue (R,G,B). In former calculations we had $R_{paper} = 1$, now, when color is involved R_{paper} becomes (1,1,1).

To calculate the contrast of the various color combinations, let us use equation 1) above and the vector elements from the ink table.

$$\text{Contrast}_{CM} = 1 - \frac{\overset{C+M}{0.5\,[\,(0.06,0.42,0.67)+(0.77,0.08,0.270)\,]}}{0.5[(\,1,1,1)+(0.046,0.036,0.213)]} =$$

$$= 1 - \frac{0.5(0.83,0.050,0.94)}{0.5(1.046,1.036,1.213)} = 1 - \frac{(0.415,0.25,0.47)}{(0.523,0.518,0.665)}$$

Converting the Reflectances to Densities the Density Contrast D Con will be:

$$\text{D Con}_{CM} = \left(1 - \frac{0.38,0.6,0.32}{0.28,0.28,0.17}\right)$$

It can be seen that the R, G, B density components for the separate dots are: 0.38, 0.60, 0.32 whereas those of the super-imposed dots; 0.28, 0.28, 0.17

This means that there will be a color change in the pattern.

The three color contrasts can be calculated:

$$\text{Red Contrast} = 1 - \frac{0.415}{0.523}$$

$$\text{Green Contrast} = 1 - \frac{0.25}{0.518}$$

$$\text{Blue Contrast} = 1 - \frac{0.47}{0.665}$$

The results for the other combinations are given below:

$$\text{C + Y Contrast} = 1 - \frac{0.52,\ 0.65,\ 0.39}{0.525,\ 0.685,\ 0.532}$$

$$\text{D Con} = 1 - \frac{0.28,\ 0.18,\ 0.4}{0.28,\ 0.16,\ 0.27}$$

$$\text{M + Y Contrast} = 1 - \frac{0.875,\ 0.475,\ 0.19}{0.885,\ 0.53,\ 0.512}$$

$$\text{D Con} = 1 - \frac{0.057,\ 0.32,\ 0.72}{0.05,\ 0.27,\ 0.29}$$

If we define a black color B by: R_B = (0.02, 0.02, 0.02)

very low reflectance we get:

$$\text{B + C Contrast} = 1 - \frac{0.04, 0.22, 0.345}{(0.5, 0.5, 0.5)}$$

$$\text{D Con} = 1 - \frac{1.39, 0.65, 0.46}{0.3, 0.3, 0.3}$$

It can be seen here that the color change will be very significant and so will be the moire pattern .

Reference: Principles of Color Reproduction
By J.A.C. Yule