The Straight-line Engraving Machine

G. Phil Poirier
Bonny Doon Engineering
Taos, New Mexico, USA

Introduction

The straight-line engraving machine has a long and rich history in the jewelry manufacturing industry. Its capabilities were exploited by many of the great companies including Fabergé and Cartier (Figure 1). Today it is being used by only a handful of jewelers, partly due to the machine's rarity but also because the machines and their processes are largely unknown to most jewelers. This paper will briefly cover its history followed by greater detail of how it works. We will also look at methods of setting up the machine for various tasks, along with a sampling of the many patterns it can engrave and how modern artists are utilizing this machine and technique today.

Figure 1 *Straight-line guilloché-engraved cigarette case with drape pattern, 1899-1908, Fabergé workmaster Henrik Emanuel Wigstrom, Metropolitan Museum of Art, Matilda Gray Foundation (L.2011.66.22)*

Brief History

The earliest published example of straight-line engraving machines is exhibited in Bergeron's *The Turner's Manual*, 1816.[1] It is described as being a "lathe, specially designed for square turning." Essentially, it was a lathe with an added linear motion chuck designed to change the rotary motion into linear motion (Figure 2, letter a). The pattern that would be engraved was created by either using rosettes as in a rose engine lathe, or by using a linear "pattern bar." The example in Figure 2 shows a pattern bar to the right of the straight-line attachment (letter b).

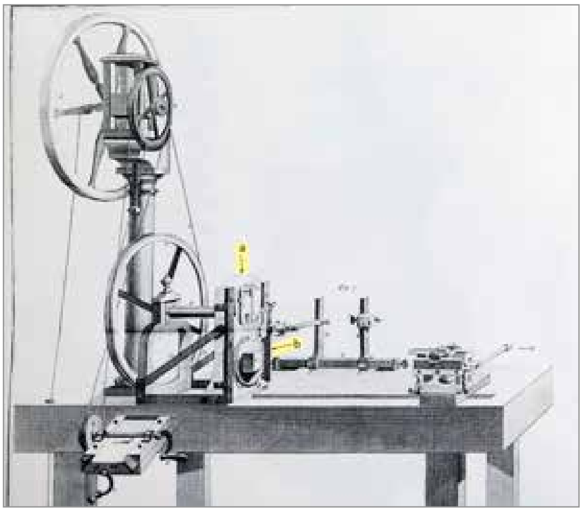

Figure 2 *Early example of a "square cutting lathe," Bergeron, 1816*[1]

Shown in Figure 3 is a Swiss rose engine built in 1913 with an attached linear motion chuck. The patterns in this machine are derived from the rosettes. The motion in this setup is derived from the rotation of the main spindle being converted into a linear up-and-down motion by way of the linear motion chuck. The linear motion chuck is commonly call a straight-line chuck, although it is also known as a rectilinear chuck.[2]

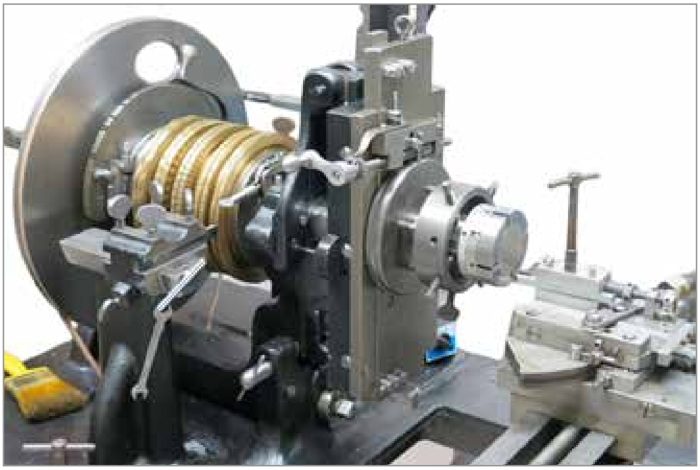

Figure 3 *Straight-line chuck on a rose engine*

Soon to follow the linear motion chuck came the square machine, sometimes referred to as an independent machine due to the fact that it is no longer a lathe with added straight-line chuck but is now a dedicated and independent linear motion machine for straight-line engraving (Figure 4). Bergeron states that the name "square machine" has different possible origins, one being that it was named after Louis Carré, a French mathematician who specialized in oscillations. Another possible origin is simply from the French "machine carrée," which translates to "square machine."[3]

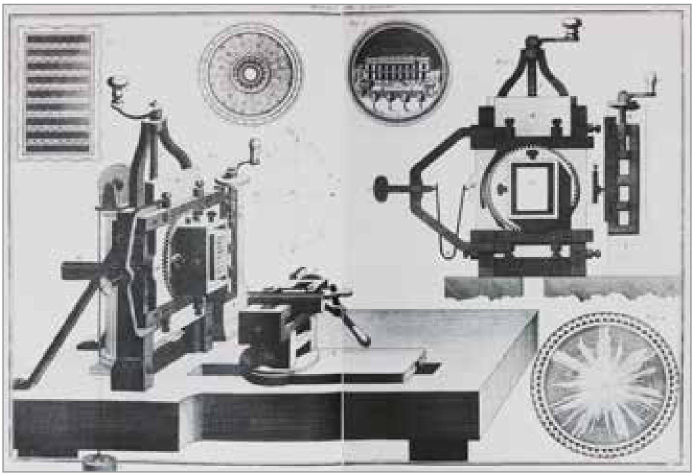

Figure 4 *"Square machine" or independent machine, Bergeron, 1816*

The square machine shown in Figure 4 was not built upon a lathe as was the earlier version shown in Figure 2. Instead, it was a dedicated linear-motion machine that used pattern bars to develop its patterned engraving lines. There were many hybrid designs, which included a variety of engineering ideas, but the design that lasted until recently is what we now call the straight-line machine and is the principal design used today in most shops.

Shown in Figure 5 is a modern-era British machine, circa 1950, by G. Plant and Son, Birmingham, U.K. Unfortunately, none of the original makers of independent straight-line machines are in business today. One must look for used machines or consider building your own. Many well-known watch manufacturers have both collected old machines and built their own new machines. The only present-day maker of straight-line machines is Lindow Machines of Pennsylvania, USA. These machines are rose engines with straight-line chucks. Some of the finest historic examples of straight-line work can be found in the book *The Fabergé Case* by John Traina.[4]

Figure 5 *Modern independent straight-line machine*

Description of the Straight-Line (SL) machine

The design and engineering of the modern straight-line machine requires two moving slides, along with a cutting tool and its support mechanism. These two slides must be perpendicular to each other and set in motion. The slides are typically built upon a bed of iron required for the rigidity necessary to create a clean and brightly-engraved cut in the workpiece. Details regarding the cutter and its support mechanism are covered extensively in the 2016 Santa Fe Symposium® paper titled "The Parts and Processes of a Rose Engine in the Modern Shop."[5]

Drive Description

There are many different techniques used to move the main slide on straight-line machines. One common method is to use a drive screw, as seen in Figure 6. Another method is to use a rack and pinion drive. Chain drives were used, and still another method is by way of a crank arm assembly. In this example we'll look at the mechanics of a G. Plant and Son machine made in Birmingham, UK, around 1950, as seen in the graphic in Figure 6 and in the photograph in Figure 5.

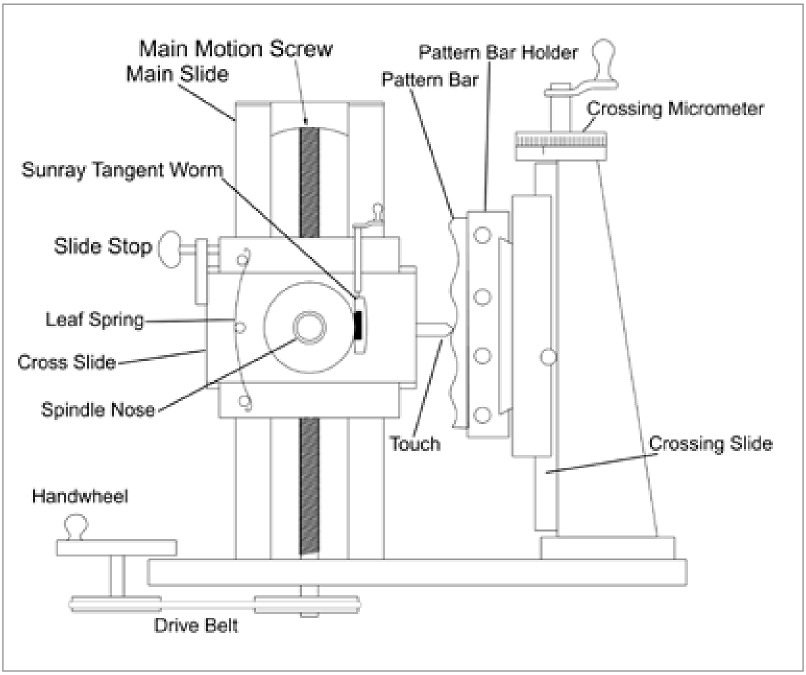

Figure 6 *Diagram of a straight-line machine, front view*

When the *handwheel* is turned the *main motion screw* rotates, which drives the *cross slide* up and down upon the *main slide*. A leaf or coil spring applies force on the *cross slide*, pushing it to the right, which thereby transfers force to the attached *touch*, which in turn keeps the *cross slide* held firmly against the *pattern bar*.

So the effect is thus: As the *main slide* moves up and down, the *cross slide* moves left and right, following a shape specified by the *pattern bar*. This action creates an oscillation to the *cross slide*. The workpiece is secured to the cross slide via the *spindle nose*, and as the cutter is engaged, the oscillation is engraved into the workpiece.

The pattern bar can be shifted up or down relative to the workpiece. This is done by turning the *crossing micrometer* (Figure 6) a given amount, which will raise or lower the *crossing slide*. The crossing slide holds the pattern bars. When raised or lowered, the relative location of the pattern on the workpiece is changed or shifted up or down. This process is known as "phasing." More details of phasing will follow in the pattern creation part of this paper.

The methods of attaching the workpiece to the spindle nose vary by the type of work being mounted and by the design of the machine. Some machines utilize a threaded spindle nose, which allows for a quick change of the chuck (Figure 5). Others use a cup-like device with four axial and four radial adjustment screws which act as a centering and leveling chuck (Figure 7).

Figure 7 *Spindle leveling fixture seen on some SL machines*

Axes of Cut

There are three fundamental axes which can be cut on a straight-line machine: Surface Parallel (Figure 8), Surface Radial (Figure 9), and Circumaxial (Figure 10).

Surface Parallel

Surface parallel is most commonly used on flat workpieces, which may be shaped into three-dimensional forms after the engraving is finished. Figure 8 shows a planar surface being engraved which, when finished, will be shaped into an anticlastic bracelet. See Figures 52 and 53 for the finished pieces. Surface parallel workpieces are held in the machine by several different methods. Workpieces that are thin and lack rigidity can be mounted to a glue chuck with shellac or, in common use today, cyanoacrylate (Super Glue). A glue chuck is nothing more than a block of material with sufficient rigidity that is mounted to the spindle nose either directly or in the jaws of a two-jaw independent chuck (Figure 9). If the workpiece has enough rigidity, then it can be held directly in a two-jaw chuck. Round workpieces can be held in multi-jaw scrolling chucks.

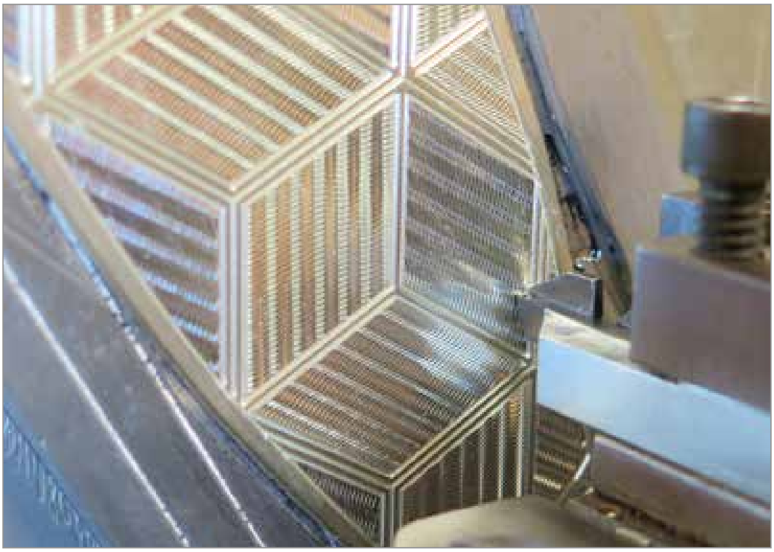

Figure 8 *Surface parallel*

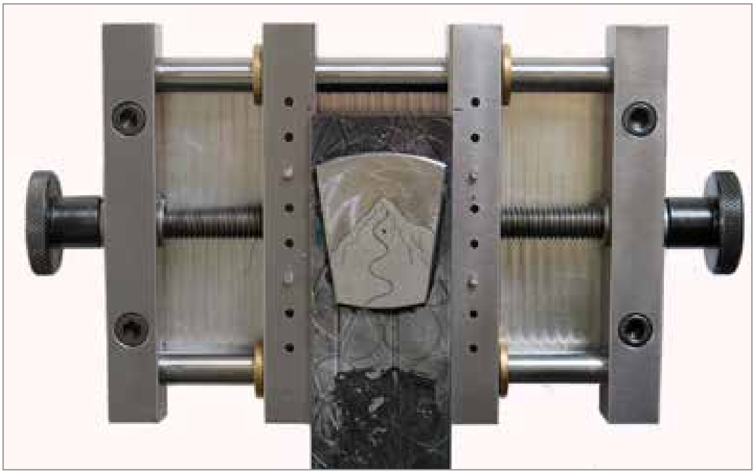

Figure 9 *Two-jaw independent chuck built by Peter Gilroy*

Surface Radial

Surface radial is seen in Figure 10, which shows the effect of indexing the workpiece in a radial manner after each engraved cut. Radial cutting creates a sunburst-type pattern. It is usually cut into planar surfaces which can then be formed into items with more dimension. Workpieces cut with radial methods are typically held in two-jaw chucks or similar. The radial motion comes from the turning of the *tangent worm* (Figure 6), which turns the spindle nose. The tangent worm allows for consistent, precision incremental radial movement.

Figure 10 *Surface radial*

Radial Setup: The setup when engraving radial patterns is as follows. A mark is made on the workpiece locating the desired center of radial motion, in other words, the center of where all the cuts will radiate from, or radiant. A workpiece can have multiple radiants. Shown in Figure 11 is a workpiece with layout dye and a mark at the desired center of radial motion.

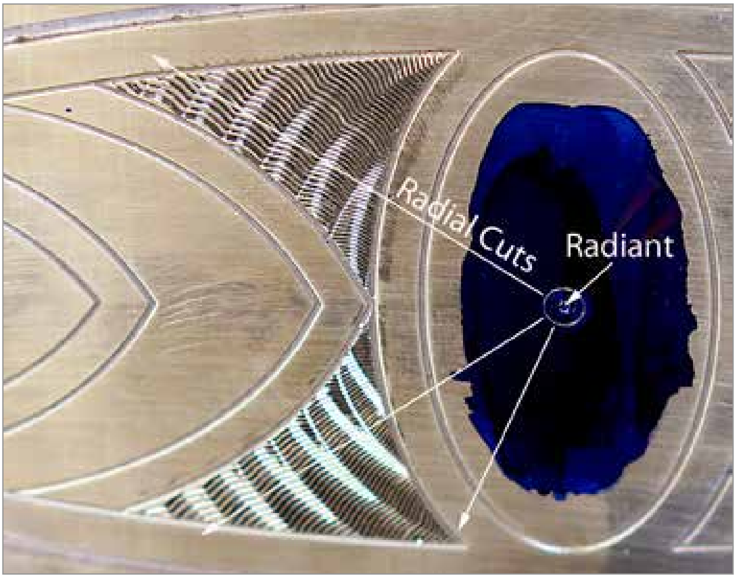

Figure 11 *Aligning the workpiece to the center of radial motion. The circles circumscribe the center of radial motion.*

Next, the workpiece is placed in a chuck and adjusted to align the center of rotation with the mark made on the workpiece. When properly adjusted, the cutter can then be lightly touched to the workpiece as the workpiece is rotated. If the workpiece is accurately centered on the radial axis, then a small dot will be made by the cutter. If, instead, a circle is made by the cutter, then the alignment is eccentric by the radius of the circle (Figure 11).

Once the radial center is aligned, then the number of cuts, or number of indexed divisions, must be determined for the pattern. Small areas will require fewer incremental radial divisions whereas larger areas will require a greater number of divisions. If the pattern does not require phasing and is a simple radial design, then the number of divisions only needs to be a whole number. If the pattern requires phasing through a cycle of cuts, then the number of divisions must be divisible by the number of cuts per cycle. As an example, if we are using a zigzag pattern (Table 2) that has a cycle of 8 cuts, then we must use a multiple of 8 for the number of radial divisions such as 96, 144, 360, or even 920.

Circumaxial

Figure 12 is a good example of circumaxial cutting. Here the cylinder is mounted into a "pen chuck." Any cylindrical workpiece can be engraved around its vertical axis in the straight-line machine. Tapers, domes and non-cylindrical work can also be engraved about their vertical axis using pen chucks, dome chucks, and/or other custom-built chucks. The workpiece is rotated about the vertical axis and indexed after each cut by a small quantifiable amount. The amount of rotation is adjusted to the design and size of the workpiece. Typically, larger cylinders have more divisions and smaller cylinders have fewer divisions.

Figure 12 *Circumaxial*

Circumaxial Setup: Most circumaxial work is held by a pen chuck, so named due to its common use of holding pen barrels. The pen chuck supports the workpiece between two lathe-type centers, which is an indexable axis. Shown at left in Figure 13 is a pen barrel being held by an antique Swiss pen chuck, and at right is a #30 handpiece of a Foredom® flexshaft machine being held in a modern American pen chuck. Circumaxial cutting is extensively used for engraving pens, but is also used to engrave patterns on boxes, *objets d'art*, and any workpiece conducive to circumaxial rotation.

Figure 13 *Two pen chucks: antique Swiss (left) and modern American (right)*

When engraving a workpiece circumaxially, the first step is to align the part precisely vertical. The alignment of the part to the vertical axis is accomplished with a dial indicator as shown in Figure 13. The goal is to have the workpiece perpendicular to the cutter's horizontal axis.

Once the workpiece is aligned, the next step is to determine the number of radial indexing movements. When cutting simple parallel patterns without phasing, the number of divisions needs only to be a whole number. When any pattern with phasing is cut circumaxially, the number of divisions must be divisible by the number of steps in the pattern cycle. As an example, if we want a sinewave pattern that has 32 steps in one cycle, or one sinewave, then we would need to select either 32, 64, 96, 128…etc. index divisions. Any other number of movements would find the last cut not aligning with the first cut when you've gone all the way around the 360 degrees of the workpiece.

The Cutter

The cutting tools used on the straight-line machine are similar to the cutting tools used on the rose engine. Two general styles of cutters are used: fixed cutters and rotational cutters.

Figure 14 shows two different cutters set up on the straight-line machine. On the left is a fixed cutter and on the right is a rotary cutter. The two workpieces were cut with different cutters using the same pattern bar. Note the difference in cut. The rotary tools are ideal for ornamentally cutting wider swaths, which make the pattern a bit more subtle. The fixed tool cuts a fine engraved line, which is ideal for creating optical effects with its bright cuts. Side and top views of a fixed cutter are shown in Figure 15.

Figure 14 *Fixed (left) and rotary (right) cutters*

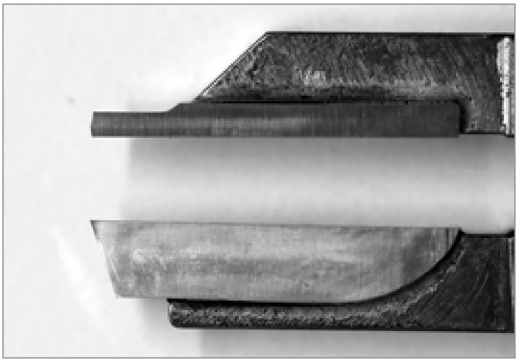

Figure 15 *Top and side views of a fixed cutting tool*

With certain workpieces the grinding of a fixed cutter may differ from what is typically used on a rose engine. The relief under the cutter's lip is sometimes ground with a more acute angle to allow for more clearance when engraving above the centerline tangent of a three-dimensional workpiece. In this case the cutting tool of the straight-line machine changes its angle of attack as the workpiece is guided past the cutting tool. Figure 16 shows two different front clearance angles, or rake angles. The lower cutter shows common clearance angles; the upper cutter shows more acute clearance angles used on straight-line machines when engraving above the centerline of a three-dimensional workpiece.

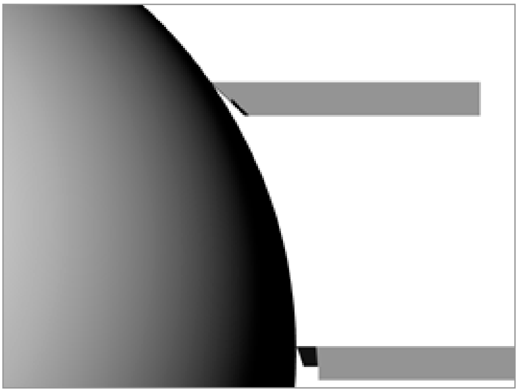

Figure 16 *Different clearance angles on fixed cutters*

The fixed cutter is commonly coupled with a guide which acts to control the depth of cut (Figure 17). The guide is clamped on one side of the cutter and has a highly polished, smooth face that contacts the workpiece when the cutter has reached its proper depth. It has an adjustment screw which acts to vary the difference between the tip of the cutter and the tip of the guide. Guides are shaped to best follow the workpiece and control precise depth. Traditionally, the burnished mark left on the workpiece by the guide was called the "black mark."

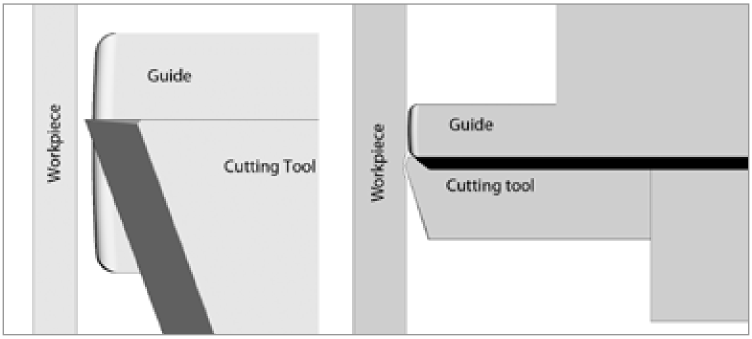

Figure 17 *Side and top views of cutting tool with guide*

Much more information about fixed engraving cutters is available in the 2016 Santa Fe Symposium® paper entitled "The Parts and Processes of a Rose Engine in the Modern Shop."[5]

Pattern Development

The number of patterns that can be created with the straight-line machine are unlimited. With this in mind, we will look at a few simple but fundamental patterns. Most engraving with a straight-line will fall into one of three style groups: textural guilloché, optical guilloché, and ornamental cutting. One good example of textural guilloché is watch faces. Watch makers use textural guilloché, which tends to be much smaller in the depths and widths of cut. Most watch makers will silver plate the face after guilloché to preserve it from tarnish and remove the optical brightness in favor of texture. This gives the face of a watch a beautiful texture which compliments the dial. (Figure 18)

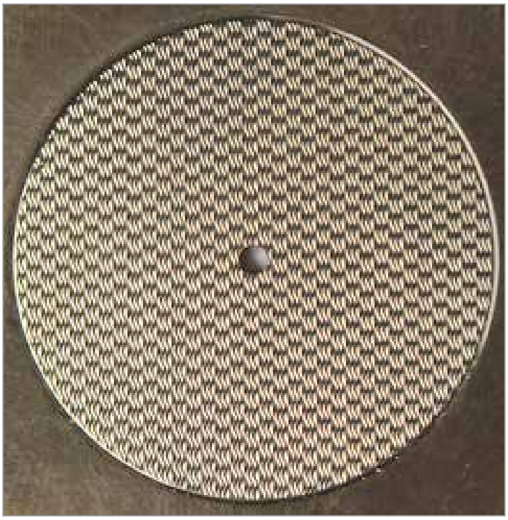

Figure 18 *Example of textural guilloché in a watch face by Calina Shevlin*

Most non-watch use of guilloché is brighter and bolder and displays an optical play of light. This style is commonly enameled with a transparent enamel which protects the brightness and optical play-of-light from tarnishing. (Figure 19)

Figure 19 *Example of optical guilloché by William Brinker, guilloché-engraved and enameled kaleidoscope, drape pattern. This kaleidoscope was awarded first place at the 2010 Saul Bell Design Award competition.*

The Variables Used to Create Patterns

There are several different pattern design variables on the straight-line machine that can be used to create patterns. These variables can be used individually or combined in different ways to create an almost unlimited number of design patterns. We will go through this list of seven one at a time and define their effects.

1. *Cutter type:* The type of cutter can be either a fixed tool or a rotary tool. Fixed tools engrave bright cuts into the metal whereas rotary tools cut larger swaths of the metal and are good for ornamental carving in the metal (Figure 14).
2. *Cutter angle/shape:* When using fixed tools, the angle of cut has a very strong influence on the optical quality of the cut. Cutters that are ground with angles as broad as 150 or 160° reflect bright light back to the viewer much better than more acute angles in the 90 to 120° range. The more acute angles are best used when engraving textural patterns such as those used for watch faces. Cutters can be ground with special shapes including round, bevel and square.
3. *Depth of cut (DOC)* and *width of cut (WOC):* The depth of cut and the width of cut play important roles in pattern development and have a distinct effect on the overall quality of the cut pattern.

   Shown in Figure 20 are six examples showing the relationship of DOC to WOC with a 160° cutter angle. In this case for every .001″ (.025 mm) of depth, the width of the cut increases by approximately .011″ (.279 mm). Figure 21 shows the effect of the cutter's tip angle and how it affects the width of cut. Shallow cuts will require a small step-over whereas deeper cuts will require a larger step-over. Step-over is the distance that the cutter is moved between cuts. Note the effect of step-over when using the same cutter angle and the same depth of cut but changing the amount of step-over as shown in Figure 22.

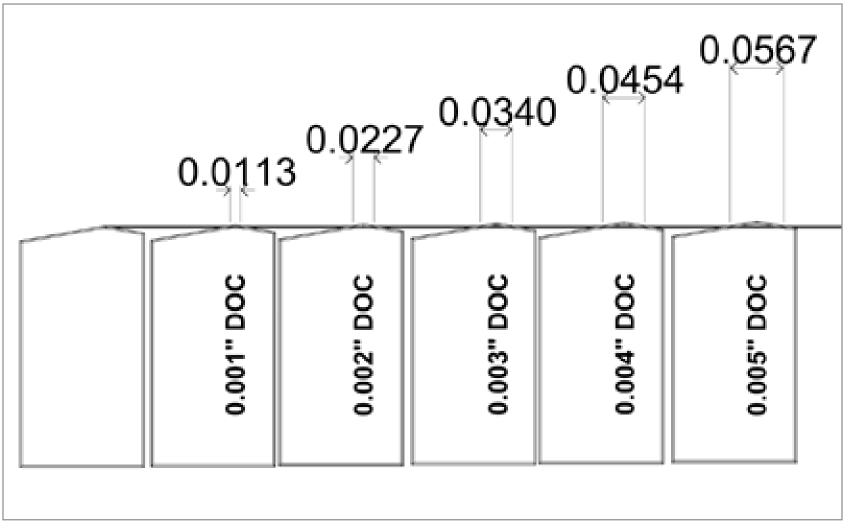

Figure 20 *Relationship between depth of cut (DOC) in inches and width of cut (WOC) in inches*

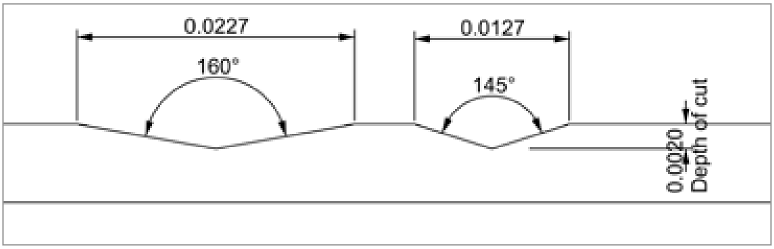

Figure 21 *Effect of cutter tip angle and width of cut*

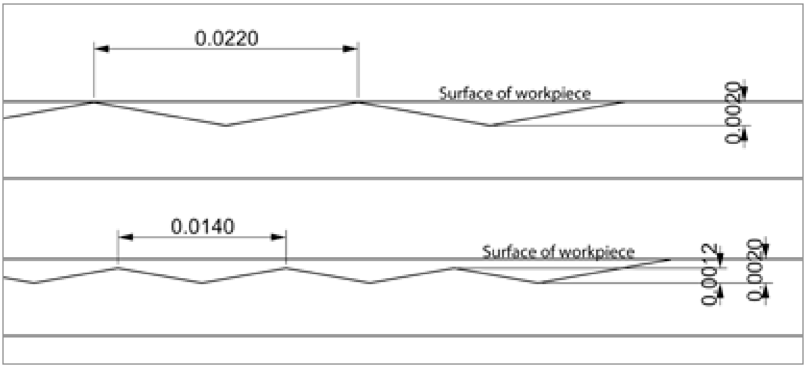

Figure 22 *Effect of using the same depth of cut with different step-overs*

Poirier

4. *Pattern bar(s):* Needless to say, the pattern bars themselves play a major role in pattern development. Pattern bars are readily available and come in many forms. (Figure 23). They can also be made in most machine shops. A common technique employed to make pattern bars is by the use of wire EDM (electrical discharge machining). This method allows for cutting the pattern into pre-hardened tool steel. By cutting through the middle of a pre-hardened steel bar, this process will produce two pattern bars, one original pattern and one mirror pattern. This allows for added capabilities in design creation.

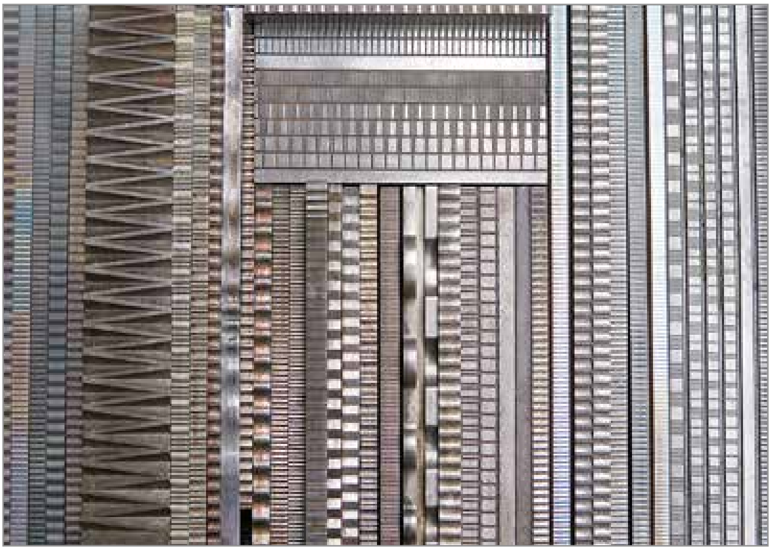

***Figure* 23** *Pattern bars*

Pattern bars can be used singly or with other bars on one project. Pattern bars are typically measured by their pitch and amplitude. Pitch is the distance from one peak to the adjacent peak. Amplitude is the distance between the bottom of a valley and the top of the peak (Figure 24). Some manufacturers will stamp the pitch or one half of the pitch distance on the bar itself for easier pattern development (Figure 28).

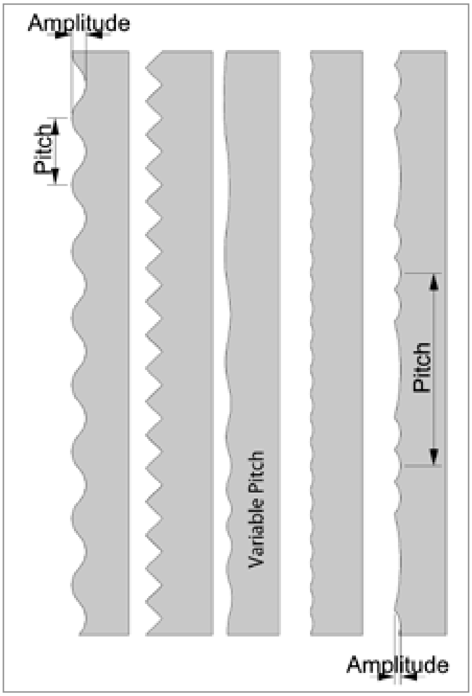

Figure 24 *Example of pattern bars, amplitude and pitch defined*

5. *Phase of pattern:* The phasing of the pattern bar between cuts creates the major effect of most patterns. Phasing is performed by turning the crossing slide (Figure 6) a given amount between cuts. This changes the location relationship of successive cuts on the workpiece. If done correctly it can create a second optical pattern in the workpiece that is unlike the pattern bar itself. Designs such as basketweave, sinewave, drape and zigzag can be made to produce a very pleasing optical effect which stimulates the eye. These same patterns, if executed poorly, will not stimulate the eye and may even be repulsive to the viewer.
6. *Step-over amount:* The step-over is the amount that the cutter is moved between each cut when cutting parallel designs using the cutter's main slide. Step-over when cutting radial or circumaxial designs is the amount that the workpiece is rotated or revolved around its rotational axis.

   The step-over amount is highly linked to phasing along with DOC/WOC. Most pattern creation starts with finding the best combination of step-over and phase amount. The simplest patterns require no phasing and only use a step-over after each cut, as seen in Figures 29, 30 and 31. A basic pattern that requires accurate step-over and phasing is the barleycorn, as seen in Figure 35.

7. *Touch radius/pattern radius:* The radius of the touch plays an important role in the final engraving. A sharp, pointed touch will produce a very different pattern than a broad radius touch when used with the same pattern bar. This is due to the offset between the pattern bar and the center of the touch's radius. The center of radius on the touch is known as the trace point (Figure 25). The trace point describes the pattern engraved on the workpiece with that touch and pattern bar combination as shown in Figure 25.

   By knowing the radius "R" of the pattern curves, one can obtain a range of patterns by adjusting the radius of the touch. With one pattern bar you can create engraving lines that range from a scallop to a sinewave to a reverse scallop.

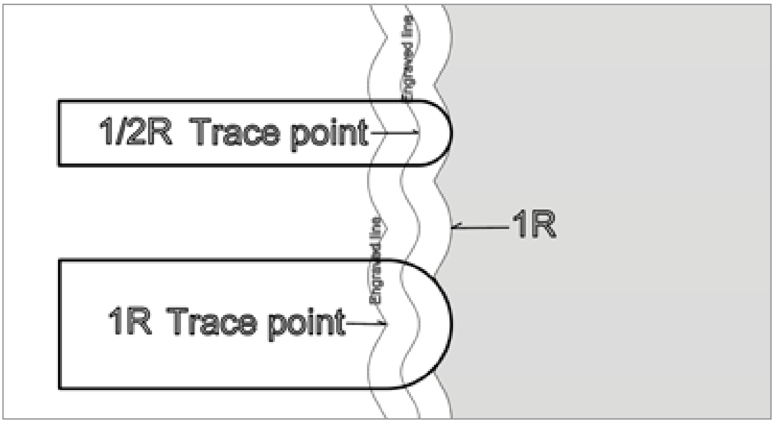

Figure 25 *Trace points of different radii touches and the resulting cut line*

Figure 26 shows three different radii on the touch with the same pattern bar. The touch on the left has the same radius as the cut in the pattern bar. In the center is a touch with ½ the radius of the cut in the pattern bar. And at right is a touch with a sharp chisel-like edge with very little radius on its tip.

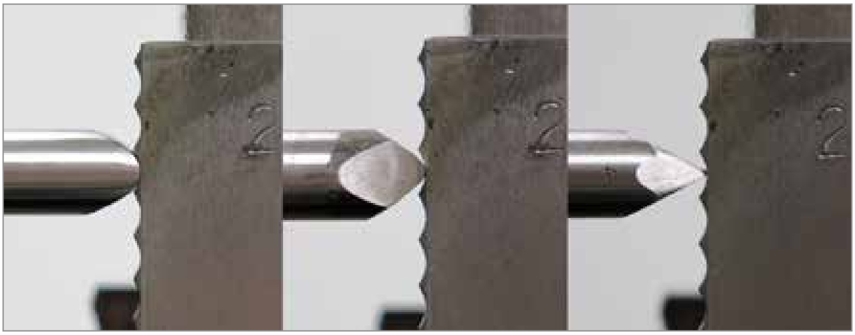

Figure 26 *Touches with different radii*

The results are shown in Figure 27. At left the engraved pattern is very similar to the pattern bar itself by using a touch with the same radius as the pattern bar. In the center the engraving shows a sinewave pattern which results from using the touch with a radius equal to ½ of the radius on the pattern bar. And at right the engraved line is a reverse scallop, opposite that of the pattern bar, by using a touch with a sharp, minimally radiused tip.

Figure 27 *Results of using different radii touches*

Wear on the touch can be a problem especially when using a pointed touch. This issue of wear was addressed by the engineers at Plant and Son in 1931 when they designed a multi-tipped touch. The multi-tipped touch spreads the force over a much larger area, thereby reducing wear. The only drawback is that the touch must be mated to a specific pattern bar. Figure 28 shows a mated pair of multi-touch and pattern bar. The stamped number "357" represents ½ pitch of the pair, or .0357" (= 1/2P). The touch pivots on an internal spherical socket (dashed curve) which keeps the pressure equal across the touch's length.

Figure 28 *Mated touch and pattern bar designed to minimize wear*

The type of metal being engraved has many different effects upon the final look. Titanium and niobium can be engraved in multiple layers, each anodized with a different color to accentuate the cut. Platinum engraving leaves a very bright reflection which is resistant to tarnish whereas sterling silver will tarnish and create a beautiful antique appearance. Silver alloys can be enameled with a transparent enamel to preserve the beauty of the optical play-of-light. Gold also can be engraved and left as-is or enameled.

With all design patterns it is always recommended that the artist/craftsman practice cutting the pattern on metal that is similar to the final workpiece. The cutting tool will need to be ground with different clearance angles depending upon the type of metal being cut. Gold and silver cut similarly, whereas titanium and niobium cut quite differently and require a cutting tool shape with more rigidity and less clearance. Platinum usually requires a larger negative relief on the top of the cutter, which keeps the cutter from diving too deep into the metal.

Design Recipes

When using any straight-line machine it is recommended that the operator create recipes of the patterns for multiple reasons. One is the ability to replicate the pattern at some point in the future. Another is to help remind you of which cut you are working on while engraving a workpiece, similar to using sheet music while playing an instrument. Recipes are typically made for a specific machine due to the fact that different manufacturers of machines use different units of measure. The recipes which follow are generic and can easily be translated to individual machine specifics.

Straight

The simplest engraving would be straight lines cut without using a pattern bar. This is useful as borders around the perimeter of a workpiece or around an area of the workpiece. It is commonly used on watch faces. It was widely used on lockets and cufflinks during the 1920s and 1930s, so much so that several straight-line machines were built specifically to cut straight lines only, with no ability to follow a pattern bar. Figure 29 shows three examples: top is a small step-over, middle is a larger step-over, and the bottom example combines both small and large step-overs.

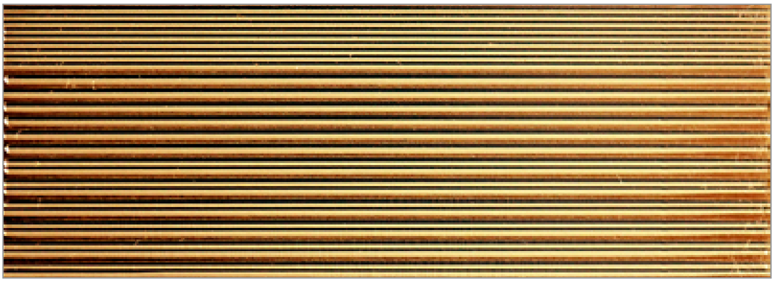

Figure 29 *Straight lines without pattern bars*

Parallel

Another simple engraving pattern is parallel cuts using a pattern bar. When engraving parallel cuts the step-over becomes an important pattern design variable. Figure 30 shows two different step-over amounts. Figure 31 shows two different step-over amounts on the left followed by an ever-increasing amount of step-over on the right.

Figure 30 *Examples of parallel cutting*

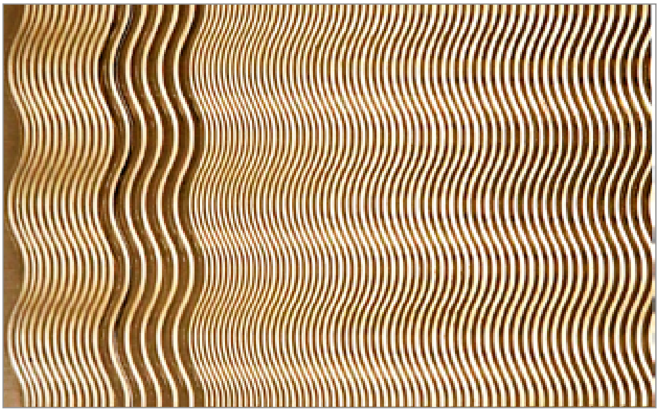

Figure 31 *The effects of step-over on a parallel pattern*

Crossing

The workpiece can be engraved with a parallel pattern, then moved or rotated and engraved over the previous cuts. The crossing cuts can be at various angles relative to the initial cut pattern. Figure 32 shows an initial series of parallel horizontal cuts that were then reoriented by 45 and 90°.

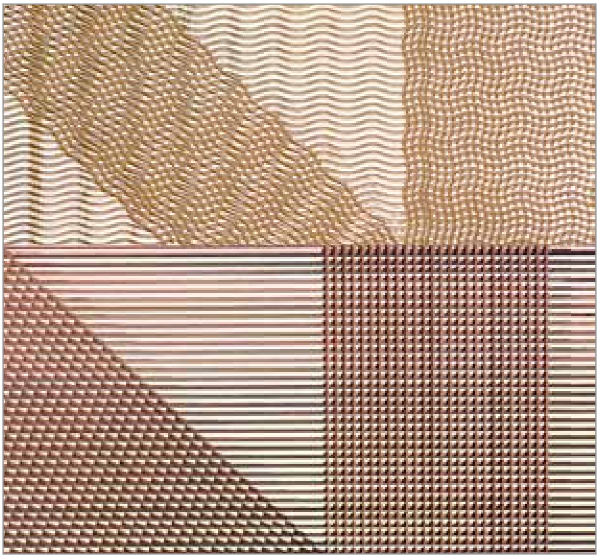

Figure 32 *Crossing cuts (moiré pattern most noticeable in the upper left diagonal)*

They were then recut with parallel diagonal and parallel vertical cuts, all using the same pattern bar. Note that with some crossing cuts, a moiré interference pattern is formed (a third pattern created by two overlapping patterns).

Diagonal

The example in Figure 33 shows a diagonal pattern. This is created by phasing a given amount after each cut and repeating. The amount of phasing will determine the angle of the diagonal. In this example the phase amount was equal to 1/8 of the pitch distance. If the phase amount was increased to ¼ of the pitch distance, then the resulting angle would be considerably steeper. Likewise, by decreasing the phase amount to 1/16 of the pitch distance, the resulting diagonal angle would be lower or less steep.

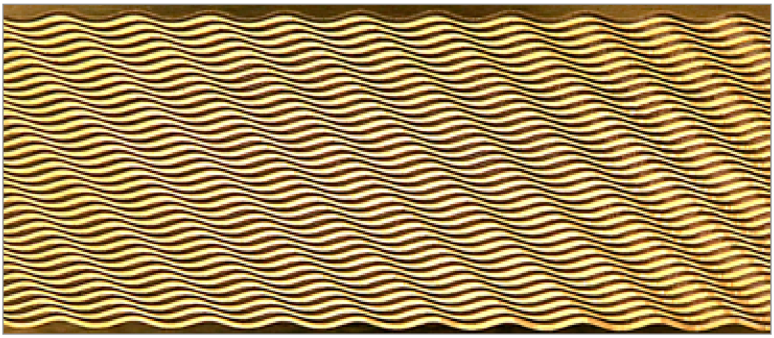

Figure 33 *Diagonal pattern*

Barleycorn

The barleycorn pattern consists of alternating cuts where the peak of one cut meets the valley of the previous cut. The pattern is created by phasing the cut by ½ of the pitch of the pattern bar after each cut. This creates a seed-like, or barleycorn shape, between cuts. Shown in Figure 34 is an example of the barleycorn pattern.

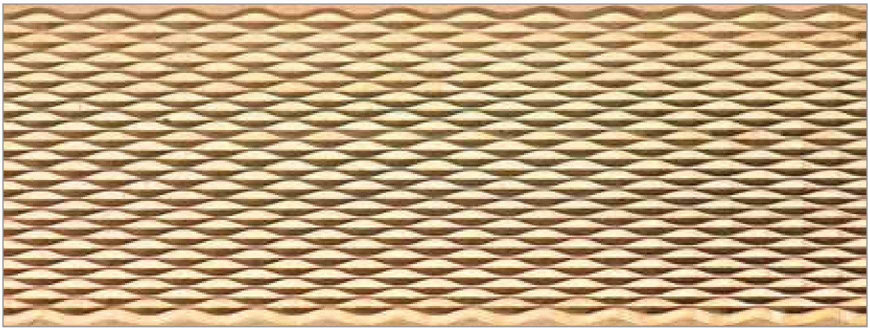

Figure 34 *Barleycorn pattern using pattern bar with pitch=.138″ (3.51 mm), step-over= 0.019″ (0.48 mm), phase=.069″ (1.75 mm)*

There are numerous variations on the barleycorn; one is shown in Figure 36, where two parallel cuts are inserted between the barleycorn rows. The depth of the cut is adjusted to cut a width slightly wider than the amplitude. The step-over is adjusted so the center of each cut is separated by approximately one-fifth of the amplitude (Figure 35). If the barleycorn does not have a centered peak ridge, then the tangent screw on the cutter slide would be adjusted to best center the peak ridge line. [6]

There are numerous variations on the barleycorn. One is shown in Figure 36, where two parallel cuts are inserted between the barleycorn rows.

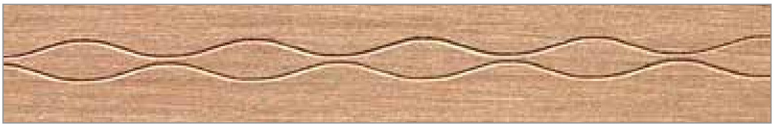

Figure 35 *Adjusting the step-over so the cuts are separated by approximately 1/5 of the amplitude*

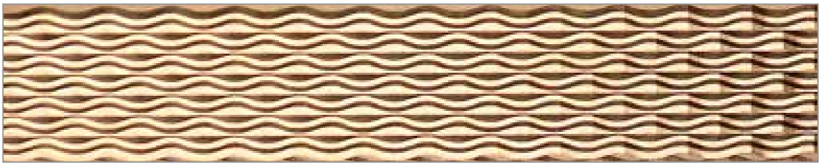

Figure 36 *Alternating Barleycorn pattern*

Table 1 shows the concept of a basic barleycorn pattern.

Table 1 *Barleycorn pattern, P = pitch of pattern bar*

Barleycorn	
Sequence of cuts	Phase amount
1	0
2	1/2P
3	1/2P
4	1/2P
5	1/2P
6	1/2P
7	1/2P
8	1/2P

Zigzag or Lightning

The zigzag pattern, also known as lightning, consists of phasing the pattern a given amount in one direction after each cut, engraving a specified number of cuts, then reversing the process by the same amounts. The amount of phase shift can be any amount and is typically anywhere between 1/4 and 1/10 the pitch of the pattern bar.

An example is shown in Table 2 where the desired number of cuts per cycle is 8 and the phase movement is 1/8 of the pitch distance (P). So if the pitch of the pattern bar were 8 mm, then the phase amount of each cut would be equal to 1 mm.

***Table 2** Zigzag recipe, P = pitch of pattern bar*

Zigzag	
Sequence of cuts	Phase amount
1	1/8P
2	1/8P
3	1/8P
4	1/8P
5	-1/8P
6	-1/8P
7	-1/8P
8	-1/8P

Figure 37 shows three examples of the zigzag pattern. At top shows a slight zigzag where the phasing was about P/20. The middle example P/10, and the bottom example is phased by P/6. Step-over in all three is the same.

***Figure 37** Three examples of zigzag*

Basketweave

The basketweave (Figure 38) is similar to the zigzag but has a much more critical relationship with the step-over distance and the phase amount. Width of cut and depth of cut also play an important role in the basketweave design. These variables must be quantified to achieve optimum results. The amplitude (A) and pitch (P) of the pattern bar must be measured accurately for use in the formulas.

Figure 38 shows two results from two different pattern bars, each resulting in a slightly different style of the basketweave pattern. Both examples in Figure 38 have three segments per weave.

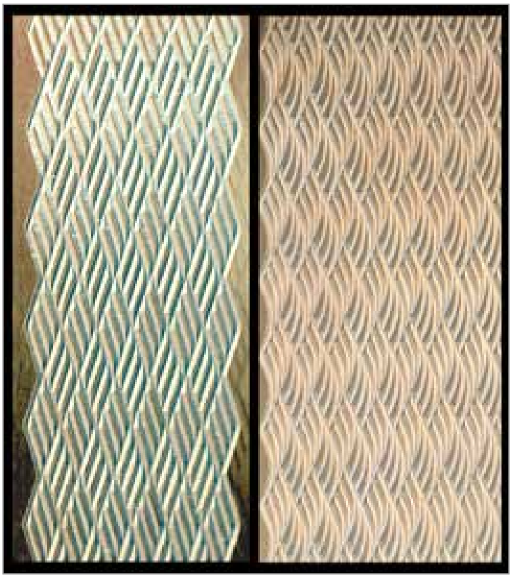

Figure 38 *Two different basketweave patterns*

In the basketweave pattern we must first define some variables:

A = amplitude of pattern bar

P = pitch of pattern bar

N = the number of segments per weave.

SO = the step-over amount

Ph = the phase amount

For the basketweave pattern we need to solve for step-over amount and the phase distance. The formula for the amount of phase movement is Ph = P/N2. The formula for the amount of step-over is SO = A2/N.

Example:

A pattern bar measures .06″ (1.52 mm) pitch length and .03″ (0.76 mm) amplitude. We select three as the number of segments per weave. Using the formula Ph = P/(product of N*2), we get .01″ (0.25 mm) for the phase amount.

Ph = P/(N2)

Ph = .06/(3*2)

Ph = .06/6

Ph = .01 inch (.25 mm)

Using the formula SO = (product of A*2)/N, we get .020″ (.51 mm) for the amount of step-over.

SO = (A2)/N

SO = (.03*2)/3

SO = .06/3

SO = .02 inch (.51 mm)

Table 3 shows the final recipe for the basketweave pattern in table form. Note the positive and negative signs of the numbers. The sign of the number represents the direction the crossing micrometer is turned, and the direction that the pattern bar shifts with respect to the workpiece.

***Table 3** The basketweave pattern*

Cut #	Ph = P/N2	SO = (A2)/N
1	0	0
2	0.01″	0.02″
3	0.01″	0.02″
4	0.01″	0.02″
5	-0.01″	0.02″
6	-0.01″	0.02″
7	-0.01″	0.02″
	repeat from cut 2	

Figure 39 shows a graphic representation of the basketweave pattern.[6] Each cut is identified with a different color and number. The numbers represent the order of cutting. Number 1 can be followed from bottom to top representing the first cut. Then 2 is followed from bottom to top representing the second cut, etc.

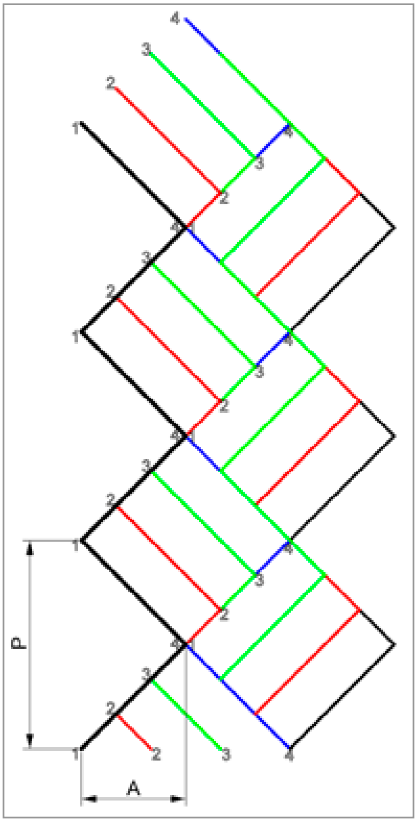

Figure 39 *Basketweave graphic showing relationships of pitch and amplitude to the cuts*

Sinewave

The sinewave pattern, sometimes referred to as a moiré pattern, creates the effect of a sinewave across the cuts. It is possible that it has been called a moiré due to its wonderful play of light. A true moiré is an interference pattern created when two similar patterns overlap one another. Moiré patterns can be cut on the straight-line machine by using crossing cut patterns as shown in Figure 32. The sinewave pattern is suitable for use with most pattern bars and is very pleasing to the eye when cut with skill (Figures 40, 41). Like many patterns, the final pattern effect is created by changing the relationship between the pattern bar and the workpiece after each successive cut. This change creates a visual pattern which the viewer sees as an optical play of light. The pattern bar itself has a rather small influence on the final optical effect, whereas the way that the successive cuts are linked to each other influences the optical effect to a much greater extant.

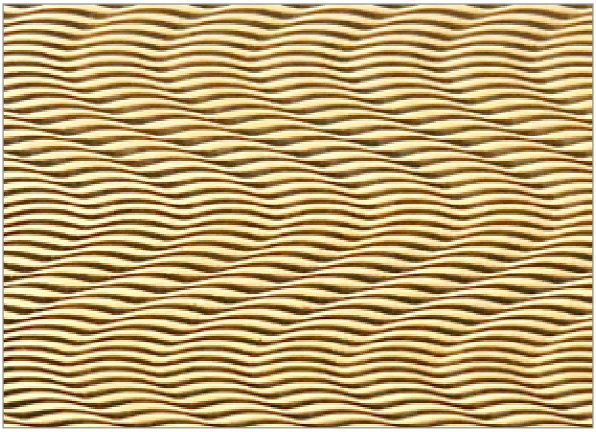

Figure 40 *Sinewave pattern with simple scallop pattern bar*

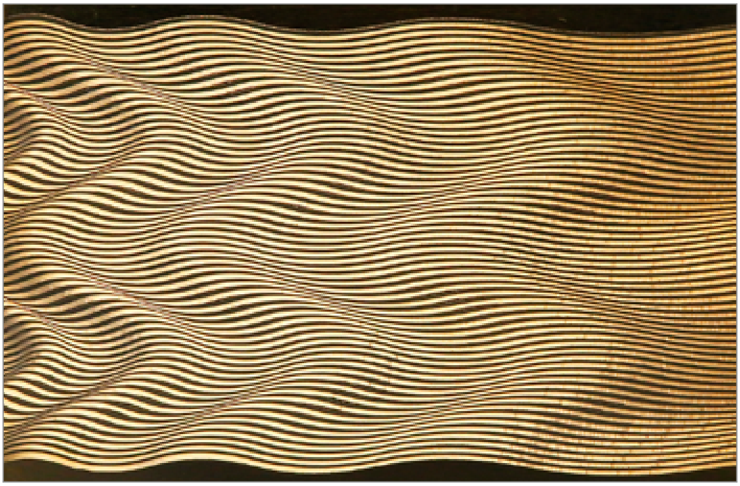

Figure 41 *Sinewave pattern with variable pitch pattern bar*

The sinewave pattern can easily be altered to create a narrow or broad sinewave effect by altering the rate of change in the phase amount. A generic recipe is shown in the Table 4. This design pattern can be highly altered with great effects by changing the proportions of the phase amount. Note that in Table 4 there are three examples. These examples can be used on any machine by simply settling on the unit of measurement. The units in example 1 can be any unit of measure or fractions thereof. Note example 1 is a simple sequence; example 2 has a greater rate of change, which would increase the overall height of the sinewave. Example 3 shows a series of phase amounts based on Fibonacci numbers (a series of numbers in which each number is the sum of the two preceding numbers). A lot will depend upon the pattern bar's amplitude and pitch and how it affects the final engraving. Note the difference between a simple scallop pattern bar and a variable pitch pattern bar in Figures 40 and 41.

Table 4 Sinewave pattern

Sinewave	Example 1	Example 2	Example 3
Sequence of cuts	Phase amount in units	Phase amount in units	Phase amount in units
1	0	0	0
2	1 unit	1 unit	1 unit
3	2 units	3 units	2 units
4	3 units	6 units	3 units
5	4 units	10 units	5 units
6	5 units	15 units	8 units
7	6 units	21 units	13 units
8	7 units	28 units	21 units
9	8 units	36 units	13 units
10	7 units	28 units	8 units
11	6 units	21 units	5 units
12	5 units	15 units	3 units
13	4 units	10 units	2 units
14	3 units	6 units	1 unit
15	2 units	3 units	0
16	1 unit	1 units	
17	0	0 units	

Drape

The drape pattern seen in Figure 42 is similar to the sinewave pattern but uses only a portion of the sinewave recipe. In Table 5 the cutting sequence shows relative movements of the phase amount, which can be adapted to any unit of measure on any machine. When all cuts are completed, repeat from the top. The final outcome will depend on the step-over, depth of cut, width of cut and pattern bar.

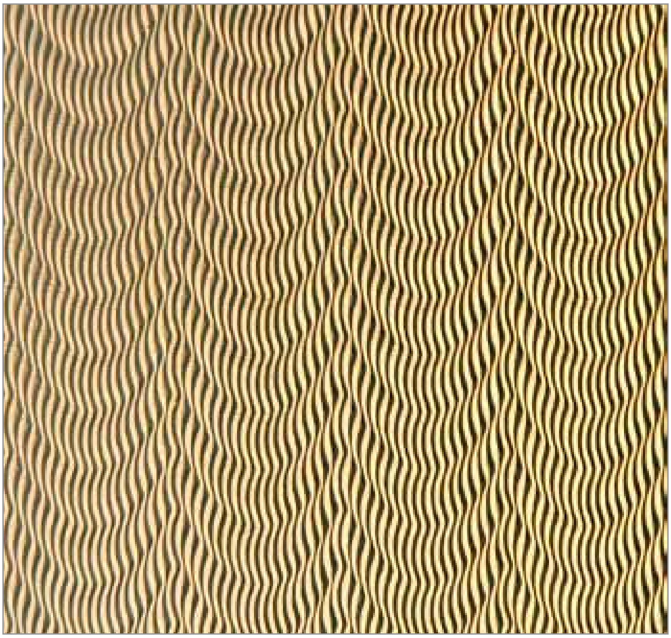

Figure 42 *Drape pattern*

Table 5 *The drape pattern*

Sequence of cuts	Phase movement in units
1	0
2	6
3	5
4	4
5	3
6	2
7	1
8	0
9	-1
10	-2
11	-3
12	-4
13	-5
14	-6

Poirier

Note that all of these recipes and patterns have been shown as surface parallel. These patterns can also be translated to radial and circumaxial designs. The step-over of the cutter slide is no longer used when engraving on these two other surface types. Radial cuts use the radial axis to move after each cut. Circumaxial surfaces are rotated around its axis a quantified amount after each cut.

State-of-the-Art Examples

The following images are examples made by contemporary artists from around the world.

Figure 43 *William Brinker—guilloché-engraved and enameled kaleidoscopes, circumaxial cutting. The pink on the left is a drape pattern; the green on the right shows a beautiful sinewave pattern.*

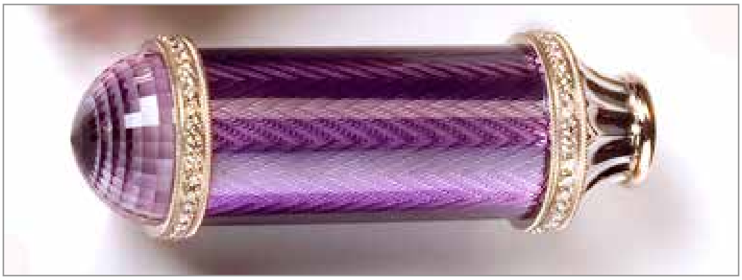

Figure 44 *William Brinker—guilloché-engraved and enameled kaleidoscope, lightning or zigzag pattern.*

Figure 45 *Frieda Doerfor—a beautifully engraved contemporary neckpiece, parallel pattern*

Figure 46 *Chris Manning—guilloché-engraved pen with enamel, sinewave pattern*

Figure 47 *Chris Manning—engraved iPhone case using a sunburst radial pattern*

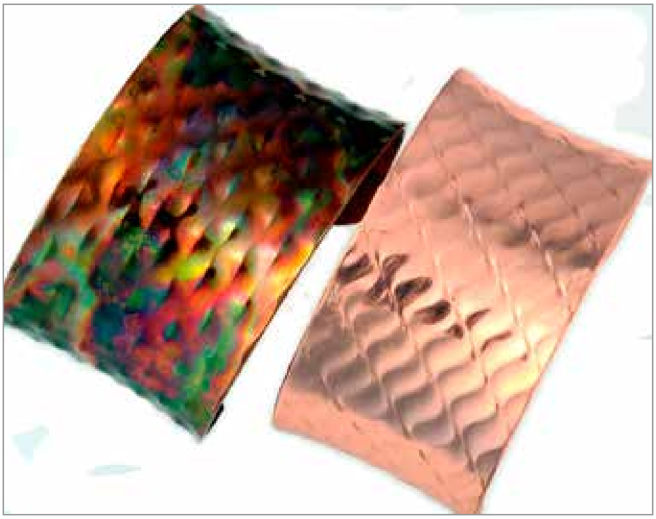

Figure 48 *David and Becky Lindow used a rotational cutter to carve these two copper bracelet examples. The left shows a barleycorn pattern, the right a diagonal pattern.*

Figure 49 *Peter Gilroy—engraved bolo tie in titanium with inlaid 18k gold, parallel patterns*

Figure 50 *Peter Gilroy—titanium ring with radial sunburst pattern*

Figure 51 *Celia Kudro—sterling silver rings with radial guilloché engraving*

Figure 52 *Brooke Barlow—engraved cuff bracelet in sterling silver, parallel patterns*

Figure 53 *Brooke Barlow—engraved cuff bracelet in sterling silver, radial, parallel and barleycorn patterns*

Acknowledgements

Thanks to William Brinker for his exemplary guilloché and enameling work. Thanks to Peter Gilroy, Chris Manning, Brooke Barlow, David and Becky Lindow, and Celia Kudro for their contributions and fine examples of straight-line work. And, as always, I wish to thank Eddie Bell and Janet Haldeman for their professional editing of this paper and for their continued support of the Santa Fe Symposium®.

References

1. H. Bergeron, *Manuel du Tourneur* (1816).
2. Holtzapffel, *Turning and Mechanical Manipulation on the Lathe* (Dover, 1973, reprint of the original Volume 5 of 1894).
3. English translation of Bergeron, edited by Jeremy Soulsby (UK: Society of Ornamental Turners, 2010).
4. John Traina and Peter Carl Fabergé, *The Fabergé Case* (NY: Abrams, 1998).
5. G. Phil Poirier, "The Parts and Processes of a Rose Engine in the Modern Shop," *The Santa Fe Symposium on Jewelry Manufacturing Technology 2016*, ed. E. Bell et al. (Albuquerque: Met-Chem Research, 2016).
6. George Daniels, *Watchmaking* (London: Philip Wilson Publishers Ltd., 1981).

Additional Resources

Jean-Yves Godechoux and Sophie de Bernis, *Boites en émail et argent guilloché 1880-1930* (Paris: Les editions de l'Amateur, 2001).

John Jacob Holtzapffel, *The Principles and Practice of Ornamental or Complex Turning* (London: Holtzapffel and Co., 1884).

John Edwards, *Holtzapffel Volume VI* (Kent: John Edwards Publisher, 2012); available directly from the author at ornamental.turning@talktalk.net, and his website http://www.ornamentalturning.co.uk/.

Calina Shevlin, *Guilloché—A History and Practical Manual* (Schiffer Publishing, 2017).

David Lindow's rose engines can be found at https://lindowmachineworks.com/.

Frieda Doerfer's work and book can be seen at http://frieda-doerfer.de/.

Peter Gilroy's website is https://www.peterwgilroy.com/.

Celia Kudro's work can be seen on Instagram at https://www.instagram.com/studiocelia/.

Chris Manning's website is https://silverhandstudios.com/.

William Brinker's work can be found at http://www.astralvessels.com/.