CUTTING FORCE OSCILLATIONS DURING ROTARY PEELING OF VENEER

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ABSTRACT

The purpose of this research was to study the effect of knife angle and profile on the instantaneous cutting force during rotary peeling of veneer. Prerounded basswood blocks were peeled with the Forest Products Laboratory minilathe, a small fixture for a knife and a pressure bar, mounted on the crossfeed bed of a machine lathe to simulate a commercial lathe with feed screws. A base dynamometer measured forces in the horizontal and vertical directions.

The horizontal force traces showed that the knife did not begin cutting as soon as it contacted the blocks. A delay (knife skip) ranging from one-sixteenth to three-tenths of a revolution caused force oscillations that persisted to some extent even after equilibrium was reached. Low knife angles resulted in longer knife skip and larger force oscillations. Equilibrium occurred 4 to 5 revolutions after cutting began regardless of the length of knife skip. It is likely that the force oscillations were related to cyclic variation in veneer thickness. Our results should be of interest to mills where veneer blocks are rounded up in a separate operation before peeling, or where the lathe operator frequently disengages the knife.

INTRODUCTION

The purpose of this research was to study the effect of knife angle and profile on the instantaneous cutting force during rotary peeling of veneer, in particular during the first few revolutions of the block before equilibrium is reached. We learned that oscillations in cutting force may be related to veneer thickness variation, which is a longstanding concern in the plywood industry.

One consequence of thickness variation is that veneer must be peeled thicker than desired to ensure that any thin areas meet the minimum thickness requirement. Another is the increased plywood thickness loss due to the greater pressure required in the press to get good contact between veneers (1).

1The Laboratory is maintained in cooperation with the University of Wisconsin. This article was written and prepared by U.S. Government employees on official time, and it is therefore in the public domain and not subject to copyright.

There are several types of thickness variation. Hoadley (6) described the continuous increase in thickness during the first few revolutions of a log before equilibrium is reached. He simulated the veneer peeling process by making successive cuts from blocks of wood using a small knife and pressure bar mounted on the end of a pendulum. The first piece cut was thinner than desired because the pressure bar partially deflected the wood away from the knife. This was confirmed by interference between the knife and the block on the return swing of the pendulum. For each of the next three cuts, the veneer thickness increased, as did the interference on the return swing. Equilibrium occurred after the fourth cut. The knife position for Hoadley's first cut was equivalent to the knife position in rotary peeling one revolution after cutting begins, for a conventional lathe with feed screws. Consistent with Hoadley's results, Lutz et al. (11) found that equilibrium is reached more quickly when the pressure bar is closed from the beginning of peeling. Feihl and Carroll (2) reported that it took 4 to 5 revolutions of the log to reach proper thickness when using a fixed pressure bar to peel red pine, white spruce, and yellow poplar.

Another type of thickness variation is cyclic, caused by improper knife angle. High knife angles give corrugated veneer, with a very short wave pattern, perhaps 0.25 to 0.375 inch between the crests of the waves and a height difference up to 0.004 inch between the raised and shallow areas. The bolt may chatter, and corrugation may be visible on both the log and the veneer (5, 9, 10). When the knife angle is too low (insufficient clearance between the knife and the block), the veneer thickness varies in waves described as one to several feet long (4, 5, 9, 10). In this case, the horizontal force acting on the knife tends to force it away from the block. The problem is reported to be especially prevalent in winter and early spring, when cutting partially frozen logs (4).

There is abundant literature dealing with cutting forces in wood machining and veneer peeling, but no mention is made of force oscillations at the beginning of cutting.

MINILATHE DESCRIPTION

The Forest Products Laboratory (FPL) minilathe is a small fixture for a knife and pressure bar that can be used for peeling veneer. It was mounted on the crossfeed bed of a large machine lathe, which had been modified to provide veneer cutting feed rates. While the machine lathe rotated the block, the minilathe was advanced as a unit into the cut (Fig. 1). The overall effect was to simulate a commercial veneer lathe with feed screws. A base dynamometer measured forces acting on the minilathe in the horizontal and vertical planes.

We used two different knives, each 5/8 inch thick, with a 21 degree main bevel. One knife had a 27 degree microbevel 0.01 inch wide on the face toward the block (Fig. 2). Both knives and the bar were 12 inches long. The bar was 5/8 inch thick with a 75 degree bevel and a 1/64-inch radius.
PROCEDURE

Horizontal and vertical forces were continuously measured while peeling prerounded basswood blocks ranging in length from 7 to 10 inches and averaging 12-1/2 inches in diameter. Some cutting trials were done without the pressure bar. An X-Y plotter recorded forces.

Two different veneer thicknesses were cut: 0.1 inch, using only the standard knife, and 0.125 inch, using both the standard and microbeveled knives. Settings of the knife and bar are listed for all the trials in Table 1. The edge of the knife was set at the same height as the spindle center. Vertical lead is the height of the bar above the tip of the knife. Horizontal gap is the opening between the bar and the knife tip as seen from the top (Fig. 2). The difference between feed and gap, expressed as a percentage of feed, is the compressive deformation of the veneer as it is cut.

All the blocks were drilled completely through the center and mounted on the 1-inch-diameter arbor of the engine lathe. The arbor was threaded on the free end, allowing the blocks to be drawn tight against the cuplike spurs on the 3-inch-diameter faceplate. The free end of the arbor was supported by the tailstock center. The blocks were at ambient temperature, and spindle speed was set to a nominal 8 rpm, which gave one revolution every 7.43 seconds.

Table 1. Minilathe settings.

<table>
<thead>
<tr>
<th>Run no.</th>
<th>Horizontal gap (in.)</th>
<th>Compression (percent)</th>
<th>Feed rate (in./rev)</th>
<th>Knife type</th>
<th>Knife angle (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.0855</td>
<td>15</td>
<td>0.1006</td>
<td>Standard</td>
<td>90</td>
</tr>
<tr>
<td>1</td>
<td>0.0855</td>
<td>15</td>
<td>0.1006</td>
<td>Standard</td>
<td>90</td>
</tr>
<tr>
<td>2</td>
<td>0.117</td>
<td>7</td>
<td>0.1258</td>
<td>Microbevel</td>
<td>90.5</td>
</tr>
<tr>
<td>4</td>
<td>0.117</td>
<td>7</td>
<td>0.1258</td>
<td>Microbevel</td>
<td>90.5</td>
</tr>
<tr>
<td>5</td>
<td>0.117</td>
<td>7</td>
<td>0.1258</td>
<td>Microbevel</td>
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</tr>
<tr>
<td>8</td>
<td>0.117</td>
<td>7</td>
<td>0.1258</td>
<td>Microbevel</td>
<td>90.5</td>
</tr>
</tbody>
</table>

1Vertical lead was 0.025 inches.

2Cutting without pressure bar.

3Sequentially set to 90, 91, 89.5, 90, 91, and 89.5 degrees.

Additional trials were made with an 89 degree knife angle, but the forces were excessive for our equipment. Figure 3 illustrates the forces acting on the minilathe. All vertical forces are positive. The horizontal force acting on the bar (H_s, Fig. 3) is always negative. Horizontal forces that tend to pull the minilathe and block together are positive.
RESULTS

The results are presented in Figures 4 to 9. Note that the vertical scale is pounds of force per inch of block width (lb/in.), and that peeling is from right to left except for Figure 8. Actual values of the forces are not as important as oscillations and trends.

Peeling 0.1-inch Veneer Without the Pressure Bar (Run A)

Figure 4 was generated while cutting 0.1-inch veneer from a single block. Knife angle was sequentially set at 90, 91, and 89.5 degrees, and then repeated, giving two cutting intervals for each angle. Knife angle did not have much effect on average forces in either the vertical or horizontal direction. The peaks seen in Figure 4 at the smaller radii were caused by knots. The force traces for the 90 degree knife angle appear smoother than for 91 and 89.5 degrees. The horizontal force on the knife \( H_h \) has both a positive and negative component. The positive component is the wedging action of the knife penetrating the block, tending to pull the knife into the block. The negative component is the rubbing of the block against the clearance side of the knife, tending to repel the knife. When cutting without the bar, the positive component is always larger.

Peeling 0.1-inch Veneer With the Pressure Bar (Runs 1–4)

Figure 5 presents the force traces for cutting 0.1-inch veneer using the bar. The interference between the pressure bar and the block is the source of \( H_b \) and tends to make the resultant horizontal force \( H_r \) negative. The bar was set the same for Runs 1 to 4 and therefore the nominal interference of 0.151 inches (feed minus gap) was the same, and one might expect the horizontal forces to be similar. The traces for 90 and 90.5 degrees (Fig. 5a and d) do look similar, except for the first few revolutions. However \( H_r \) was much more negative for 89.5 degrees (Fig. 5b), and it was positive for 91 degrees (Fig. 5c).

The fact that \( H_r \) was more negative at low knife angles may imply that the gap closes up slightly because of knife deflection, thus causing the veneer to be cut thinner than the feed rate. This in turn would cause the interference between the bar and the block (and therefore \( H_b \)) to increase. The data of Lutz and Patzer (12) showed that when the knife deflected away from the block, the load on the roller bar increased. The force trace for 89.5 degrees (Fig. 5b) suggests the gap closed slightly because the most negative \( H_r \) occurred well into the block, at a radius of about 5.5 inches.

Sugiyama and Mori (14) directly measured the force acting on the pressure bar and related it to the indentation of the bar in the wood, in tests done without cutting. In our work, we estimated the forces on the bar by comparing the average forces for knife-only cutting (Fig. 4) to the average forces for cutting with the pressure bar (Fig. 5a–c). The force data were compared over matching cutting intervals. The estimated force on the bar varies considerably with knife angle (Fig. 6), being the greatest for 89.5 degrees.
For knife angles of 89.5, 90, and 90.5 degrees $H_r$ gradually became less negative as the block was peeled. The reason for this is not precisely known. $H_n$ may get smaller because the area of contact between the bar and the block gets smaller. The net change in $H_b$ as the block gets smaller is less obvious. The wedging action tending to pull the knife into the block may get smaller, while the force tending to repel the knife may also get smaller due to less rubbing between the block and the knife on the clearance side. However the effective clearance angle also gets smaller if the knife height is set even with the spindle centers, as is common (7). The effective clearance when peeling 0.1–inch veneer with a 90 degree knife angle is a negative 9 minutes at a 6–inch block radius, and a negative 27 minutes or nearly half a degree at a 2–inch radius. To maintain a constant clearance angle, Huang (7) showed that the knife tip must be set slightly below the spindle centers by a distance equal to the veneer thickness divided by twice the value of Pi.

For 91 degrees, $H_r$ seems to remain at about the same level throughout peeling. In this case, knife rubbing and the change in clearance angle may not be significant factors because of the large nominal clearance angle (1 degree).

Kinoshita (8) observed peaks in the force acting on the knife that corresponded to the formation of lathe checks. However our data is not detailed enough to show the effects of lathe checks.

Effect of Knife Type on Peeling 0.125–inch Veneer (Runs 5–8)

All the 0.125–inch veneer was cut using the bar, and the results (Fig. 7) were similar to those for 0.1–inch veneer. For the standard knife, $H_r$ was mainly positive for a 90 degree knife angle (Fig. 7a) and mainly negative for 89.5 degrees (Fig. 7b). For the microbeveled knife, $H_r$ was mainly positive for 90.5 degrees (Fig. 7c) and negative for 89.5 degrees (Fig. 7d). The microbeveled knife at 90.5 degrees gave force levels very similar to the standard knife at 90 degrees. When the angle was 89.5 degrees for both knives, the force levels were larger for the microbeveled knife. The microbevel caused negative clearance at the knife tip, which had the same effect on forces as reducing the knife angle. Equilibrium of the forces occurred 4 to 5 revolutions after the knife began cutting. (The peaks in the force traces occur with each revolution of the log.) Previous work has indicated that veneer thickness also reaches equilibrium after 4 to 5 revolutions (2, 6, 11).

Cutting Delay and Transient Forces at the Start of Peeling

The force traces in Figure 8 clearly show that the knife did not begin cutting as soon as it contacted the block. There was a delay for part of a revolution which was longer for lower knife angles. We refer to the cutting delay as knife skip; it is the interval between knife contact at time $T_0$ and the beginning of cutting at time $T_c$. (Note that peeling is from left to right.) Only Runs 2 and 3 are shown because they had the largest and smallest values of knife skip.
respectively. Knife skip caused oscillations in the forces, especially in the horizontal direction, which dominated the character of the force traces for the first 4 to 5 revolutions. Longer knife skip resulted in larger force oscillations, even after equilibrium was reached.

The $H_r$ trace reveals more about the peeling process than does the $V_r$ trace. The time of knife contact $T_o$ was the point where $H_r$ rapidly became negative due to the knife pushing against the block. When cutting actually began at time $T_c$, the knife plunged into the wood and $H_r$ rapidly became positive. ($H_b$ was still zero at this time so $H_r = H_K$.) Less than 1 revolution later, at time $T_b$, the bar made contact with the block and $H_b$ was no longer zero. This is noted on Figure 8 as the point where $H_r$ reversed direction and started to become negative again. However, this point occurred sooner than expected compared to the ideal case of immediate cutting on contact, showing that the knife had penetrated too deeply into the block. As the block kept turning the bar came against the area where there was knife skip on the first revolution and $H_r$ reached its maximum absolute value ($|H_r|$) (or nearly so for Run 2 -- see above discussion and Fig. 5b). This suggests there was a raised area on the block causing extra interference with the bar.

The block continued to turn and $H_r$ became smaller, reaching a local minimum (min $|H_r|$) 1 revolution after initial bar contact. This was due to a minimum of interference between the bar and the block, and suggests there was a shallow area on the block. In fact, this was the area where the knife had cut too deeply on the previous revolution. Additional revolutions of the block repeated this force cycle but the range of the forces decreased until they reached equilibrium values, in 4 to 5 revolutions.

Newall and Grosert (13) are the only authors who mentioned the occurrence of a cutting delay and subsequent plunging of the knife. They described attempts to cut 0.005-inch veneer without a pressure bar, with the knife set at a negative knife clearance angle of 40 minutes (89.33 degrees). No cutting occurred for several revolutions, until a continuous sheet was produced with a maximum thickness of 0.07 inch, considerably greater than the feed amount. The authors referred to the blocks as billets, indicating they were prerounded.

Horizontal Force and Interference of Bar and Block (Runs 1 to 8)

By knowing the magnitude of the presumed raised and shallow areas, the maximum and minimum interference between the bar and block can be estimated, to determine any relationship to horizontal force. The presumed raised area on the block is equal to the amount of feed that takes place during knife skip.
Raised area = \((T_c - T_o) \times R \times F\)

where \(R\) is the number of block revolutions per second and \(F\) is the feed rate. One revolution after cutting begins, the nominal interference between the bar and block is the difference between the feed and the gap. However, the raised area must be added to this to estimate the maximum interference. Table 2 gives the results for knife skip, size of the raised area, maximum interference with the bar, and the corresponding value of \(H_r\) for Runs 1 to 8. Knife skip was determined from enlargements of the original graphs, but the values should nevertheless be viewed as estimates.

Table 2. Knife skip and computed raised area for Runs 1 to 8.

<table>
<thead>
<tr>
<th>Run</th>
<th>Veneer thick. (in.)</th>
<th>Knife type</th>
<th>Knife angle (degree)</th>
<th>Knife skip rev. (s)</th>
<th>Log raised area (in.)</th>
<th>Interference (H_r) (lb)</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1</td>
<td>Standard</td>
<td>90</td>
<td>1.5</td>
<td>0.202</td>
<td>0.0203</td>
<td>0.0354</td>
</tr>
<tr>
<td>2</td>
<td>0.125</td>
<td>Standard</td>
<td>89.5</td>
<td>2.25</td>
<td>0.303</td>
<td>0.0305</td>
<td>0.0456</td>
</tr>
<tr>
<td>3</td>
<td>0.125</td>
<td>91</td>
<td>0.5</td>
<td>0.067</td>
<td>0.0135</td>
<td>0.0068</td>
<td>0.0219</td>
</tr>
<tr>
<td>4</td>
<td>0.125</td>
<td>Standard</td>
<td>90.5</td>
<td>1</td>
<td>0.135</td>
<td>0.0135</td>
<td>0.0286</td>
</tr>
<tr>
<td>5</td>
<td>0.125</td>
<td>Microbevel</td>
<td>90.5</td>
<td>1.5</td>
<td>0.155</td>
<td>0.0195</td>
<td>0.0283</td>
</tr>
<tr>
<td>6</td>
<td>0.125</td>
<td>Standard</td>
<td>89.5</td>
<td>2.05</td>
<td>0.276</td>
<td>0.0347</td>
<td>0.0435</td>
</tr>
<tr>
<td>7</td>
<td>0.125</td>
<td>Microbevel</td>
<td>90.5</td>
<td>1.6</td>
<td>0.215</td>
<td>0.0271</td>
<td>0.0359</td>
</tr>
<tr>
<td>8</td>
<td>0.125</td>
<td>Standard</td>
<td>89.5</td>
<td>2</td>
<td>0.269</td>
<td>0.0339</td>
<td>0.0427</td>
</tr>
</tbody>
</table>

\(^1\text{Maximum absolute value of } H_r.\)

The shallow area on the block, which is caused by the knife cutting too deeply during the first revolution, can also be estimated. At time \(T_b\), the knife position is known -- it has penetrated the surface of the block to a depth equal to the horizontal gap. The ideal knife depth (i.e., no knife skip) can be calculated, and the difference between the two is the shallow area or excess depth of cut.

Shallow area = Gap - [ \((T_b - T_o) \times R \times F\) ]

where the quantity in brackets is the ideal knife depth. The local minimum interference, occurring one revolution after time \(T_b\), equals the nominal interference minus the shallow area. These computations are given in Table 3 for 0.1-inch veneer. A negative result would indicate clearance between the bar and the block, and \(H_r\) would be positive because the knife would be pulled in. In face, this was the case for the 91 degree knife angle (Run 3).
Table 3. Bar contact time and computed shallow area for 0.1-inch veneer.

<table>
<thead>
<tr>
<th>Run</th>
<th>Knife angle (degree)</th>
<th>Bar contact time (s)</th>
<th>Ideal knife depth (in.)</th>
<th>Actual knife depth (in.)</th>
<th>Shallow area (in.)</th>
<th>Min. interference</th>
<th>Min. Hr (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90</td>
<td>5.65</td>
<td>0.0765</td>
<td>0.0855</td>
<td>0.0090</td>
<td>0.0061</td>
<td>-22</td>
</tr>
<tr>
<td>2</td>
<td>89.5</td>
<td>6.25</td>
<td>0.0847</td>
<td>0.0855</td>
<td>0.0008</td>
<td>0.0143</td>
<td>-32</td>
</tr>
<tr>
<td>3</td>
<td>91</td>
<td>5.1</td>
<td>0.0691</td>
<td>0.0855</td>
<td>0.0164</td>
<td>-0.0013</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>90.5</td>
<td>5.4</td>
<td>0.0732</td>
<td>0.0855</td>
<td>0.0123</td>
<td>0.0028</td>
<td>-10</td>
</tr>
</tbody>
</table>

Local minimum of absolute value of Hr,

The time of bar contact could not be clearly determined from the force traces for the 0.125-inch veneer, and so the minimum interference was not computed. Figure 9 shows Hr and interference corresponding to the presumed raised and shallow areas on the block when peeling 0.1-inch veneer (Runs 1 to 4). The overall correlation of interference with force is -0.97 for these runs. The results of Sugiyama and Mori (14) showing force at different amounts of bar indentation are overlaid on our data. We adjusted their data for the difference in specific gravity between the species they used (red lauan) and the species we used (basswood).

CONCLUDING REMARKS

The slow cutting speed used in our study differs greatly from common industrial practice, but it facilitated data collection and analysis. Likewise, the density of basswood is less than that of commercially important species such as Douglas-fir and the southern pines. We cannot say if cutting high-density species at high speed would give results similar to our results.

The force oscillations were probably caused by cyclic veneer thickness variation since horizontal forces seem related to the interference between the bar and the block. It is also interesting to speculate on whether the "thick and thin" veneer wave pattern, observed by others for low knife angles, is a cyclic phenomenon related to the rotation of the log. Further research will be needed to provide answers. Machine play is not discussed in this report but it is present to some degree in any mechanical system. The effects of machine play in commercial veneer lathes are discussed in detail in reference (3).
REFERENCES


Figure 2. Schematic of knife and pressure bar; enlargement of tip of microbeveled knife.

Figure 1. Peeling veneer with FPL minilathe.

Figure 3. Forces on minilathe. 
$V_k$, vertical force on knife; 
$V_b$, vertical force on bar; 
$H_k$, horizontal force on knife; 
$H_b$, horizontal force on bar.
Figure 4. Peeling 0.1-inch veneer without pressure bar. Knife set sequentially at 90, 91, and 89.5 degrees. Top, vertical force $V_k$; bottom, horizontal force $H_k$. Peeling right to left.
Figure 5. Peeling 0.1-inch veneer with pressure bar. Top, vertical force $V_r$; bottom, horizontal force $H_r$. Peeling right to left. The breaks in the traces in Figure 5a were caused by stopping the peeling to change the graph paper. The drop in $V_r$ in Figure 5c near the 5-inch radius was caused by a temporary electrical disconnection.
Figure 6. Estimated forces on pressure bar when peeling 0.1-inch veneer. Knife angles labeled for each interval. Top, vertical force $V_b$; bottom, horizontal force $H_b$. 
Figure 7. Peeling 0.125-inch veneer with pressure bar using standard (Std) and microbeveled (Micro) knives. Top, vertical force $V_v$; bottom, horizontal force $H_h$. Peeling right to left.
Figure 8. Transient forces at start of peeling for 0.1-inch veneer. Top, vertical force $V_r$; bottom, horizontal force $H_r$. Peeling left to right.

Figure 9. Horizontal force $H_r$ and interference of bar and block for 0.1-inch veneer, Runs 1 to 4.