IMPROVING THE SAWING PROCESS BY MANAGEMENT OF STRESSES IN THE TOOL AND IN THE WOOD:

Three Case Histories

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Introduction:

An effective response to a difficult wood machining problem may require the integration of mechanical engineering, materials science, and statistics with the intuition of an observant saw doctor, the sustained attention of a dedicated quality control person, or an isolated finding from decades before. Here we will consider three examples of this process at work. Each case involved successful management of stresses in the tool or in the work piece:

I. Increasing feed rate in band sawing
II. Improving surface quality and process reliability in cross-cutting
III. Improving cutting accuracy and product value in circular sawing

I. Increasing feed rate in band sawing: managing stress imposed on the saw.
Analysis of a sawmill's product flow following an equipment upgrade revealed significant unused capacity, due to the constraint provided by a key band-sawing unit. In order to take advantage of the opportunity to increase production provided by the under-utilized downstream machines, the feed rate at the band saw would have to be increased by 30 percent.

The desire was to accomplish this change in a way such that there would be no increase in saw kerf, saw plate thickness, or lumber target size.

One approach to this problem is to attempt to maintain a constant ratio between sawing power and saw plate lateral stiffness – a ration called the "Load Index" by Klaasen – as the saw and the process are changed.

The cutting power required was calculated using the method of Allen, which represents specific horsepower as follows:

Specific Power (Power per unit of wood volume removed)
$= B_o$ x $t\_^{-o}$,

where t is the chip thickness and where B and _ are constants characteristic of the wood species under consideration. For green wood at chip thicknesses which are less than about 1.3mm, this expression may be replaced by one similar to

Specific Power = B_1 x (1-B_2 x t^{-1}),

which provides a transition to a more linear relationship between specific power and chip thickness as chip thickness diminishes, in accordance with Taylor's experimental results.

For Douglas fir and the particular operating parameters, a 30 percent increase in feed rate represented a calculated power increase of about 22 percent. If the Load Index approach is applied, the lateral stiffness of the band saw blade must be increased by the same factor of 1.22.

A band saw blade can be modeled as a rectangular plate upon which tensile stresses are imposed by an external "strain" system, which acts to force the top and bottom band wheels apart. Increasing the strain force increases the tensile stress along the lengthwise axis of the saw plate, which in turn increases the mechanical work which must be done to deflect the plate perpendicular to its plane.

Since saw plate thickness could not be increased, it was necessary to increase the level of tensile stress in the saw blade in order to achieve the required increase in stiffness. A calculation modeled on Porter's method estimated that the strain force would need to be elevated by 10.4 percent.

However, an obstacle presented itself as sawing tests were carried out under increasing levels of strain. The band saw steel's resistance to the formation of fatigue cracks was found not adequate to withstand the combined stresses due to strain load and the cyclic bending of the 1.47mm (.058") thick band as it traveled around the 72" diameter band wheels. An increase in strain of about 9.4 percent resulted in crack formation in the saw tooth gullets. At this strain level and with the higher feed rate, sawing accuracy did not match the prior level.

The problem was addressed in the following way: a band saw steel of higher strength, processed to severely restrict the size of non-metallic inclusions associated with fatigue crack formation, was used to make the test blades. The cyclic tensile bending stress, combined with the constant tensile stress due to the strain load, was within the design limit of the Sandvik Multishift grade which was selected. The band thickness was changed to 1.40mm (.055"), due to a different range of sizes in which this product is made. Calculation indicated that a strain load increase of about 13.3 percent was required with the slightly thinner steel.

Change in Band Saw
Operating Parameters

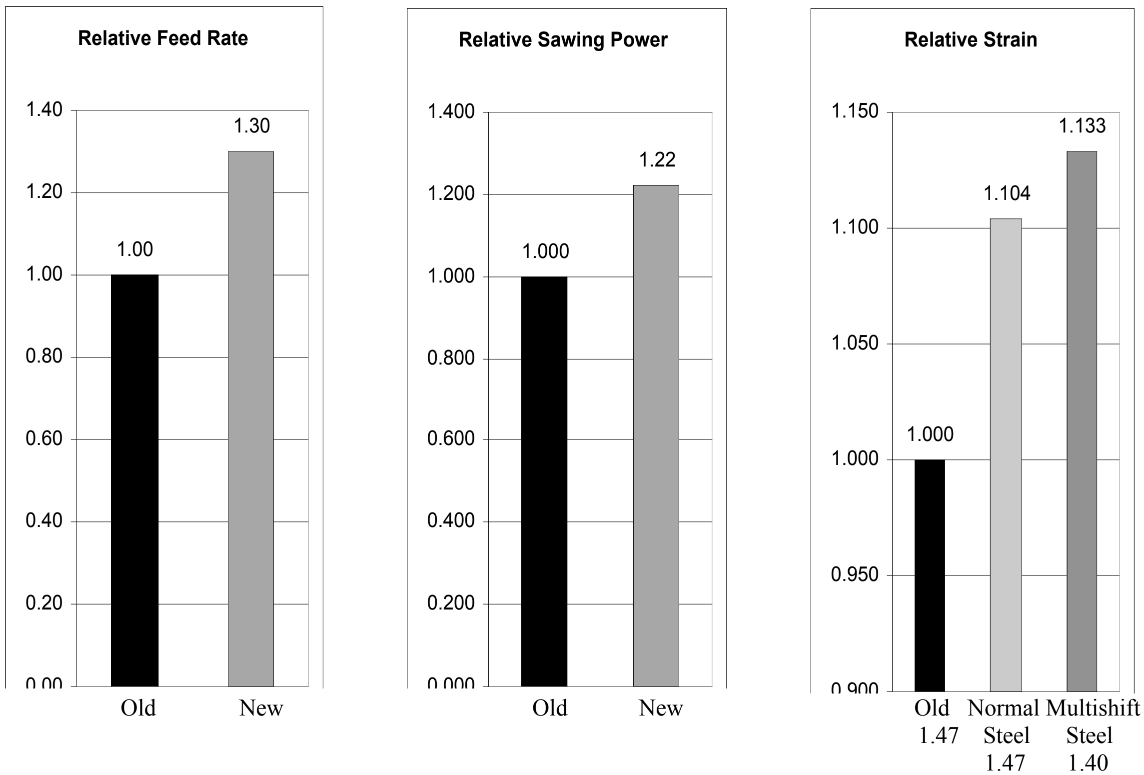

Figure 1

Multi-shift steel is more commonly used to increase saw run time, or to increase saw durability. In this case, the intent was to leave run time unchanged, but to subject the saw to a higher stress level over that period. There is another design factor associated with higher feed rates which is common to band and circular saws: the gullet area must be increased in proportion to the increased volume of sawdust which is produced by each tooth. If it is not, additional cutting power is required to overcome sawdust friction, which in turn introduces more heat into the saw plate and degrades sawing accuracy. In order to achieve crack-free performance, it was necessary for the saw maintenance staff to adhere to tooth grinding and finishing procedures which produced low levels of residual stress and appropriate surface morphology in the tooth gullets. In a typical gullet, the tensile stress present in the body of the saw may be magnified by a factor of three in the bottom of the gullets due to the effect of the gullets' curved profile. The Multishift grade provides resistance to formation of fatigue cracks. But if a crack is introduced, by grinding, for instance, failure which is characteristic of high strength steels will occur.

The combination of elevated tensile stress, material selection, gullet design, and maintenance technique resulted in successful implementation of the targeted level of production.

II. Improving surface quality and process reliability in cross-cutting: managing stress in the wood as it is being cut.

The growth in sales of lumber into the North American home improvement market – often directly to the homeowner - has caused producers who target that market to attach greater importance to the appearance of their product. When wood is cut at 90° to its fiber axis – as is the case when trimming lumber to its final length, or when removing knots in an optimizing cutoff saw - the principal sawing defect which is encountered as the saw teeth become dull is the emergence of jagged slivers of wood which are left protruding from the edge of the board. The severity of this problem determines when the process must be halted to change saws.

Crosscut saws or trim saws are usually robust saws with rather large kerf, since kerf loss is a minor concern in end-trimming applications. Emphasis is placed on the squareness of the cut and on the geometry of the cutting teeth in order to obtain cutting angles which will sever the wood fibers in a certain way, operating under the correct assumption that low cutting forces are desirable.

However, teeth with smaller included angles are subject to more rapid wear. In addition, they are more vulnerable to damage in operation – or from the grinding process which generated them. Teeth with hollow faces or hollow tops – features which effectively increase the angle of inclination of the cutting edge relative to the direction of the cutting path – present difficulties in re-sharpening, although they have been shown to provide increased time of operation between saw changes.

A senior manager from a large U.S. producer assigned one of its saw filers to address this problem. Consideration of the mechanism of sliver formation provided insight into how the process of sawing across the fiber axis could be improved. Observation of the trimmed ends of radiata pine and Douglas fir lumber revealed that the slivers are almost always formed from the darker, late wood portions of the annual rings. Since the specific gravity of the late wood zone of each ring is much greater than that of the early wood zone (about four times greater for Douglas fir), the strength and toughness of the late wood is significantly greater, as well.

As the saw tooth approaches the exit edge of the workpiece and begins to protrude through it, there remains a small beam of uncut wood. This beam, of roughly triangular cross section, is still attached at one (or both) ends to the original workpiece.

If the tooth has a square face –without bevels on its face or top surfaces – the unsevered beam is attached to the workpiece at both ends. If – as is usually the case for trim saws – the teeth are beveled, the uncut beam is attached at one end, and not at the other. The chips which are formed by a saw with alternate-top-beveled teeth are shown in Figure 2.

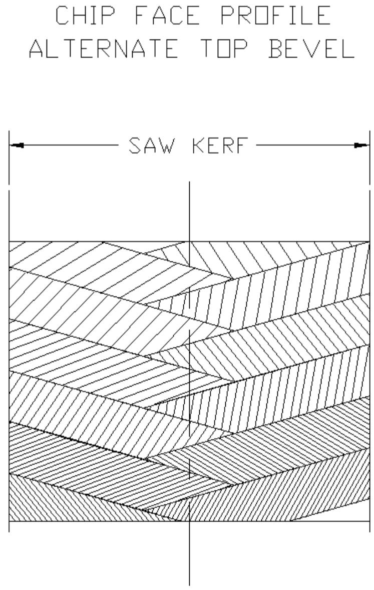

Figure 2

When the beam's attachment is severed by the tooth, a square clean edge is left behind on the end of the board. If, however, the load exerted against the beam exceeds a certain level, the beam will undergo bending failure at its point of attachment, and may swing away from the forces imposed on it by the approaching tooth, thereby evading the shearing action of the tooth's cutting edge as it passes by. The sliver is left behind, still attached to the wood.

For a classic uniformly loaded cantilever beam, the magnitude of the bending moment is proportional to the square of the length of the beam. If we are looking at the square tooth of a rip saw, the length of the beam is simply the saw kerf; in other words, the bending moment is proportional to the square of the kerf.

When a beveled tooth is sharp, its extended apex and associated knife edge pierce and slice their way through the wood fibers before the beam load and associated bending moment have become large. But as the tooth dulls, its apex (or point) retracts and the cutting edge becomes rounded. Severing of the wood fibers is delayed, while at the same time the face of the tooth forces itself against the tiny cantilever beam extended before it. The cross section – and moment of inertia – of the beam decreases as the tooth begins to exit the wood.

The result is that, after the dulling process has proceeded far enough, the beam – or sliver – fails in bending before it is cut free from the workpiece.

The dulling process is inevitable. We are concerned here with how to extend the saw's performance by managing the stresses in the wood which arise from the increasingly blunt saw tooth pushing against it.

The uncut beam length for a saw with square teeth is the width of the saw tooth. For a saw with a 15 degree top bevel, as is commonly employed for cross-cutting, the lengthwise profile of the beam is as shown in Figure 3. Due to the added effect of 10 degree rake and top clearance angles, the angle of inclination of the chip is 15.65 degrees.

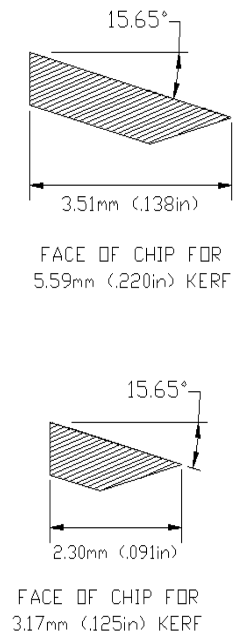

Figure 3

The expression for calculating the bending moment suggests that if the width of the tooth is reduced by a factor of 2, the bending moment is reduced by a factor of 4. The effect is similar for saws with beveled teeth, except the geometry is more complex.

Trim saws with reduced kerf were made for one sawmill on the Pacific coast of Oregon and for another in the northern interior of British Columbia. Both mills used carbide tipped saws with a 15° alternate top bevel and a 10° rake angle, with a kerf of .220", cutting 1.57" to 1.65" thick lumber. The saw kerf was reduced to .110" for the 22" diameter saws; and to .120" for the 23" saws. In order to retain saw rigidity, the 3 inch-wide portion of the saw plate extending through the wood was reduced in thickness from .150" to .085", while the remainder of the saw plate remained at the original thickness of .150".

Calculation of the uncut chip bending moment for the .110" kerf saw indicated that its magnitude was about one third of that for the .220" saw. The result was a greater than fourfold increase in saw operating time, a significantly greater improvement than was achieved with the original kerf combined with hollow face or hollow top geometries.

Tests are now underway in a radiata pine mill which is equipped to capture exact numbers of cuts made at every location in its multi-saw trimmer.

III. Improving Cutting Accuracy and Product Value in Circular Sawing: reducing grade loss in high value lumber from double arbor gang edgers, benefiting from increased saw plate stiffness under cutting loads; adapting board measurement and statistical analysis to predict changes in lumber value.

In a band saw, saw plate stiffness is increased significantly by imposing added tensile load through the band wheel support system. In a circular saw, there is no comparable opportunity to impart stiffness to the saw plate from an external source. The methods which have been attempted lack both the simplicity and the effectiveness of a band saw strain system.

Circular saws which are clamped between rigid collars can be stiffened by buttressing the plate thickness profile outside of the cutting zone and tapering the profile within it. These measures provide an increase in stiffness derived from the powerful cubic exponential effect of thickness, plus the opportunity to add more tensioning stresses to counteract the compressive hoop stresses induced by heat traveling radially inward from the teeth.

In saw mills, the guided spline arbor circular saw was developed around 1970. It is firmly established as the circular saw system which affords the best combination of volumetric yield - low kerf loss and high cutting accuracy – coupled with productivity and reliability. Almost every single arbor and double arbor gang sawing machine built today is of this design.

Stresses in the saw plate are controlled by managing the process heating which produces the radial thermal gradient which gives rise to the thermal expansion which induces the compressive stresses which lower the plate's lateral stiffness. Generation of heat is usually managed by proper selection of tooth geometry and scheduling of saw changes. Heat is extracted from the saw plate by application of cooling water.

There is an additional method for enhancing circular saw stiffness through management of in-plane thermal stresses. About five years ago it was discovered that stainless steel saw plates cut lumber more accurately than did standard alloy steel saws under the same operating conditions. In a guided, double arbor machine cutting 12" Douglas fir lumber with 19" diameter saws which were .085" thick, it was found that the average offset – or step - between surfaces cut by top arbor and bottom arbor saws was decreased by 35 percent. At the same time, recovery of the highest lumber grade, after planing, changed from 11 percent of all boards to 17 percent. This change was entirely due to reduction of the number of pieces whose offset exceeded the planing allowance.

For boards sawn on single arbor machines at a depth of about 6", measurements taken along the edge furthest from the saw guides showed a reduction in saw deflection (the difference between the thicknesses of top and bottom edges) close to 50 percent with respect to levels for alloy steel saws. The difference between the double arbor and single arbor results is explained by the added effect, in double arbor saws, of any displacement between the positions of the cutting planes of the top and bottom arbor saws. In other words, double arbor offset reflects both saw position and saw deflection.

The explanation for the behavior of stainless steel saws lies in the thermal properties of the saw plate material. Martensitic stainless steels exhibit the following differences with respect to the high strength alloy steels typically employed to make circular saws:

i) specific heat: 10 percent higher
ii) thermal conductivity: 30 percent lower
iii) thermal expansion: 15 percent lower

This array of properties exhibits a strong depressing effect on the magnitude of thermally-induced plate stresses, provided that the heat involved is that which is generated by formation of chips at the tooth tips and which then can be kept away from the body of the saw plate by the low conductivity. For this reason, good saw guide lubrication and cooling is critically important with a stainless steel saw.

In some saw mills in British Columbia, a portion of the lumber produced possesses characteristics – color, annual ring spacing, size and separation of knots – that command a price in Japan which far exceeds its highest value as construction material in North America. Interest in this class of product typically rises when commodity lumber prices are low and when exchange rates are favorable; when prices for the special grades may offer twice the revenue.

These products are usually sawn in double arbor gang edgers, in widths of 7.5" to 12". Lumber dimensions are extremely critical as well. The most valued grade is purchased as-sawn for further processing in Japan; it is rejected if the double arbor offset on one side exceeds 1.5mm (.059").

In a mill whose logs were especially suited for this product, (called "Gen Ban"), the quality control department was charged with tracking the percentage of lumber which was downgraded as a result of the presence of this manufacturing defect. Over an eleven-month period, 29.1 percent of 8" to 12" wide qualified boards were downgraded due to excessive sawing offset. Offset measurements were sampled – manually – by the same person over a period of several years, providing unusually reliable data. The saws used in this double arbor machine were 19" diameter, and .100" thick. These thicker saws are expected to be somewhat less sensitive to thermal stresses than are the .085" saws.

Sawmill management investigated the possible benefit of decreasing saw blade deflection with stainless steel saws. A question that arose was this: how does one estimate the effect of diminished offset on the percentage of boards which are rejected? How are sawing accuracy statistics related to lumber quality statistics?

When we graphically represent the distribution of lumber thickness measurements over a suitably long period, we expect to see the bell-shaped curve characteristic of normal distribution. It makes sense to say that, if each reading is partly the result of a lateral force acting against the resistance of the saw plate, that an increase in plate stiffness will have a corresponding effect on the location each point; i.e., if stiffness is doubled, then deflection decreases by half. The result is that the standard deviation is reduced by 50 percent of that part of the normal distribution of offset which is produced by saw deflection.

Double arbor offset (or step) measurements, which may be regarded as possessing neither positive nor negative sign, can be represented by a single sided normal distribution. From a table, or from integration of the probability density function, one can estimate how a particular shift in offset values will affect the size of the population which lies beyond a certain value.

When stainless steel saws were put into service, the percentage of rejected boards dropped to 11.9 percent (Figure 4). What was the relationship between the change in sawing accuracy and the associated change in the distribution of product quality? Sawing accuracy measurements allow us to determine the probability that a particular measurement will lie outside a selected value. If we reduce the average offset values by one third, we can infer that the percentage of board surfaces with offset beyond a specified value can be estimated by shifting the number of standard deviations which correspond to the original percentage by a factor of [1/(1- _)] = 1.5. A much smaller percentage of the board population will lie beyond a particular offset value if that value now represents 1.5 x the original number of standard deviations.

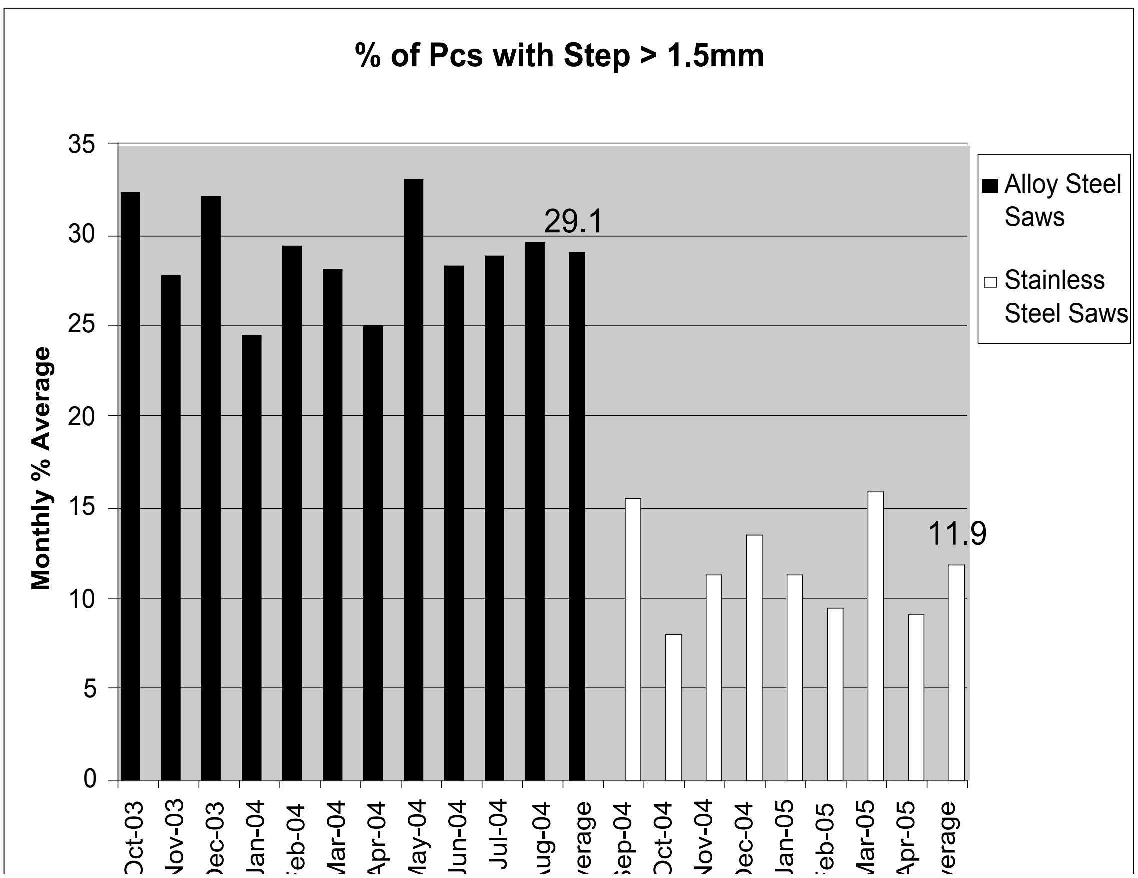

Figure 4

But, since each board contains two such surfaces, generated independently, there are three possible offset quality outcomes:

1. two sides are good,
2. one side is good and one side is bad,
3. two sides are bad

Measurements of the change in average offset inform us of the change in the probability that one side will be bad. However, there is a probability that some boards will have two bad sides.

If the presence of one bad side causes downgrade, then the number of pieces which are downgraded will be the total of those with one bad side plus those with two bad sides.

The probabilities P of these outcomes are related as follows:

1) P(2 good sides) = P(1 good side) x P(1 good side)
= 1 - P(1 or 2 bad sides)

2) P(1 bad side) = 1 - P(1 good side)
= 1 – [1 – P(1or 2 bad sides)]$^{-}$

If we know the percentage of downgraded boards, we are able to estimate the probability that a particular surface exhibits offset beyond the limit. Conversely, if we know the improvement in offset measurements, we can estimate the influence of that improvement upon the grade distribution.

We use the equation (2) above to convert the single-sided standardized normal distributions of offset size to the single-sided standardized normal distribution for sawing variation as represented by double arbor offset. The probability of offset on one side being less than .059” for alloy steel saws is 1 – (1-.2908)$^{-}$ = .158; for stainless steel saws, 1 – (1-.1185)$^{-}$ = .0611.

The change in the offset distribution which is required to account for this change in the quality distribution is as follows: the number of standard deviations represented by a .059” offset increased from 1.25 standard deviations to 1.90 standard deviations, which represents a reduction in offset of 34 percent. In summary, a 34 percent improvement in sawing accuracy decreased the level of downgrading from 29.1 percent to 11.9 percent.

Stainless steel saws cut more accurately than alloy steel saws. In addition, we can estimate the gain in lumber value that is derived from an improvement in sawing accuracy.

Summary:

These case histories demonstrate how the management of tension stresses in band saws, uncut chip bending stresses in circular end-trimming saws, and thermal stresses in guided double arbor circular saws can be directed to improve process speed, process reliability, and product value.

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