Toward Sharper Saws, Straighter Cuts, Higher Recovery: Managing the Process and Measuring the Results

Warren M. Bird
California Saw & Knife Works
San Francisco, California
October, 2003

www.calsaw.com

INTRODUCTION

In the ongoing pursuit of saws that never become dull, the most significant development may be the emergence of a strikingly simple idea: that strategic manipulation of basic parameters like run time and maintenance protocol could be the most effective method of keeping saws sharp and recovery high. More valuable than any new technological innovation is the opportunity afforded by making better use of what is already known and available. The sawmillers who arguably have advanced the art the furthest have reached that level not through the use of secret or novel technology, but by first understanding and then managing the sawing process.

A host of products and machinery – and recommendations for how to use them – are promoted as improving sawing performance for both primary and secondary manufacturers of wood products. The potential user, in order to sift through and make sense of the claims presented, must have an understanding of the dominant factors that determine saw performance. This knowledge of physical principles is crucial even to make a valid preliminary evaluation. In other words, it can provide an answer to the question: Is there a legitimate reason to expect greater accuracy, recovery, or production from this strategy or tool?

The next challenge to arise, once a new product or procedure is put into service, is proper evaluation of the magnitude of the change – positive, negative, or negligible -- that it brings. In general, the most important benefits are those that affect product value or yield. We rely on established quality control methods to determine the changes in sawing accuracy that might allow us to improve grade recovery, reduce saw kerf, or increase throughput. However, the standard statistical analysis of board size is based on assumptions that may not apply to guided, spline arbor saws operating in gang edgers. Instead, a functional analysis, which better reflects the sources of inaccuracy in the sawing process, can be used to greater benefit.

SAWING VARIATION: FORCE AND STIFFNESS

Band and circular saws can be regarded as flexible steel plates that are subjected to force and heat at their cutting teeth. They differ in their shape, and in how and where they are held in position. In the case of a guided, spline arbor circular saw, a pair of guide pads on either side of the plate maintains the saw's location. As a circular saw generates chips, the process of cutting imposes tangential and radial forces at each tooth in turn as it passes through the wood. At the same time, variability in wood properties and asymmetries in the tooth shape and sharpness produce lateral forces.

The lateral tooth forces, which are resisted by the elastic stiffness of the saw plate, cause the saw to deflect and cut outside of its intended path.

Sawing accuracy is improved by decreasing lateral forces and increasing elastic stiffness; conversely, it is worsened by increasing lateral forces or by decreasing elastic stiffness. Most problems involving sawing accuracy can be resolved into this static model.

Heat is generated at the teeth during cutting. The rate of heat generation is related to sawing power, or the rate at which mechanical work is done against the cutting forces. The heat is conducted into the outer zone of the saw plate, which then becomes warmer and expands relative to the cooler inner zone. The presence of compressive thermal stresses in the warmer outer zone of the saw plate lowers the plate's lateral stiffness, contributing further to saw deflection.

The principal factors that can alter the tangential and radial cutting forces, and saw heating, are:

1. **Tooth width**, or nominal saw kerf. Cutting force is directly proportional to tooth width. If saw kerf can be lowered by ten percent by reducing unnecessary side clearance, then cutting force and plate heating will be lowered by ten percent as well.
2. **Rake or hook angle**. Kivimaa's research more than half a century ago demonstrated the strong dependence of cutting force on rake angle. In the region of the commonly used 30° angle, cutting forces change markedly with rake angle, increasing about 50% as the angle drops toward 20° and decreasing about 25% toward 40°. Top bevels of various types also reduce cutting force.
3. **Saw sharpness**. Dull saw teeth generate higher cutting forces and more heat. The state of tool sharpness at any particular point in time is a function of:
   i) initial tooth sharpness;
   ii) how much cutting the saw has performed;
   iii) how well abrasive foreign material has been removed from the workpiece before sawing.
4. **Feed rate**. An increase in the feed rate, in general, produces greater cutting forces, requires more power, and generates more heat. A further consequence can be over-filling of the tooth gullets with sawdust, which may be associated with added force and heat.

The factors that introduce lateral cutting forces include those that make the workpiece non-uniform, such as knots, sloped grain, and heartwood-sapwood boundaries. The effects of these factors are more or less random. However, a second group of factors, the common irregularities or errors that occur in grinding the shape of the saw teeth, introduces a more stable force component that is perpendicular to the plane of the plate. These factors include:

1. **Uneven side clearance**. The tooth is ground so that it projects farther from one side of the saw plate than from the other.
2. **Uneven radial or tangential clearance angles**. The tooth is ground so that these angles differ from one side of the plate to the other.

Non-random tooth asymmetry forces a saw to cut predominantly toward one side, the magnitude increasing with projection beyond the saw guide, producing boards of uniformly wedge-shaped cross-section in single arbor machines, or boards with offset or mismatch in double arbor machines.

Saw stiffness is governed by the following factors:

1. **Plate thickness**. This is the dominant factor in determining saw plate lateral stiffness. Specifically, stiffness is proportional to the cube of the thickness. When we take into account that the ability of the plate to conduct heat diminishes with thickness, its role is magnified.

Two other factors that exert an influence on lateral plate stiffness are those which affect the plate's response to peripheral heating:

2. **Tension**. The in-plane tensile stresses induced by tensioning the saw plate act to counter the compressive stresses induced by a radial temperature gradient.
3. **Material properties**. Saw plate materials with different thermal conductivity, specific heat, and thermal expansion may exhibit significantly different lateral stiffness when subjected to the same heat input. Saw steel alloys are also subject to moderately high rates of stress relaxation, the naturally occurring reduction of internal stresses over time. It is therefore critical that thin saws be manufactured in such a way that saw flatness does not depend on the introduction of high local stresses, the magnitudes of which continually decline.

Usually, we desire either to decrease saw kerf or to increase feed rates without loss of cutting accuracy. It is impossible to achieve these goals without making corresponding changes in tool or process parameters that act to maintain the proper balance between lateral forces and saw stiffness.

Keys to the operation of saws at the optimal limits of kerf and accuracy are:

- Eliminate unnecessary side clearance of saw teeth.
- Determine the hook angle that provides the desired balance of cutting force with adequate edge durability.
- Manage saw sharpness: determine the relationship between run time and board thickness variation, and select operating time accordingly.
- Monitor debarker performance.
- Measure the effect of feed rate change on sawing variation.
- Monitor sharpness and clearance angles on new saws and on saws that have been resharpened, in order to ensure that sharpness and clearance angles remain consistent across the tooth and correct over time.
- Maintain guide cooling and lubrication

EVALUATING GUIDED SAW PERFORMANCE

We may fail to take advantage of new developments, or to recognize problems, because we do not properly understand the overarching factors that affect saw performance. We may use quality control procedures that are not adapted to revealing the sources of sawing inaccuracy. What is required is a functional, common sense approach to board measurement and analysis that facilitates problem solving. By monitoring workpiece size while tracking the way in which the sawing system introduces inaccuracies, we are able to specifically identify and address the causes of resolvable quality variations.

The standard approach to monitoring lumber sizes is a statistical analysis based on the assumption that one can combine measurements from both edges of the board, and that overall sawing variation can be resolved into two components:

1. **Between board variation**, produced by variation in saw position or saw kerf.
2. **Within board variation**, produced by saw bending or vibration.

In other words, the assumption is that lumber size varies because of the superposition of saw position variation and variation due to saw vibration and bending. Assuming a normal distribution of thickness measurements, standard deviations are calculated for between board, within board, and total sawing variations.

Guided saw operation, however, does not conform to this model of board size variation. Although there is random variation present along both edges, observation of boards cut by guided saws in a single arbor gang edger reveals a dominant pattern of sawing inaccuracy: consistent and accurate board thickness at the edge closest to the guide, and a wedging effect, caused by the saw's tendency to bend to one side or the other, toward the board's far edge. This wedging effect is minimal at the board's leading end, and increases along the length of the cut as the saw plate gathers heat. Boards cut by guided saws in a double arbor gang edger display a related pattern of inaccuracies -- known as mismatch or offset -- caused by saws independently wedging from each edge of the board toward its center, where top and bottom saws overlap.

Board thickness measurements were taken at a sawmill using a bottom arbor gang edger. Two types of saw were tested simultaneously; all other parameters were held equal. By graphing top and bottom edge measurements separately, we can identify the type and magnitude of sawing inaccuracy that occurs and draw useful comparisons between the two saw types. An equivalent analysis of double arbor gang edger performance would include, in addition to graphs of edge width, graphs of offset height. In fact, the worst misuse or corruption of statistical quality control in sawing is the determination of double arbor sawing accuracy by measuring only the top and bottom edges of the board.

Two histograms were created from the same data set. As is consistent with a traditional board size analysis, top and bottom edge measurements were graphed together for each saw type. In this presentation, the magnitude of the difference between the two saw types is minimized or disguised, as are the sources of cutting inaccuracy and the number of boards with at least one edge sufficiently undersize to result in loss of value.

Arithmetic means and standard deviations calculated for the distribution of board thickness values illustrate the difficulty of assessing guided saw performance with standard board size analysis. Tables 1 and 2 summarize this problem.

Table 1: Saw Type A

	Mean thickness	Standard deviation
Top edge	0.643	0.031
Bottom edge	0.652	0.006
All measurements	0.648	0.023

Table 2: Saw Type B

	Mean thickness	Standard deviation
Top edge	0.660	0.010
Bottom edge	0.655	0.005
All measurements	0.658	0.008

We can draw three conclusions:

1. In a small sample of boards, the bottom edge mean is the only reliable indicator of saw position and kerf variability. The reason is that wedging effects may distort the top and combined mean values, although in a large group of boards thick and thin measurements will tend to cancel each other.
2. The thickness variation about which we need to be concerned is along the top edge, the edge most distant from the guide. Planer skip, if it occurs, will be seen along the top edge of the board. Total sawing variation combines accurate bottom and inaccurate top measurements, and therefore provides an inadequate picture of sawing performance: it fails to alert us to the magnitude of the value lost due to boards that are undersize along one edge. It understates both the magnitude of an existing problem or the effects – positive or negative – of changes in operating parameters or equipment. For example, Saw A's top edge Saw B's by .021". If we refer to the total standard deviation, the difference drops to .015", a discrepancy that could lead to an erroneous calculation of a new target size or an underestimate of degrade.
3. For bottom arbor spline arbor saws with a single guide, it is useful to associate bottom edge variation with traditional between board variation, and to associate top edge variation with traditional total sawing variation. The inverse applies to top arbor spline arbor saws.

Similarly, in double arbor machines one can gain useful knowledge of sawing accuracy only by measuring the magnitude of the offset generated by top arbor and bottom arbor saws.

CONCLUSION

Looking at the sawmills that have enjoyed the greatest advances in sawing performance, it becomes apparent that the technology they employ is the same as that available to the worldwide wood products industry. The gap between their achievements and those of similarly equipped mills generating like products is not the result of novel technology. Instead, it springs from the recognition of -- and the commitment to capture -- the enormous benefits that lie in measuring, controlling, and optimizing the fundamental aspects of the sawing process.