

Machining

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Introduction

Wood machining can be defined as the application of energy to sever the workpiece at a chosen internal surface. The purpose of wood machining is to produce a desired shape and dimension with requisite accuracy and surface quality in the most economical way. Major developmental trends in wood machining involve: attempts to reduce material losses in both the machined material and the cutting tools; improvement of the quality of machined products by attaining necessary accuracy of shape and dimensions as well as surface quality of the workpiece; increasing production output and minimizing cost; improvement of worker safety by machine guarding; and controlling generation of noise and dust.

Machining processes in the manufacture of wood products may be classified as follows: sawing; peeling and slicing; planing, molding, shaping, and routing; turning and boring; sanding; and nontraditional machining processes such as cutting with laser beam and high-energy liquid jet.

Wood as a Material to be Cut

Wood is anisotropic and a heterogeneous material. The structural nature of wood, in terms of its three-dimensional properties, is very important in wood machining, particularly the relationship between the strength of wood parallel and perpendicular to the grain. As indicated in **Figure 1**, the cutting force of birch wood is about two to four times as high across grain as along it.

Wood strength and cutting resistance are dependent on specific gravity, moisture content, and temperature during processing as well as growth-related characteristics of wood such as spiral or interlocked grain, presence of knots, growth stresses, reaction wood, and drying stresses.

Sawing Technology

Sawing is the most important frequent cutting process. Sawing machines are classified according to the basic machine design; that is, sash gang saws (reciprocating, multiple blade frame saws), circular saws, band saws, and chain saws. Circular saws are designated rip saws if they are designed to cut solid wood along the grain,

as bucking or trim saws if they are designed to cut across the grain, or as combination saws if designed to cut along and across the grain, as well as at a certain angle to the grain (e.g., miter saws). Sawing machines are further classified according to their use. For example, a bucking saw is used for cutting logs to length, a headrig for primary log breakdown, a resaw for resawing cants into boards, an edger for edging boards, a trimmer for cutting boards to length, table saws for rip sawing and crosscutting of solid wood, panel saws for cutting plywood, fiberboards and particleboards, and a scroll saw for general-purpose cutting of intricate patterns.

In general, saw blades are made from cold-rolled, hardened, and tempered steel. For band saws a high carbon content, nickel-alloyed saw steel has been used in most cases (e.g., Uddeholm Steel UHB 15N₂O:0.75% C and 2.0% Ni). Other saw steel alloys may contain manganese, chromium, and vanadium. With the gradual transition from swaged saw teeth to Stellite-tipped saws, saw blade manufacturers such as Uddeholm and Sandvik have developed special band saw steels. The Uddeholm ANKAR-R steel, formulated for Stellite tipping, has improved stability of tensioning stresses, welding properties, and mechanical strength. The Sandvik Multishift steel increased fatigue resistance and the capacity to operate at higher strain rates.

Circular saw blades made from stainless steel were recently introduced by California Saw and Knife Works to bring under control the problems associated with corrosion-initiated material loss in guided saws. Other benefits are attributed to thermal and mechanical properties which make stainless-steel saws stiffer when cutting, and which allow them better to retain their original flatness compared to saws made from alloy saw steels.

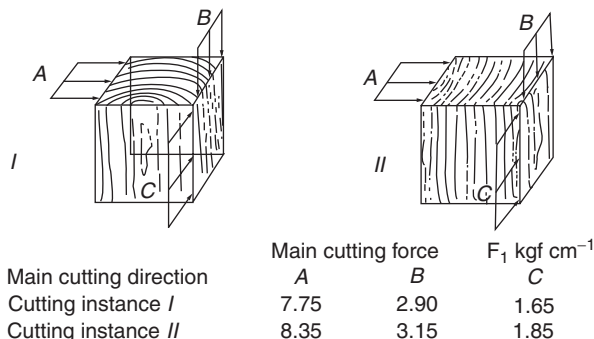


Figure 1 Schematic illustration of main cutting directions in respect to the annual rings and values of the main cutting force obtained with a work-sharp normal knife and 0.1mm chip thickness. The specific gravity of the birch used for the tests is 0.64 and moisture content 12%.

Circular saws typically range from 1.0 to 5.0 mm in thickness and from 150 to 1800 mm in diameter. The thickness of a bandsaw may range from 0.4 to 2.1 mm. Bandsaw width ranges from 60 to 360 mm for saws used in lumber manufacturing, and 6 to 50 mm for the narrow bandsaws used in furniture manufacturing and for portable sawing machines. As a rule, the saw blade thickness should not exceed 0.1% of the wheel diameter, and the bandsaw width should not be greater than wheel width plus gullet depth and an additional 5 mm. The typical sash gang saws used for primary wood processing are 2.0 mm in thickness and approximately 175 mm in width.

Saws vary considerably with regard to tooth and gullet design. The primary design considerations include tooth strength and gullet loading capacity, the function of the gullet being sawdust removal. Other important factors are tooth wear and noise generation. The typical bandsaw tooth geometry is described by specifying rake and clearance angle as depicted in **Figure 2**. If the saw tooth has a face and/or top bevel, those angles should also be specified. The optimum tooth geometry, as determined from the measurement of cutting forces and power requirements, mainly depends upon cutting direction, wood species, density, and moisture content. Tooth geometry may vary considerably: for example, the rake angle for crosscut circular saws ranges from $+10^\circ$ to -30° . In the case of circular rip saws and band saws, the rake angle will vary from 10° for high-density hardwoods to 30° for softwood species. The top clearance angle may range from 8° for dense hardwoods to approximately 10° for softwoods. Many sawmills in the USA and Canada are currently using variable sawtooth spacing in order to reduce the problem of 'washboarding' during sawing.

The side clearance for wide bandsaws, which is required to reduce friction between the saw blade and generated surface, may range from 0.30 to 0.35 mm for hardwoods and from 0.50 to 0.60 mm for softwoods. Certain specialty circular saws such as

miter saws can be tapered (hollow ground) to provide side clearance.

The purpose of tipping saw teeth with hard alloys is to increase their wear resistance, which prolongs the useful life of the blade. Most bandsaws are Stellite-tipped, while circular saws in addition to Stellite are tipped with tungsten carbide and polycrystalline diamond (PCD) tips. Optimizing the relationship between the saw-tipping material properties and the cutting edge geometry is a precondition for high performance of circular and bandsaws.

Each single tooth will remove a certain volume of wood given by the feed per tooth and the cutting height. This volume should correspond to the chosen gullet capacity $V=0.5 A$ up to $0.75 A$. The feed per tooth t is given by $t=p (F/C)$ where p is the pitch (mm), F is the feed rate (m min^{-1}), and C is the cutting speed (m min^{-1}). The average blade velocity C is about 3000 m min^{-1} .

The use of thin-kerf circular saws (thickness of cut 3 mm or less) has proved to be very beneficial to industry in the reduction of kerf losses, as long as saw stability is maintained. One of the principal manifestations of circular-saw instability is standing-wave resonance. The rotation speed, at which a standing wave is formed, is called the critical speed. All in-plane or membrane stresses (i.e., stresses due to temperature gradients, rotation, cutting forces, and tensioning or prestressing) shift the saw natural frequencies and alter its critical speed accordingly. Computer programs such as CSAW are available for estimating the critical speed of circular saws based on design and operation variables. The operating speed, for saws clamped in the center, should be at least 15% below their critical speed. The sawing accuracy improves with the increase of the critical speed margin. In the case of bandsaws, currently available computer programs can be used to evaluate bandsaw design relative to band vibration and stability. The effective stiffness and stability of circular saws can be increased by introducing radial slots, by prestressing or tensioning, by using guiding systems, by online cooling near the cutting edge, and by heating near the center (i.e., thermal tensioning). Radial slots in circular saws reduce compression hoop stresses at the saw periphery due to temperature gradients, introduce asymmetry into the saw-blade design and consequently reduce transverse vibration and reduce noise. The application of various guiding systems in conjunction with the use of splined-arbor saws, which can float on the arbor, is a common and particularly effective method used for stability control of thin-kerf circular saws. Most sawmills in North America resaw cants with spline arbor saw blades with fluid-lubricated guides which generally work

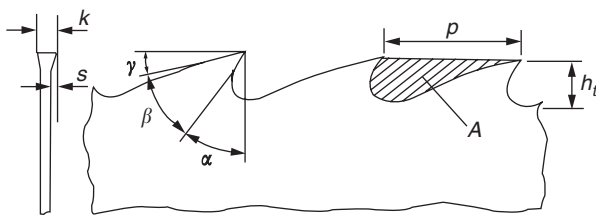


Figure 2 Bandsaw tooth geometry. α , rake or hook angle; p , pitch or tooth spacing; β , sharpness angle; h_b , depth of gullet or tooth height; γ , clearance angle; A , gullet area; k , kerf width (theoretical); s , side-clearance. Reproduced with permission from *The Wood Bandsaw Blade Manual* (1993), Uddeholm Strip Steel AB, Munkfors, Sweden.

better than clamped saws. Circular saw guides serve to position the saw blade relative to the workpiece, to lubricate and cool the saw blade, to stiffen the saw blade against the transverse forces generated during sawing, and to dampen saw vibrations. This sawing system allows the use of thin saw blades having a kerf width as small as 1.8 mm at a cutting depth of 140 mm and feed rate of 30 m min^{-1} .

In the case of bandsaws, in addition to prestressing and the use of saw-guiding systems, the type of straining mechanism for providing axial tension and its response will significantly affect saw stability and consequently sawing accuracy. The saw blade must operate under maximum applied tension force, consistent with the endurance strength of the saw blade material, in order to maximize stiffness and critical edge-buckling load.

The general practice in the industry has been to select saws on the basis of past experience or by an expensive trial-and-error process. Due to extensive research on saw dynamics, however, it is now possible to design both circular and bandsaws on the basis of sound engineering principles.

Regardless of the operating conditions, the stress level in saw blades must be kept constant. The online control of circular and bandsaw stability basically consists of either modifying the forces exciting the blade or altering the effective saw-blade stiffness and damping to reduce vibration. This can be achieved, for example, by online thermal tensioning of circular saws, i.e., introduction of thermal stresses beneficial to saw stability. At present, the trend is to use online monitoring of bandsaw displacements and measurement of sawing accuracy, and online control of feed speed.

Veneer Peeling and Slicing

Rotary cutting (peeling) and slicing of wood are used in the manufacture of veneer. At least 95% of veneer is produced by peeling, for which a veneer lathe is used, and about 5% by slicing, for which a horizontal or vertical slicer is used. The primary components of any lathe or slicer are the knife and pressure flat nose bar or powered roller nose bar. They are similar in both machines and perform the same function. The cross-section of a typical lathe presented in Figure 3 illustrates the position of the knife and the pressure nose bar. The most common knife thickness for a lathe is 16 mm, and, for the face veneer slicer, 15–19 mm. The knife's Rockwell hardness on the C scale may vary from 56 to 60.

While the knife severs the veneer from the bolt or flitch, the pressure nose bar compresses the wood and thus reduces splitting of wood ahead of the knife.

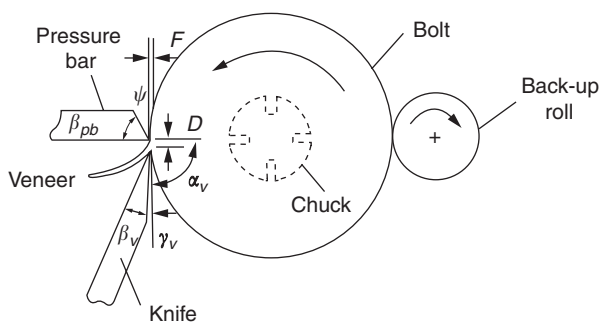


Figure 3 Cross-section of a veneer lathe with fixed pressure bar. α_v , knife angle; β_v , knife bevel angle; γ_v , clearance angle; D , lead or vertical gap; β_{pb} , pressure-bar bevel angle; ψ , pressure-bar compression angle; F , gap (horizontal gap).

The amount of compression depends on wood density and will vary from species to species. For Douglas-fir, it is about 15% of the veneer thickness; for western white spruce about 8%. In both lathe and slicer, the wood compression is important in controlling roughness, depth of checks, and thickness of the veneer. The slicer has a fixed nose bar while the lathe may have either a fixed nose bar or a rotating roller bar. The flitch on a slicer is backed by the flitch table while support for a veneer bolt may be provided by a powered back-up roll on a veneer lathe. Full-length powered back-up rolls reduce spin-outs, and prevent the bolt from flexing during peeling. For maximum yield of rotary peeled veneer it is essential that bolts are chucked in the geometric center. Laser scanning and computerized centering systems are currently used with modern X-Y lathe chargers, which allow determination of chucking centers for best yield of each individual block. Other developments in veneer manufacturing equipment include high-speed veneer lathes having spindle speeds of 500 rpm and over, digital carriage drive which eliminates the mechanical clutch assembly, hydraulic powered back-up rolls, and dual hydraulic spindles.

The production of high-quality veneer requires proper pretreatment of the wood prior to cutting. This is done by heating green wood in water or steam. Heating wood above 50°C makes it more plastic and reduces veneer checking during peeling or slicing. The recommended peeling temperature ranges from 50° to 90°C and will vary with the average specific gravity of the species.

Planing, Molding, Shaping, and Routing

Planing refers to the peripheral milling of wood. Its purpose is to smooth one or more surfaces of the workpiece and at the same time bring the workpiece to some predetermined dimension. The machinery used for planing operations includes: (1) surfacers

designed to smooth one or two sides of the workpiece and reduce it to a predetermined thickness; and (2) planers and matchers defined as double surfacers which are further equipped with two opposed profile side heads that can simultaneously machine the two edges to the desired pattern or profile.

The molding operation aims to machine lumber into forms of various cross-sectional shapes, such as picture-frame moldings. Both planing and molding machines employ rotating cutterheads. By definition, a molder differs from a planer in that the molder side heads are staggered instead of directly opposed. The typical operating speed for multiknife cutter heads ranges from 3600 to 6000 rpm. The number of spindles may range from one to 10. Molding machines can be equipped with variable feed rate typically ranging from 6 to 60 m min^{-1} .

Shaping involves machining an edge profile or edge pattern on the side and/or periphery of a workpiece. The basic types of shapers include single and double spindle shapers, double head automatic shaper, and center profiler. The shaper spindle speeds range from 7200 to 10 000 rpm.

Routing is similar to the shaping operation. While a shaper always shapes the periphery, a router is used to make a variety of cuts such as mortises, irregularly shaped holes, and three-dimensional plunge cuts using computer numerical control (CNC). Most router spindle speeds are from 10 000 to 30 000 rpm, depending on the diameter of the cutter. When machining abrasive composite wood products, there is a trend to use PCD cutting tools in routing and shaping operations.

In all three operations, it is of prime importance to adjust the operating conditions and knife geometry so that machining defects are minimized. The most commonly encountered defects are torn or fuzzy grain, raised and loosened grain, and chip marks. These defects are caused by improper cutting angles, chip thickness which is too large, dull knives, low-density species, and often the presence of reaction wood. In the case where the torn-grain defect is highly probable, the most important variable is the number of marks per centimeter or inch (reciprocal of the feed per cutter). The marks per centimeter should be between three and five for rough planing operations and between five and six for finishing cuts. The clearance angle should in all cases exceed a value of 10° . The optimum cutting angle (angle between the knife face or knife bevel and a radius of the cutter head) lies between 20° and 30° for most planing situations; however, in the cases of interlocked or wavy grain, it may be necessary to reduce the cutting angle to 15° or even 10° .

Turning and Boring

Turning of wood is a machining process for generating cylindrical forms by removing wood, usually with a single-point cutting tool. The turning machines include single- and multiple-spindle lathes. The tools used for turning on the lathe perform operations primarily directed to machining the outer surfaces of the workpiece. From practical experience and experimental investigations, lathe clearance angles between 12° and 18° offer optimum cutting conditions. In practice, a lip or wedge angle between 20° and 30° is recommended for softwoods, the wedge angle corresponding to the sharpness angle in the case of saw teeth and to the knife bevel angle in the case of a veneer knife. For hardwoods, wedge angles between 50° and 60° are recommended. The quality of surfaces of most turned-wood articles is of the utmost importance, for example, for tool handles. The roughness perpendicular to the grain increases with the feed speed. The specific pressure of the tool on the turned surface also has a remarkable influence on the roughness.

Most machines which will perform turning operations can also perform boring operations, although machines are available which will perform boring, drilling, and other related operations. Boring machines can have many configurations, ranging from the simple vertical single-spindle boring machine to complex transfer machines involving multiple vertical, horizontal, and angular spindles. There are many specialized boring-bit designs in use. The common bit types include: (1) double-spur, double-lip solid-center bit on which the spurs cut ahead of the lips; (2) double-spur, double-twist bit on which the spurs cut after the lips; and (3) twist drill. The first is a fast-boring general-purpose bit; the second bit is particularly suited for boring to extreme depth. The twist drill is frequently used on machine boring equipment for drilling in end grain and for boring dowel holes. The quality of finish produced by a twist drill may be inferior to that produced by a bit equipped with spurs.

Sanding Technology

Sanding is the abrasive machining of wood surfaces to obtain a smooth surface quality. The abrasive tool consists of a backing material to which abrasive grains are bonded by an adhesive coat. The abrasive or sanding tool is specified by the sanding and backing materials. Sanding materials vary according to type, size, and form of grain. Typical abrasive materials for wood-working applications are garnet, aluminum oxide, and silicon carbide. Garnet is the most commonly used because of its low cost and acceptable working qualities. It is used with all types

of machines for sanding softwoods. Aluminum oxide abrasives are used extensively for sanding hardwood, particleboard, and hardboard. Silicon carbide abrasive is used for sanding and polishing between coating operations and for sanding softwoods where the removal of raised fibers is a problem. The size of the abrasive particles is specified by the mesh number (i.e., the approximate number of openings per linear inch in the screen through which particles will pass); mesh numbers range from about 600 to 12.

Backing materials vary according to the strength, flexibility, and required spacing of the sanding tool and are made of paper, cotton, or polyester cloth, or cloth-paper combinations. Bonding materials are generally animal glues, urea resins, or phenolic resins. The choice of these materials depends upon the required flexibility of the tool and the work rate required of the tool. Animal-glue bonds are the most flexible, whereas resin bonds are harder, more moisture- and heat-resistant, and have superior grain retention.

Sanding machines include multiple-drum sanders, wide-belt sanders, automatic-stroke sanders, and contact wheel disk sanders. The drum sander is probably the oldest of all the wood-working machines using coated abrasive, and it is used in solid-wood furniture manufacturing.

The drum sanding machine is used following the planer or veneer press. Multiple-drum sanders are of the endless-bed or roll-feed type and have from two to six drums. The abrasive is usually a heavy paper-backed aluminum oxide product. In very heavy sanding operations, a fiber-backed abrasive is recommended. A sequence of 60, 80, and 100 mesh abrasive is frequently used on a three-drum endless-bed sander.

Wide-belt sanders use an abrasive belt at least 30 cm wide and are commonly used on panels (plywood, particleboard, hardboard). Silicon carbide is normally used as the abrasive. They have higher production rates and greater accuracy than multiple-drum sanders.

Heavy-duty high-speed (up to 600 m min^{-1} feed rate) wide-belt sanders are called abrasive planers when used for dimensioning and surfacing. Abrasive planers are used for dimensioning of accurately sawn, kiln-dried lumber, plywood and particleboard, and for furniture production. In comparison with the knife planer, the abrasive planer has in general higher production rates, a lower noise level, and virtually no machining defects. New developments in wide-belt sanding include the use of antistatic belts and sanding with aerostatic (air cushion) supported belts. It is critical when using sanders and abrasive planes to have an adequate dust removal system.

Surface finish during the sanding process is for the most part independent of pressure and cutting speed. The optimum belt speed as determined by the specific

quantities of abrasion is about 30 m s^{-1} for particle size 60 and slightly less than 30 m s^{-1} for particle size 120.

Automatic-stroke sanders use a narrow abrasive belt and a reciprocating shoe which creates contact between the abrasive and the workpiece. This sanding machine is commonly used in furniture plants for final sanding operations and touch-up sanding.

The contact-wheel sander also uses a narrow abrasive belt. Contact wheels normally range from 150 to 350 mm in diameter. A typical application is the sanding head on an edge banding machine where the edging tape is given a finish after application to the board. Cloth belts are usually preferred because of their durability.

The disk sander consists of a revolving back plate to which a coated abrasive disk of paper or cloth is attached by an adhesive. It usually incorporates a tilting action for angle or miter sanding. The major disadvantage of this method is a pattern of circular scratches which have to be removed by other means before finishing.

Nontraditional Machining Processes

Various new cutting techniques have been investigated during the last 40 years for possible use in the wood industry in an effort to reduce or eliminate kerf losses. These include the laser beam and the high-energy water jet. Major advantages of a laser beam and water jet include the ability to cut intricate patterns, high cutting accuracy, and the possibility of numerical control.

A wide variety of materials can be cut using a continuous carbon dioxide laser. The laser beam produces a very narrow kerf, in most cases approximately 1 mm. The major disadvantages of cutting wood and wood-based panels with the laser are low feed rate, resulting in high cost per unit of lineal cut, and the charring of the generated surface. Therefore, the application of laser machining, most economically justified, includes laser engraving, automatic preparation of wooden die blocks for the folding-carton industry, cutting chair backs, and veneer inlays in furniture industry.

Cutting with abrasive liquid jet has been useful for a wide variety of materials but has rather limited application in the wood industry. The application of the liquid jet as a cutting tool depends on the availability of high-pressure pumping equipment capable of generating a high-velocity continuous jet. For the generation of a high-energy continuous flow, a pressure level of about 4100 kp cm^{-2} (60 000 psi) is required. The nozzles range from 0.1 to 0.4 mm in diameter and are made from ruby or sapphire. The liquid jet, like the laser, approaches the

ideal single-point cutting tool, which can follow highly complicated patterns. It eliminates crushing or deformation of the material such as corrugated paper board and generation of dust. Water jet technology reduces cutting noise significantly and offers the ability to cut without high temperatures. The greatest use of liquid-jet cutting is in the paper and paper-board industry where it has been quite successful in cutting laminated paperboard into upholstery frames. In the paper industry liquid-jet slitting systems are used to cut paper at higher speeds than with a mechanical knife – as high as 3200 m min^{-1} .

See also: **Solid Wood Processing:** Finishing. **Solid Wood Products:** Construction; Logs, Poles, Piles, Sleepers (Crossties); Lumber Production, Properties and Uses; Structural Use of Wood. **Wood Formation and Properties:** Formation and Structure of Wood; Mechanical Properties of Wood; Physical Properties of Wood. **Wood Use and Trade:** History and Overview of Wood Use.

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SOLID WOOD PRODUCTS

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Wood-based Composites and Panel Products

Glued Structural Members

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Published by Elsevier Ltd., 2004

Introduction

The material in this article is adapted from the Forest Products Laboratory *Wood Handbook*, which is

especially concerned with use of wood as an engineering material in the USA. However, the use of wood in laminated form is common worldwide and the same principles apply. Glued structural members are manufactured in a variety of configurations. Structural composite lumber (SCL) products consist of small pieces of wood glued together into sizes common for solid-sawn lumber. Glued-laminated timber (glulam) is an engineered stress-rated product that consists of two or more layers of lumber in which the grain of all layers is oriented parallel to the length of the lumber.