

Audel™

**Machine Shop Tools
and Operations
All New 5th Edition**

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and Operations
All New 5th Edition**

**Rex Miller
Mark Richard Miller**



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About the Authors

Rex Miller was a Professor of Industrial Technology at The State University of New York—College at Buffalo for over 35 years. He has taught on the technical school, high school, and college level for well over 40 years. He is the author or coauthor of over 100 textbooks ranging from electronics to carpentry and sheet metal work. He has contributed more than 50 magazine articles over the years to technical publications. He is also the author of seven Civil War regimental histories.

Mark Richard Miller finished his B.S. degree in New York and moved on to Ball State University where he obtained the master's and went to work in San Antonio. He taught in high school and went to graduate school in College Station, Texas, finishing the doctorate. He took a position at Texas A&M University in Kingsville, Texas, where he now teaches in the Industrial Technology Department as a Professor and Department Chairman. He has coauthored seven books and contributed many articles to technical magazines. His hobbies include refinishing a 1970 Plymouth Super Bird and a 1971 Roadrunner. He is also interested in playing guitar, which he did while in college as lead in The Rude Boys band.

Introduction

The purpose of this book is to provide a better understanding of the fundamental principles of machine shop practices and operations for those persons desiring to become machinists. The beginning student or machine operator cannot make adequate progress in his or her trade until he or she possesses a knowledge of the basic principles involved in the proper use of various tools and machines commonly found in the machine shop.

One of the chief objectives has been to make the book clear and understandable to both students and workers. The illustrations have been selected to present the how-to-do-it phase of many of the machine shop operations. The material presented here should be helpful to the machine shop instructor, as well as to the individual student or worker who desires to improve himself or herself in this trade.

The proper use of machines and the safety rules for using them have been stressed throughout the book. Basic principles of setting the cutting tools and cutters are dealt with thoroughly, and recommended methods of mounting the work in the machines are profusely illustrated. The role of numerically controlled machines is covered in detail with emphasis upon the various types of machine shop operations that can be performed by them.

This book is presented at a time when there is a definite trend toward expanded opportunities for vocational training of young adults. An individual who is ambitious enough to want to perfect himself or herself in the machinist trade will find the material presented in an easy-to-understand manner, whether studying alone or as an apprentice working under close supervision on the job.

Chapter I

Power Hacksaws, Power Band Saws, and Circular Saws

Power hacksaws, power band saws, and circular saws are very important to machine shop operations. A large number of power hacksaws and power band saws are in use in the metalworking industry.

Power Hacksaws

A power hacksaw is an essential machine in most machine shop operations. For many years a hand-operated hacksaw was the only means for sawing off metal. Power-driven machines for driving metal-cutting saw blades have been developed to make the task easier. The power hacksaw can do the work much more rapidly and accurately. The machinist should be familiar with these machines, the blades used on the machines, and the operations performed on them. One type of power hacksaw commonly found in machine shops is shown in Figure 1-1.

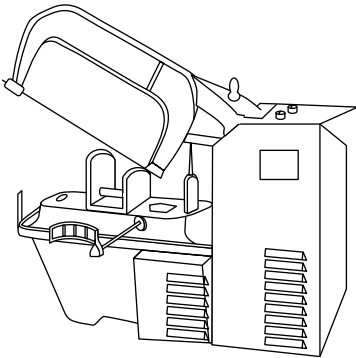


Figure 1-1 Power hacksaw.

Basic Construction

Power hacksaws are designed to make the sawing of metal a mechanical operation. The stock is usually held in a vise mounted on the base of the machine. An electric motor is used to supply power for the machine.

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Drive Mechanism

The drive shaft is connected by a V-belt and gears to the electric motor mounted on the machine. The drive mechanism is shielded by guards for safety in operation.

Frame

A U-shaped frame is used on the smaller power hacksaws to support the two ends of the saw blade, which is under tension. The heavier machines use a four-sided frame and a thin backing plate for the blade of the saw.

Worktable and Vise

Most worktables are equipped with a vise that can be mounted either straight or angular to the blade. The worktable is usually mounted on a ruggedly constructed base. Many worktables are provided with T-slots for the purpose of supporting special clamping devices.

Special Features

Nearly all power hacksaws raise the blade on the return stroke. This feature prevents dulling of the blade by dragging it over the work as the blade is returned to the starting position.

Another important feature is a blade safety switch that automatically stops the machine if the blade should break during operation of the saw. The safety switch prevents any damage that could result if the machine continued operation with a broken blade.

Coolant System

Some power hacksaws are equipped with a coolant system that delivers a coolant to the hacksaw blade. The coolant passes from a receiving tank to a pump and then to the work. The machine is equipped with a trough to catch the coolant, which may be screened to remove any chips of metal.

Saw Capacity

Small power hacksaws can be used on square or round stock ranging from $\frac{1}{8}$ inch to 3 inches. The larger machines have a capacity ranging to 12 inches (square or round), or even larger.

The capacity of a machine for angular cuts is different from its capacity for straight cuts. The cutting surface is longer for angular cutting. Thus, the saw must be equipped not only with a swivel vise but also with a long enough stroke to make the angular cut.

Blades

High-speed tungsten steel and high-speed molybdenum steel are the most commonly used materials in power saw blades. If only the teeth are hardened, the blades are called *flexible blades*.

Power hacksaw blades are ordered by specifying length and width, thickness, and teeth per inch. For example, they are available in 12" \times 1" length and width at 0.050-inch thickness. The teeth per inch (TPI) would be either 10 or 14. The 14" \times 1" \times 0.050" blade is available in only 14 TPI. Blades also come in 17" \times 1" with a thickness of 0.050 inch and either 10 or 14 TPI. Blades with a thickness of 62 thousandths of an inch (0.062 inch) are usually 1¼ inches wide.

High-speed, shatterproof blades are designed to meet safety and performance requirements. The high-speed molybdenum blades are longer wearing and give the best results for general use. They, too, come in 12-inch, 14-inch, and 17-inch lengths with a 1-inch or 1¼-inch width. These blades are made in both 10 and 14 TPI sizes. Thickness of the metal being cut determines the number of teeth per inch chosen to do the job. There should be no fewer than two or three teeth touching the metal being cut.

Figure 1-2 shows the power hacksaw blade end with a hole for mounting in the machine and the pointed nature of the teeth.

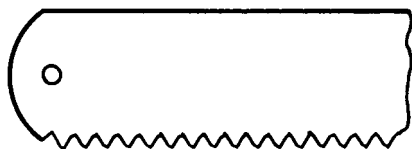


Figure 1-2 Power hacksaw blade.

Hacksaw Operation

Straight cuts are made easily on power hacksaws. The vise is stationary, and the cut is made at a right angle to the sides of the stock.

Most machines are equipped with an adjustable vise. Angular cuts at any desired angle up to 45 degrees can be made by swiveling the vise.

To operate the power saw properly, the work should be fastened securely in the vise so that the blade will saw in the proper place. The blade will break if the work loosens in the vise.

The saw blade should be lowered onto the work carefully to start the cut. On some machines this is done by hand, but it can be done automatically on some saws. In either method, the points of the teeth will be broken or damaged if the blade is permitted to strike the work suddenly.

The machine should be watched carefully to make certain that the saw blade lifts about ⅛ inch on the return stroke. If the blade

fails to lift, adjustments should be made immediately, as the blade will be damaged if operation is continued.

When making angular cuts with the work turned at an angle in the vise, another precaution is to be certain that the saw blade can make both the backward and the forward strokes without the saw frame making contact with either the work or the vise. Serious damage to the machine can result from failure to observe this precaution.

When a saw blade is replaced, or a new blade is started in an old cut, it should be remembered that the set of the new blade is wider. The new blade will stick in the old cut unless the work is rotated in the vise a quarter turn. If the work cannot be rotated, the new blade should be guided into the old cut.

The cutting speed of a power hacksaw, of course, varies with the material being cut. Suggested cutting speeds are as follows: for mild steel, 130; for tool steel (annealed), 90; and for tool steel (unannealed), 60. For example, on a machine with a 6-inch stroke, the revolutions per minute of the driving crank should be 130.

All steels should be cut with a cutting compound. Bronze should be cut with a suitable compound at the same speed as mild steel. The saw blade will heat rapidly if an attempt is made to cut brass without a cutting compound adapted to brass. Brass may be cut at the same speed as steel if a suitable compound is used.

Power Band Saws

In the past few years the power band saw has become very important in machine shop operations. In some instances it is used in production operations prior to final machining operations.

Basic Construction

Power band saws are also designed to make the sawing of metal a mechanical operation (Figure 1-3). The stock can be held in a vise mounted on the machine or it can be supported by the operator's hand. Electric motors are used to supply the power for the band saws.

Drive Mechanism

Wheels on the power band saw can be adjusted to apply tension to the band saw blade, which is a flexible, thin, narrow ribbon of steel. One of these wheels is powered by the electric motor mounted on the machine. These wheels are enclosed by guards for safety in operation.

Frame

Many variations of power band saws are available. However, band saws can be grouped into three classifications: horizontal machines for cut-off sawing, vertical machines for straight and profile sawing

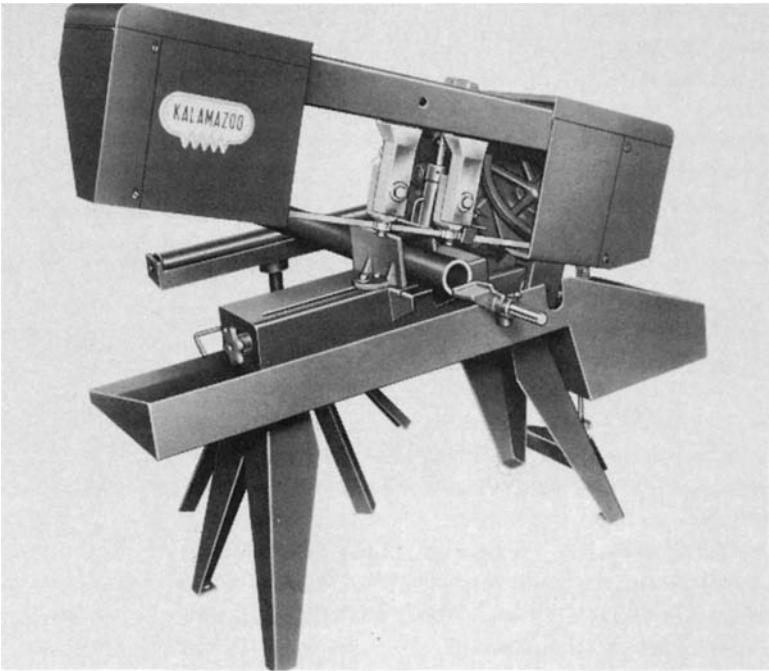


Figure I-3 A power band saw. (Courtesy Kalamazoo Saw Div., KTS Industries.)

at conventional speeds, and vertical machines for nonferrous cutting and friction cutting.

Worktable and Vise

Power band saws have either a worktable or vise to hold the metal that is to be cut. The worktable is usually part of the band saw. The vise, if there is one, is usually designed to fit the worktable. Many worktables also have T-slots for the purpose of supporting special clamping devices to hold the work to be cut.

Special Features

Some power band saws have automatic tensioning devices so that the proper amount of tension is applied to the band saw at all times. This type of device reduces excessive wear and damage to the blade.

Coolant System

Coolant systems are common on power band saws designed for high-speed production work. These systems deliver coolant to the

band saw blade and the work. After the coolant has been used, it is recycled through a screen and filter to remove any chips.

Capacity of Power Band Saws

The maximum capacity of power band saws varies according to the size of the band saw. Some of the larger machines can accommodate work that is 18" \times 18" and larger. Band saws also have the capacity to do a wide variety of operations that include cut-off, straight sawing, and contour, or profile, sawing. Rough shaping and semifinishing can be accomplished on almost all types of ferrous and nonferrous materials.

Blades

The development of the heavy-duty band saw machine tool has been designed and built to operate with high-speed blades at maximum efficiency. Use of the band saw offers several important advantages over the hacksaw. These advantages include a narrower kerf, which results in greatly reduced losses; fast, efficient cutting with low per-cut costs; and consistently smooth, accurate cutting.

The type of blade used on the power band saw is very important. Blades are available with many different types of teeth, tooth set, and pitch.

The three types of teeth are the regular tooth, skip tooth, and hook tooth (Figure 1-4). The regular tooth blade provides from 3 to 32 teeth per square inch. Teeth may be raker set or wavy set. Regular tooth blades are preferred for all ferrous metals and for general-purpose cutting.

Skip-tooth blades feature widely spaced teeth (usually from 2 to 6 TPI) to provide the added chip clearance needed for cutting softer materials. Teeth of the skip-tooth blade are characterized by straight 90° faces and by the sharp angles at the junction of the tooth and gullet. Since these sharp angles and flat surfaces tend to break up chips, this type of tooth is preferred for the very soft nonferrous metals that would otherwise tend to clog and gum the blade. This blade is also widely used in woodcutting.

Hook-tooth blades provide the same wide tooth spacing as the skip-tooth blade. The teeth themselves have a 10° undercut face. Gullets are deeper with blended radii between the teeth and the

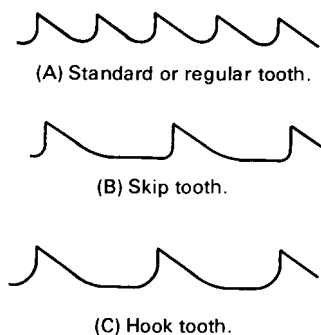


Figure 1-4 Three tooth styles for blades.

gullets. Since the undercut face helps the teeth dig in and take a good cut, the blended radii tend to curl the chips. This type of tooth is preferred for the harder nonferrous alloys and many plastic operations.

There are three basic types of tooth set on metal-cutting band saw blades. Each tooth set is designed for a specific type of cutting application. These three basic types of tooth sets are the raker set, the wavy set, and the alternate set. See Figure 1-5.

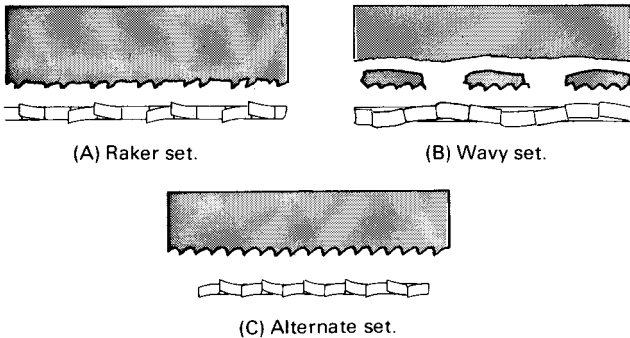


Figure 1-5 Types of tooth sets for blades.

The raker set—one tooth set left, one tooth set right, and one tooth not set—is preferred for all long cutting runs where the type of material and the size and shape of the work remain relatively constant. It is also for all contour, or profile, cutting applications and for band sawing with high-speed steel blades.

The wavy-set blade, a rolled set with alternate left and right waves, provides greater chip clearance and a stronger, nearly rip-proof tooth. This blade is preferred for general-purpose work on conventional horizontal machines.

The alternate set has every tooth set—one to the left, one to the right—throughout the blade. Taken originally from the carpenter handsaw, it was supplied in band saws for brass foundry applications.

Band Saw Operation

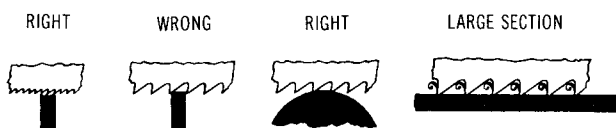
When operating a band saw, there are some general principles that should be followed so that you will be able to select the blade with the proper pitch:

- Small and thin-wall sections of metal require fine teeth.
- Large metal sections require the use of blades with coarse teeth so that adequate chip clearance is provided.

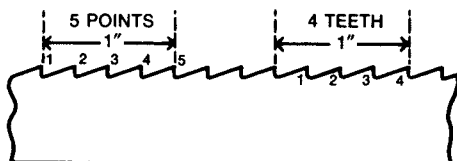
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- Two teeth should be engaged in the metal to be cut at all times.
- Soft, easily machined metals require slightly coarser teeth to provide chip clearance. Hard metals of low machinability require finer teeth so that there are more cutting edges per inch.
- Stainless steel should be sawed with a coarse (NQ) tooth saw blade for best results.

Figure 1-6 shows tooth pitches.



(A) Correct and incorrect tooth pitches.



(B) How determined.

Figure I-6 Tooth pitches.

Select the widest blade that your machine will accommodate when straight, accurate cutting is required. Blade widths for contour sawing depend upon the specific application.

Profile (or contour) sawing is an accurate, fast, and efficient method of producing complex contours in almost any machinable metal. With the proper blade selection, radii as small as $\frac{1}{16}$ inch can be cut. Either internal or external contours can be sawed. If an internal contour has to be sawed, it is first necessary to drill a hole within the contour area to accommodate the saw blade. The band saw blade has to be cut to length, threaded through the drilled hole, and then rewelded. It is for this reason that band saws designed and built for contour sawing have a built-in butt welder. Blades for profile sawing are always raker set because this type of tooth provides

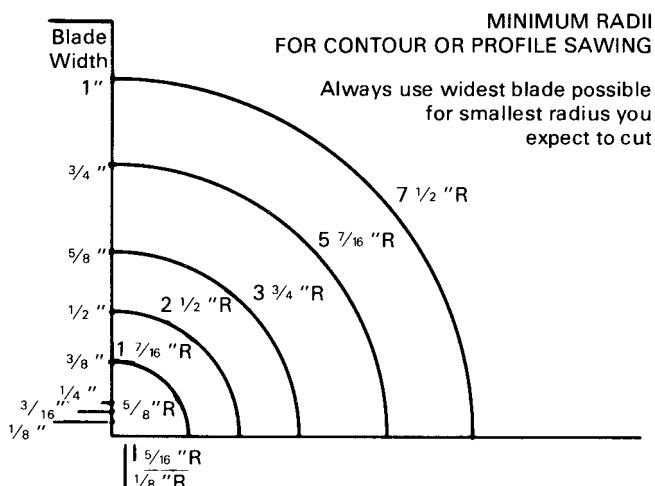


Figure 1-7 Bandwidth selection for profile or contour sawing.

the necessary side clearance. These blades are usually narrower than those chosen for straight cutting; the extra width for any specific job depends upon the smallest radius to be cut. Figure 1-7 will aid you in selecting the correct blade for any application.

Profile sawing requires cutting and rewelding the blade. Because of this, it is necessary to make a good weld. This can be accomplished very easily if certain steps are followed. The steps are as follows:

1. Square both ends of the blade accurately.
2. Align both ends of the blade so that they join evenly across the entire width of the blade.
3. Select the correct dial setting for the blade width.
4. Select the correct annealing period.
5. Dress the blade to remove the welding flash.
6. Anneal for stress relieving.

With the exception of cast iron, coolant should be used for all band-sawing operations. Cast iron is always cut dry. Almost all of the commercially available soluble oils or light cutting oils will give good results when cutting ferrous metals. When aluminum is cut, paraffin and beeswax are commonly used lubricants.

The recommendations shown in Table 1-1 are based on four types of cutting fluids:

- A. *Cutting oil mineral base with fatty oils added* (has sulfur for antiweld characteristics and chlorine for film strength)
- B. *Cutting oil with light viscosity fatty oils* (for cold-weather operations, mix with (A); when cutting copper alloys, additives and chlorine should be added)
- C. *Synthetic water-soluble cutting agent*
- D. *Soluble oil cutting agent with fatty oils* (sulfurized for extreme pressure with antiweldment properties; water-soluble for greater heat removal)

Table 1-1 Recommended Cutting Fluids

Materials to Be Cut—Cutting Fluids Recommended						
Operation	Free-Cutting	Alloy	Stainless		Aluminum	
	Steels; Carbon Steels; Cast Steels; Malleable Iron	Steels; Nickel Steel; Nickel-Chromium Steel	Steels (Free Cutting); Ingot Iron; Wrought Iron	Stainless (Austenitic); Manganese Steels; High-Temp Alloys	Alloys; Lead Brass; Magnesium Alloys; Phosphor Bronze; Zinc	Brass; Gun Metal; Nickel; Monel; Inconel
Production sawing using MARVEL high-speed steel, high-speed-edge, and intermediate alloy steel band blades	FLOOD	FLOOD	FLOOD	FLOOD	FLOOD	FLOOD
	(B)	(A)	(A)	(A)	(B)	(A)
	(C) Mix 1 to 5 with water.	(C) Mix 1 to 5 with water.	(D) Mix 1 to 5 with water.	(C) Mix 1 to 5 with water.		(C) Mix 1 to 5 with water.
	(D) Mix 1 to 5 with water.	(D) Mix 1 to 5 with water.	(C) Mix 1 to 5 with water.	(D) Mix 1 to 5 with water.		(D) Mix 1 to 5 with water.

Table I-1 (continued)

Operation	Materials to Be Cut—Cutting Fluids Recommended					
	Free-Cutting Steels; Carbon Steels; Cast Steels; Malleable Iron	Alloy Steels; Nickel Steel	Stainless Steels (Free Cutting); Ingot Iron; Wrought Iron	Stainless (Austenitic); Manganese Steels; High-Temp Alloys	Aluminum Alloys; Lead; Magnesium Alloys; Phosphor Bronze; Zinc	Brass; Gun Metal; Nickel; Monel; Inconel
General sawing using MARVEL hard-back & flexible-back hardened-edge band blades	DRIP (blade just wet)	DRIP (blade just wet)	DRIP (blade just wet)	DRIP (blade just wet)	DRIP (blade just wet)	DRIP (blade just wet)
	(B)	(B)	(B)	(A)	(B)	(A)
	(D)	(D)	(D)	(B)	Paraffin dry	(B)
Contour sawing using MARVEL high-speed-edge or hard-back & flexible-back carbon blades	SPRAY OR DRIP	SPRAY OR DRIP	SPRAY OR DRIP	FLOOD OR DRIP	FLOOD	
	(C)	(C)	(C)	(D) Mix 1 to 10 with water.	(B)	(B)
	(D) Mix 1 to 10 with water.	(D) Mix 1 to 10 with water	(D) Mix 1 to 10 with water. (B)	(C) Mix 1 to 10 with water. (A)	Paraffin dry	(A)

Courtesy Armstrong-Blum Mfg. Co.

The three types of feeds used on power band saws are hand, hydraulic, and mechanical. The number of factors involved in the efficient and trouble-free operation of a power band saw make it difficult to provide specific information on the proper speed or pressure required (see Table 1-2). When a cut is started, the blade should not be forced. If the work is forced into the blade, it will result in a shorter blade life and defective work. The following principles should be used as a guide in selecting the proper feed pressure:

- Use moderate feed pressure when straight, accurate cutting is desired.
- Avoid heavy feed pressures because they will cause the power band saw to chatter and vibrate.
- Study the chips produced. Fine powdery chips indicate the feed is too light. The teeth on the blade are rubbing over the surface of the work instead of cutting the work. Discolored, blued, or straw-colored chips indicate that there is too much feed pressure. This excess pressure can cause teeth to chip and break. In addition, the blade will wear prematurely because of overheating. A free-cut curl indicates ideal feed pressure with the fastest time and the longest blade life.

Table 1-2 Common Band Sawing Problems and Their Connections

<i>Problem</i>	<i>Cause</i>	<i>Correction</i>
Blade develops camber.	Roller guides not correctly adjusted.	Readjust.
	Feeding pressure is too heavy.	Use lighter feed.
	Saw guides too far apart.	Adjust closer to work.
	Blade riding against flange on metal wheel.	Tilt wheel for proper blade position.
Blade develops twist.	Saw is binding in cut.	Decrease feeding pressure.
	Side inserts or rollers of saw guides too close to saw.	Readjust.
	Wrong width of blade for radius being cut.	Check for correct blade width.

Table 1-2 (continued)

Problem	Cause	Correction
Saw dulls prematurely.	Saw speed too great; teeth sliding over work instead of cutting.	Reduce saw speed.
	Improper coolant or coolant improperly directed.	Check type and mixture of coolant. Apply at the point of cut, saturating teeth evenly.
	Saw idling through cut.	Keep teeth engaged; use positive feeding pressure.
	Feed too light; teeth sliding over work.	Use a feed heavy enough to generate a full curled chip.
Saw loses set prematurely.	Saw is too wide for radius being cut.	Check for the proper width.
	Saw speed is too fast.	Reduce speed.
	Saw rubbing against vise or running deep in guides.	Check blade along complete travel.
Saw vibrates in cut.	Wrong speed for the material and work thickness.	Check for the proper width.
	Insufficient blade tension.	Increase tension.
	Pitch too coarse.	Select a finer pitch.
	Excessive feeding pressure.	Reduce pressure.
Saw teeth rip out.	Pitch too coarse.	Use a finer pitch on thin work sections.
	Work not tightly clamped or held.	Reclamp or hold more firmly to prevent vibration.
	Sawing dry.	Use coolant when possible.
	Gullets loading.	Use a coarser pitch and/or a higher viscosity lubricant—or brush to remove chips.
	Excessive feed pressures.	Reduce.

(continued)

Table I-2 (continued)

Problem	Cause	Correction
Saw breaks prematurely.	Blade too thick for the diameter of wheels.	Check recommendations for your machine.
	Cracking at the weld.	Weld improperly made; try a longer annealing period.
	Pitch is too coarse.	Use finer pitch.
	Excessive feeding pressure or blade tension.	Reduce.
	Guides too tight.	Readjust.

Courtesy Henry G. Thompson Co., Subsidiary of Vermont American Corporation.

One of the most important factors in successful band sawing is a proper cutting speed. If the machine is operated at too fast a speed for the material being cut, the teeth are not allowed sufficient time to dig into the material. As a result, they merely rub over the surface of the work, creating friction that rapidly dulls the cutting edge and wears out the blade. Table 1-3 gives average speeds and cutting rates for cutting a wide variety of commonly used ferrous and non-ferrous metals and nonmetallics. These recommendations will ensure optimum performance under most conditions.

Table I-3 Average Speeds and Cutting Rates

Flexible and Hard-Back Carbon—Raker Tooth								
Material	Size of Material							
	1/4 in.		1/2 in.		2 in.		4 in.	
	Speed	Teeth	Speed	Teeth	Speed	Teeth	Speed	Teeth
Steels:								
Armor plate	150	18	125	12	75	8	50	6
Angle iron	175	24	150	14				
Carbon steels	250	24	200	14	150	10	100	6
Chromium steels	150	24	125	14	100	10	50	6
Cold-rolled steel	250	12	200	10	150	8	125	6
Drill rod	100	14	100	14				
Graphite steels	175	18	150	14	100	10	75	6
High-speed steels	150	24	100	14	75	10	50	8

Table I-3 (continued)

<i>Flexible and Hard-Back Carbon—Raker Tooth</i>								
<i>Material</i>	<i>Size of Material</i>							
	<i>¼ in.</i>		<i>½ in.</i>		<i>2 in.</i>		<i>4 in.</i>	
	<i>Speed</i>	<i>Teeth</i>	<i>Speed</i>	<i>Teeth</i>	<i>Speed</i>	<i>Teeth</i>	<i>Speed</i>	<i>Teeth</i>
Machinery steels	250	18	200	14	150	10	125	6
Molybdenum steels	150	18	125	14	75	10	50	8
Nickel steels	150	18	125	14	75	10	50	8
Silicon manganese	175	18	150	14	75	10	50	6
Stainless steels	100	24	100	14	50	10	50	6
Structural steels	175	24	150	14				
Tungsten steels	175	18	150	14	75	8	50	6
Foundry metals:								
Brass—hard	500	18	400	14	300	10	200	6
Brass—soft	1500	18	1000	14	750	10	300	6
Bronze—aluminum	500	18	400	14	225	10	100	6
Bronze—manganese	300	18	250	14	200	10	150	6
Bronze—navel	300	18	275	14	225	10	150	6
Bronze—phosphorous	500	18	400	14	200	10	150	6
Cast iron—gray	200	18	175	14	100	8	75	6
Cast iron—malleable	200	18	175	14	150	10	125	6
Cast steel	225	18	200	14	100	8	75	6
Copper—beryllium	400	18	350	12	250	10	150	6
Copper—drawn	1100	18	700	10	350	6	200	6
Gunnite	300	24	200	18	150	10	100	6
Meehanite	150	18	100	14	75	8	50	6
Monel	200	18	150	14	75	10	50	6
Nickel—cold-rolled	200	14	150	10	75	8	50	6
Nickel silver	250	18	250	14	175	10	125	6
Silver	250	24	250	18	175	10	150	6

(continued)

Table I-3 (continued)

<i>Flexible and Hard-Back Carbon—Hook Tooth</i>								
<i>Material</i>	<i>Size of Material</i>							
	<i>½ in.</i>		<i>2 in.</i>		<i>5 in.</i>		<i>10 in.</i>	
	<i>Speed</i>	<i>Teeth</i>	<i>Speed</i>	<i>Teeth</i>	<i>Speed</i>	<i>Teeth</i>	<i>Speed</i>	<i>Teeth</i>
Nonferrous metals:								
Aluminum—soft	4000	4	3600	3	3200	3	3000	2
Aluminum—medium	3000	6	2000	4	1500	3	1200	2
Aluminum—hard	600	6	500	4	400	3	300	3
Babbitt	4000	6	3500	4	3000	3	2500	3
Beryllium copper	2000	6	1800	4	1400	3	1000	3
Brass—casting	3200	6	3000	4	2500	3	1800	3
Brass—commercial	3700	4	3500	3	3000	3	2500	2
Brass—naval	3500	4	3000	3	2500	3	2000	2
Brass—yellow	3200	4	3000	3	2500	3	1800	2
Cadmium—Kirsite	3200	6	3000	4	2500	3	1700	3
Copper	3000	4	3000	3	2500	3	2000	2
Lead	4000	6	3500	4	2700	3	2000	3
Magnesium	4000	6	3000	4	2500	3	2000	2
Silicon bronze	1000	6	1000	4	600	3	300	3
Titanium #150A	60	6	50	6	50	4	50	3
Steels:								
Alloy steels	80	6	70	6	60	4	50	3
Low-carbon steel	170	6	150	4	125	3	100	2
Medium-carbon steel	120	6	110	4	100	3	90	2
High-carbon steel	90	6	80	6	70	4	65	3

Courtesy Armstrong-Blum Mfg. Co.

Friction cutting differs from all other types of metal-sawing methods. It is not actually a cutting operation, but a burning process similar to torch cutting. It is much faster than conventional sawing methods. Very hard materials (which could not normally be sawed) are cut rapidly and easily. Bulky and irregular shapes can be cut handily because there is little blade drag.

Basically, the friction-cutting operation involves the use of a very fast moving blade that travels at speeds between 6000 and 18,000 feet per minute (see Table 1-4). At these speeds, terrific heat is built up in the workpiece at its point of contact with the blade, and burning begins. Teeth are not needed to generate burning heat, but they generate increased cutting speed and efficiency by carrying additional oxygen into the work area, thus creating greater oxidation. Set teeth are also important. They give the operator the control required to cut a straight line or follow a specific curve.

Table 1-4 Recommended Friction Cutting Speeds for Common Metals

Description	Average Recommended Cutting Speeds, ft/min.
Armor plate	7000–13,000
Carbon steel	6000–12,000
Cast steel	7000–13,000
Chromium steel	8000–15,000
Chromium-vanadium steel	8000–15,000
Free-machining steel	6000–12,000
Gray cast iron	7000–13,000
Malleable cast iron	7000–13,000
Manganese steel	6000–12,000
Moly steel	8000–15,000
Molybdenum	8000–15,000
Nickel-chromium steel	8000–15,000
Nickel steel	8000–15,000
Silicon steel	8000–15,000
Stainless steel	7000–13,000
Tungsten steel	8000–15,000

Courtesy Henry G. Thompson Co., Subsidiary of Vermont American Corporation.

There is a definite advantage to using a special blade for this type of operation. The friction-cutting blade is made from special steel. The blade is specially heat-treated to withstand the fast speeds and severe flexing that are encountered in friction sawing.

Many difficult manufacturing problems have been solved with friction sawing because this process has distinct advantages. Before deciding whether to use friction sawing, consideration should be given to the specific job requirements. There are important limitations involved with friction sawing. Following are some of these limitations:

- Friction cutting leaves a very heavy burr on the underside of the material being cut.
- Thicknesses over $\frac{5}{8}$ inch are extremely difficult to cut.
- Heat from the friction-sawing process may have a tempering effect on the edges of some materials.

Circular Saws

Circular saws have some advantages. They produce a burr-free mill finish when slow-speed cold sawing is used. This eliminates secondary operations on tubing, channels, angles, and solid stock of most steels and other ferrous materials, as well as most nonferrous metals. The rigidity of the blade produces cuts of extreme accuracy and close tolerances. The cutting operation is safe, clean, and quiet because of the slower speed.

Figure 1-8 shows a manually operated saw. Semiautomatic types with an air-operated vise are available. Special vise insets for holding thin-walled pipe or tubing to prevent distortion are shown in Figure 1-9A. The other holding arrangement is shown in Figure 1-9B. This shows square material being held for optimum cutting angle. Other special shapes can be made to fit in the vises, or they can be purchased from the saw manufacturer.

The semiautomatic machines have heavy-duty feed mechanisms to feed the metal to the saw. The saw can do straight cutting, miter cutting, slot (or longitudinal) cutting, or any number of other arrangements that will fit within the limits of the machine.

Nonferrous Saw

A machine specifically suited for aluminum or nonferrous and hard plastics is shown in Figure 1-10. The machine cuts from the bottom up. The cutting blade speed is 9840 surface feet per minute (sfpm). The workpiece is held from the top by a quick-clamping vise. Maximum saw diameter is 12 inches. A built-in spray mist coolant system provides effective blade lubrication. Mitering is possible in either 45° or 60° and in both directions.