METHODS AND EQUIPMENT FOR SAWING QUARTZ CRYSTALS

WILLIAM PARRISH,
North American Philips Co., Inc.
Research Laboratory
*Irvington, New York.**

CONTENTS

ABSTRACT

The principal types of equipment and methods for sawing, dicing and squaring quartz crystals are described. In down-cutting, the most widely used method, the diamond blade moves downward into the crystal which is fixed. The Felker-type saw with work-table adjustable for horizontal and vertical angle corrections determined by x-ray measurements is the most successful. Surface grinders and milling machines are not as good because they require expensive reconversion, the quartz must be preset, and little or no angular correction is possible. Diamond blades of the notched or metal bonded type are used. Their efficiency and accuracy are dependent upon the quality of the sawing machine, type of entering surface, size of cut, speed, pressure and coolant. The best results are obtained when the arc of contact is small, the entering surface flat and perpendicular to the blade, the saw relatively free of vibration, large flanges and a copious flow of proper coolant, low pressure and relatively high blade speeds (4000–6000 s.f.m.). Methods for dicing and squaring are also described.

INTRODUCTION

The quartz crystal industry employs a huge number and varieties of sawing equipment and methods. Only a few of the most successful of these can be described here. The sawing equipment to a great extent de-

* Mail address: Dobbs Ferry, N. Y.

termines the orientation procedures and vice versa. Cutting schemes and orientation techniques are described in detail in previous papers.[1]

Both equipment and procedures admittedly could be considerably improved. In common with most things in the quartz industry they were hurriedly developed for the emergency. The job has been an amazing accomplishment when we realize that several hundred million *blanks* were cut in less than three years. Generally speaking, the best results are obtained in those plants which maintain a well-equipped shop for servicing the numerous mechanical details that are continuously required. Mineralogists will find many of the techniques useful and may obtain excellent detailed information on the operating conditions and equipment from the manufacturers and nearby crystal plants.

Acknowledgments. The crystal industry is indebted to the Felker Manufacturing Co., Inc., Torrance, Calif., manufacturers of saws and rim-lock diamond blades and the Norton Co., Worcester, Mass., manufacturers of metal bonded-type diamond blades for their cooperation in making available equipment for cutting quartz crystals. Some of the data included in the section on diamond blades were obtained from Mr. C. R. Van Riper, Research Laboratories, Norton Co. The photograph of the crystal edging machine, Fig. 14, was submitted by Volkel Bros. Machine Works, Los Angeles, Calif.

Sawing Methods

The four principal methods of cutting quartz are shown in Fig. 1. The most widely used method for wafering and cutting blanks from bars is *down-cutting*. The crystal position is fixed and the blade moves into the crystal. In the Felker-type of saw, an automatically controlled variable hydraulic retardant, controls the rate of down-feed. This is superior to manual control or free-falling type of control in which the down-feed is as fast as the blade is cutting.

In *cross-cutting* or through-cutting, the vertical blade position is locked and the crystal is pushed, manually- or motor-driven into the blade. This is a useful procedure when the entering surface in down-cutting is at an angle to the blade and it is difficult to obtain a smooth cut (e.g., cutting X-sections on faced crystals). The cut is started at the broken end of the crystal for the apex end is just as difficult to enter as the sloping prism faces. The method is not widely used and has been more successful when a power-driven feed is employed.

Rotary and step cutting are commonly used abroad but not in this

[1] Gordon, Samuel G., and Parrish, William, Cutting schemes for quartz crystals: *Am. Mineral.*, this issue. Orientation techniques for the manufacture of quartz oscillator-crystals: *ibid.*

country. There is no machine available here for the former, and only an experimental model for the latter, and it has not been successful. The equipment required for this type of sawing is far more elaborate and

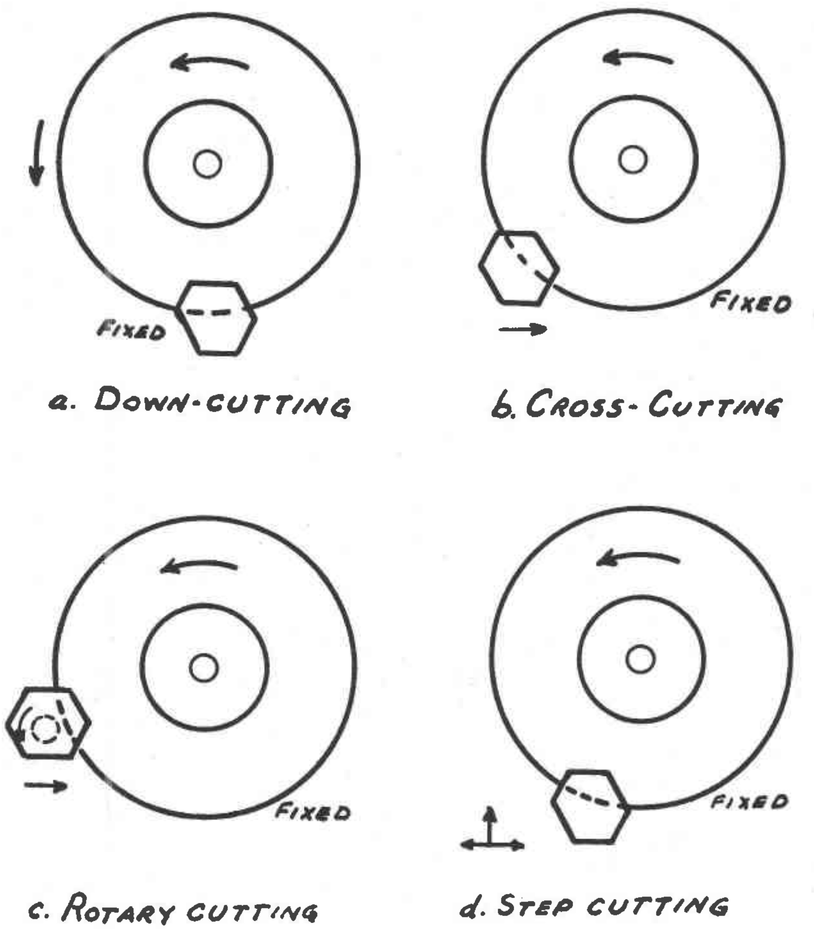


FIG. 1. Sawing methods. Down-cutting is the most widely used and successful method. The methods and equipment used in the diamond industry were found to be totally inadequate for quartz.

expensive than that commonly used here. It has been stated that the advantage of these methods over those described above is that diamond surface is in contact with the quartz only over a very small arc and hence the blade is more efficient, cuts faster and with less saw marks. The little experimental work carried out thus far has not borne out these claims. In rotary cutting, the vertical blade position is fixed and the crystal rotated in the same direction as the blade at low speeds up to 50 r.p.m. and moved into it. One of the disadvantages is that a small tip remains on the center of the wafer and must be lapped off. In addition, the wafer is tapered toward the center. In step cutting, the vertical blade position is also fixed but the crystal is mechanically driven back and forth under the blade and moved up slightly with each sweep. This is the method sometimes employed on surface grinders converted for quartz work. The experimental work conducted thus far shows that the wafers have relatively deep saw ridges, and the cutting is slower and more complicated than by the methods commonly employed.

SAWING EQUIPMENT

Two principal types of saws are used in the quartz crystal industry. The Felker-type[2] permits angular adjustments in the horizontal and

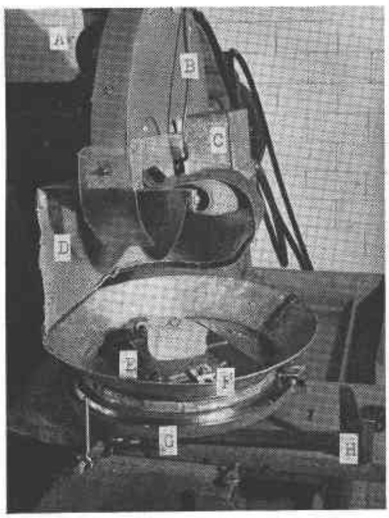


FIG. 2. Felker saw mounted on concrete block. (A) Adjustable counterweight; (B) depth stop; (C) coolant tank and circulating pump.

FIG. 3. Felker rotary table. (A) Hydraulic retardant; (B) pipe for feeding coolant into flange; (C) housing for light; (D) apron for splash guard; (E) reference edge; (F) clamps for holding mount; (G) graduated circle and vernier; (H) vertical angle scale.

[2] Manufactured by Felker Manufacturing Co., Torrance, Calif. The most widely used are the model #80 and #120 (same as #80 but larger), with HVCT-12 rotary table. The Atlas Sales Co., Chicago, Ill., makes a quartz cutting saw converted from a bench model drill press.

vertical plane and has been the most successful and widely used type employed in this country (Figs. 2–3). The converted milling machine type of saw allows little or no angular adjustments and requires the quartz to be preset to the proper cutting angle (Fig. 4). Both types require considerable mechanical work before being placed in operation.

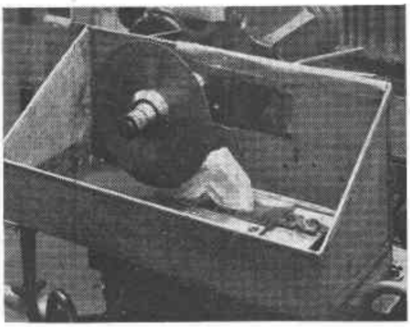
Felker Saw. The spindle carrying the blade and arbor are part of the same assembly and move in a radius about a pivotal point in the back of the saw (Figs. 2 and 3). A heavy adjustable counterbalance weight connected to a pin at the rear of the yoke permits varying the blade pressure. An adjustable hydraulic retardant controls the rate of down-feed. The rotary table and pulley must be carefully covered to prevent abrasive action of the quartz particles. The horizontal angle scale is graduated to degrees around the entire circumference and a vernier permits reading to 1′. The vertical angle is marked at 10′ intervals and can be tilted 10° on either side of the horizontal. Two manually operated screws, each graduated to 0.001″, permit translating the crystal parallel and perpendicular to the blade. The table requires the installation of a flat plate with reference edge adjustable to parallelism with the blade when the scale is set to 0°0′. This plate also should contain three slots, 90° apart, for screws and clamps for holding the mounted crystal in position. The saw must be rigidly mounted to keep vibration to a minimum. An efficient way is to mount the saw on a concrete block as shown in Fig. 2 and clamp the bed tightly by means of metal claws directly to the block.

The cutting angle is accurately controlled by x-ray measurements. A test piece is cut and a vertical arrow pointing up is marked on the outer surface to preserve the sense of direction. The test piece is measured by x-rays and the indicated horizontal and vertical angular adjustments made on the saw table. The procedure for correlating the readings is described in detail in an accompanying paper.[3] The saw should be regularly checked to make certain the angles are being maintained. Usual practice is to check every third or fourth wafer and correct the saw if necessary. With care, the X-block method and well-maintained saws, the saw maintains the angles within tolerance in wafering an entire crystal (10–20 cuts) once the saw has been corrected as indicated by the test cut.

When the crystals are irregularly shaped so that one or both of the bottom ends are not cemented to the plate, the wafering is started from one end and continued to the middle part cemented to the glass plate. The crystal is then translated to the opposite end and wafering continued from there. In this way butt ends of crystals do not fall off the mounting.

[3] Parrish, William, and Gordon, Samuel G., Precise control of quartz cutting with x-rays: *Am. Mineral.*, this issue.

Converted Milling Machines and Surface Grinders. Many types of expensive milling machines (Fig. 4) and surface grinders (Fig. 5) have been converted for sawing quartz but these have not had the success of the



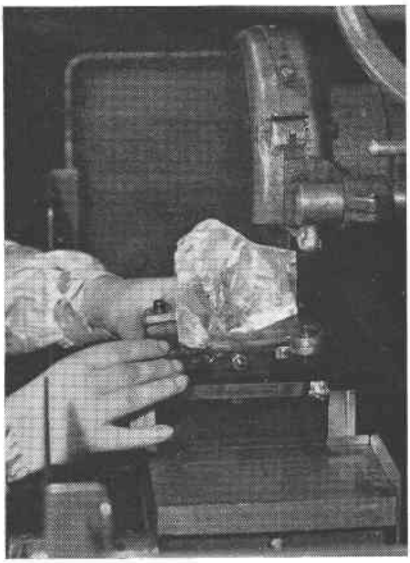


FIG. 4. Milling machine converted for quartz cutting.
FIG. 5. Surface grinder converted for quartz cutting. Magnetic chuck holds jig on which quartz is mounted.

Felker-type machines. They all require expensive reconversion and generally are not designed for 24-hour operation. Most of them require cross-cutting which is not as good as down-cutting and allow little or no adjustment of the cutting angles. Off-angle wafers must therefore be corrected on a special lap of the type shown in Fig. 6. Machine-operated feeds are required to obtain smooth surfaces.

In the early days of the crystal industry, milling machines were used for "gang" cutting. Several blades spaced at equal distances were mounted between flanges on the same spindle. The blades were either diamond blades or metal discs rotating in a trough of wet silicon carbide ("muck" saws). The method has not proven practical for modern oscillator-plates with rigid angular tolerances because of the excessive vibration, difficulty in keeping the blades true, excessive waste of quartz, etc.

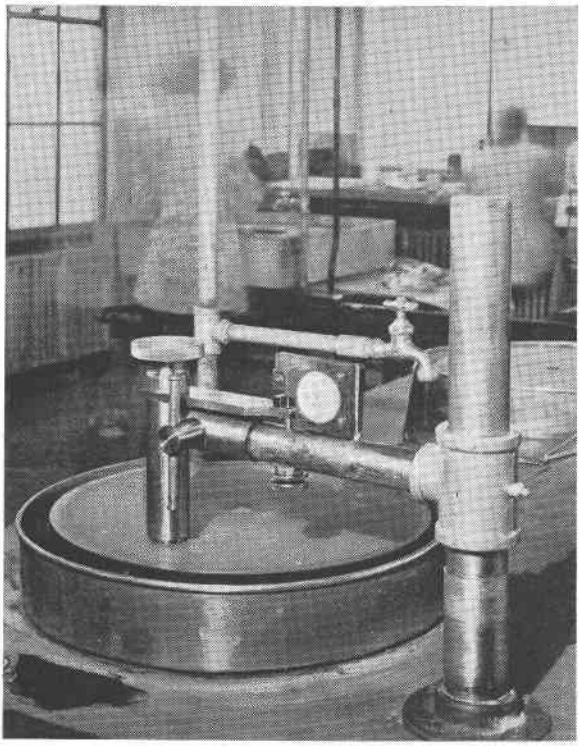
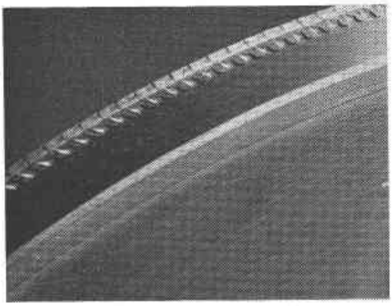


FIG. 6. Angle-correction lap. Off angle blanks are cemented to a plate which is attached to the arm. The plate is tilted with respect to the lap by the amount indicated by x-ray measurement and lapped true.

DIAMOND BLADES

The "muck" type of saw is totally inadequate for the precision type of cutting required in the quartz crystal industry. Used in "gang" form in the early days for making X-cuts, they have been replaced by fine diamond blades. The two types most widely used are shown in Fig. 7. The outer rim of the blade first developed is notched, the diamonds rolled into the openings which are then pressed together to hold the diamonds by friction contact with the metal.[4] A relatively recent development is the metal bonded diamond blade in which diamond and a bronze powder are mixed, pressed and sintered by powder metallurgy methods onto the rim of a steel disc.[5] These blades are available in various diamond concentrations and grit sizes and the proper blade should be selected for the



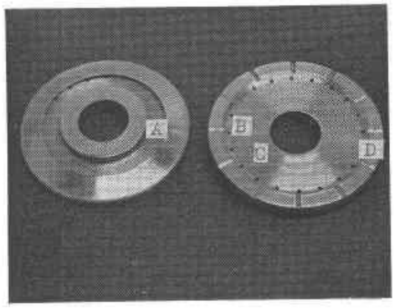


FIG. 7. Two widely used types of diamond blades. Front, Norton metal bonded blade; rear, Felker Di-Met notched blade.

FIG. 8. Flanges which are also used to apply coolant. See text for description.

particular cutting operation. The life and quality of the cuts of both types of blades are dependent upon the quality of the sawing machine (amount of vibration, stability of spindle, etc.), type and amount of coolant, the crystal being cut (type of entering surface, stability of mounting, size of cut, etc.) and the cutting speeed (r.p.m. of blade, rate of down-feed).

There is a real need for thinner diamond blades. Weight losses up to 70–80% are caused in the wafering operations because the blade is generally thicker by a considerable factor than the wafer. Wafers must also be cut three to four times thicker than final thickness to allow enough quartz to be lapped off to remove tears and scratches caused by the blade.

[4] This type of blade (Di-Met Rimlock) is manufactured by Felker Manufacturing Co., Torrance, Calif., and is available in steel (for fast cutting) and copper (slower cutting but longer life). Sizes: 3″ to 24″ diameter. Several crystal manufacturers have made their own notched blades but this practice is not common today.

[5] This type of blade is manufactured by Norton Co., Worcester, Mass. Sizes: 3″ to 14″ diameter.

Coolants. A copious flow of coolant on both sides of the blade is required. Mixtures of one-third to one-half deodorized kerosene and two-thirds to one-half light oil (such as transformer oil) are better than the water-soluble oil mixtures for the metal bonded blades.[6] One part of mineral (*not* vegetable) base water soluble oil to four parts of water (proportion is critical) is recommended by the manufacturers for the DiMet blade. The coolant is raised to the saw by means of a small circulating pump set in a reservoir with a series of baffles for settling out the quartz particles.

Flanges. The best results are obtained by using large flanges which should be at least one-third the diameter of the blade and preferably larger. The flanges may also be utilized in an efficient method of applying the coolant. A circular channel (A) with outer side sloping outward is cut into the flange, Fig. 8. The coolant is fed from tubing connected to the coolant tank directly into this channel. Holes (B) admit the coolant into reservoir (C) from which it is forced centrifugally into slots (D) which are flush with the blade. When the blade rotates, the coolant stays against the blade, does not splash and is directed into the cut.

Operating Conditions. The speed recommended for both types of blades is 4000 ± 500 s.f.m. With good sawing equipment and procedures, even higher speeds of 6000 to 7000 s.f.m. are used. The pressure is measured with the blade running and retardant open and should be small, not exceeding 5 to 7 lbs. The average rate of cutting with an 8″ blade under these conditions varies from 3 to 5 sq. in. per minute. A better finish is obtained with lower speeds and pressures but the blade is less efficient with present types of saws. In the metal bonded blades, the coarser the diamond grit, the faster the cut and the longer the blade life, but they produce deeper scratches. The following data were obtained for a 12″ Norton blade with 5″ diameter flanges, 1825 r.p.m., in cutting wafers of 5 sq. in. area:

Time	*Pressure*
92 sec.	9 lbs.
123	6
185	4

The truer the blade runs the better the wafer finish. The maximum allowable run-out on the o.d. of the blade is 0.002″ with maximum side run-out 0.005″. The edge of the blade must be kept symmetrical to minimize drift. Since it wears faster on the side towards the block, this may

[6] Although this mixture has a high flash-point, CO_2 fire extinguishers should be immediately available.

be accomplished by cutting one block starting from the left, the next block from the right and so forth. The Norton blades should be dressed lightly about every four hours, wet or dry, on the high corner with an abrasive stick but the side of the blade should never be dressed.

Drift of the blade is reduced to a minimum if the cut is started very slowly until the blade has cut about 1/32″ into the quartz. This is readily accomplished on the Felker #80 and #120 saws by holding back by hand the handle until the entering slit is made and then the speed is controlled by the hydraulic retardant. To prevent ridges, the down-pressure should not be varied once the cut has begun. The depth stop is adjusted so that the blade cuts slightly into the glass mounting plate to facilitate removing the wafer. The through feed is operated only after the blade has entered the glass plate to cut the front and back of the wafer.

TABLE 1[a]

Arc of Contact	Blade Size		Blade Specification		Flange Diameter	Minimum Wafer Thickness
	Diameter	Thickness	Grit Size	Concentration		
Up to 1½″	8″	0.045″	100	L25M	4 -5″	0.040″
Up to 2½″	8	0.050	80	L25M	3 -3½	0.045
2½″	8	0.055	60	L25M	2½	0.050
Up to 2½″	10	0.050	80	L25M	5	0.045
Up to 3″	10	0.055	80	L25M	3½	0.045
>3″	10	0.060	60	L25M	3 -3½	0.050
>3″	12	0.060	60	L25M	4 -5	0.050

[a] Data from Norton Co., Worcester, Mass.

Cutting Large Sections. In cutting X-planes and Z- or Y-sections and in rough trimming operations, a very thick blade with coarse diamond grit is required. This permits cutting into sloping surfaces, reduces drift and speeds the cutting and following etching operation. In this type of cutting, the thickness of the blade is of no importance because at this stage the yield is not yet a factor. The Norton D46-125M has been successfully used for this work.

Wafering from Thin Bars. Cutting blanks from Y- or complementary-bars is the simplest and most precise procedure. Since the arc of contact is very small and the entering surface is flat and perpendicular to the blade, a small, fine diamond grit size, thin blade with large flanges may be used. This is the ideal condition for minimizing blade drift and also allows cutting the blanks as thin as 0.035″, thus permitting a considerably greater yield for the same weight of quartz than is obtainable in wafering by the other procedures. When thin bars, the same size as blanks are cut, microscope slides or thin glass may be cemented to the surfaces

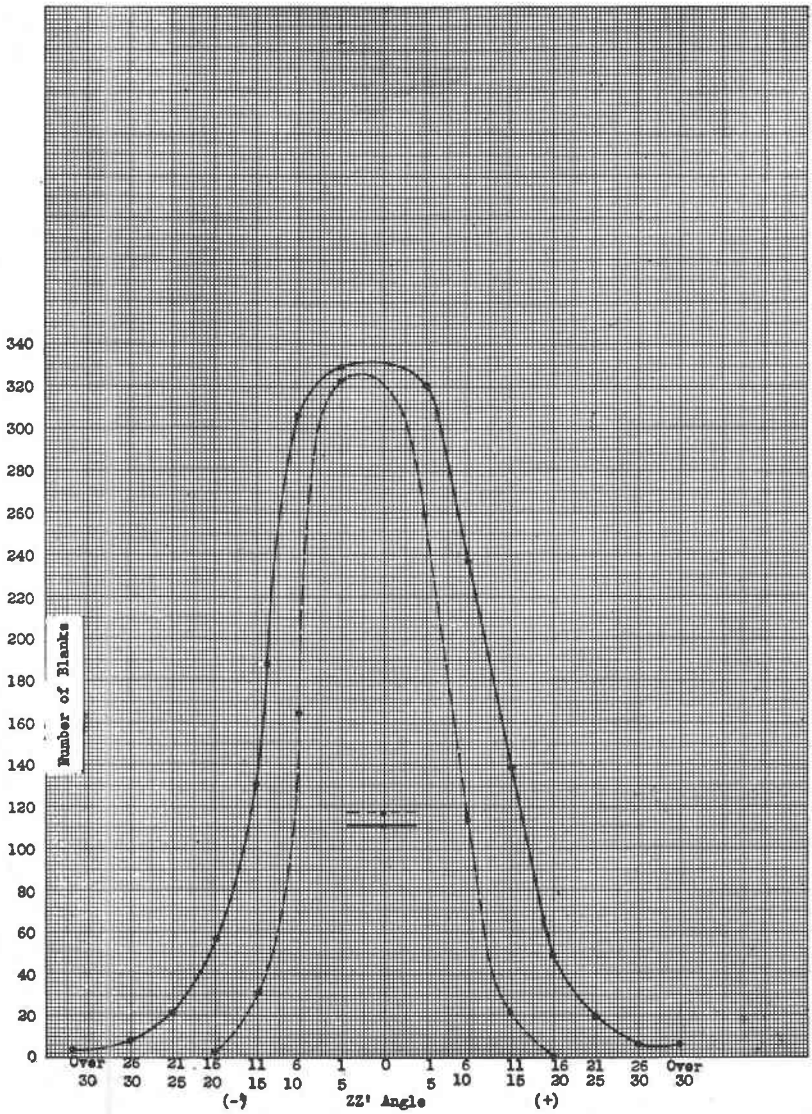


FIG. 9. Cutting accuracy. X-block method, Felker saws, Norton blades. Outer curve for ±15′ specified angular tolerance; inner dotted curve for ±10′ tolerance.

to prevent chipping of the blanks at the entering position of the blade or the sides. Two blades recommended by the Norton Co. for this procedure are 8″ dia., 0.045″ thick, 100S-L25M and 6″ dia., 0.035″ thick, 100S-L25M.

Wafering from X-Blocks. Wafering from X-blocks is an ideal set-up for cutting efficiency, precision and yield because the mount is firmly clamped to the saw table, thereby minimizing vibration. The entering surface is flat and perpendicular to the blade and the arc of contact is not excessive, so that thin blades and large flanges may be used (Table 1). About 5000 sq. in. would be a good life from a Norton blade used under these conditions.

The data given in Fig. 9 show the accuracy that is attainable with the X-block, wafering method. These results were obtained with Felker #80 and #120 saws using Norton metal bonded 8″ and 12″ diameter diamond blades. Cutting $\frac{1}{2}$″ sq. BT blanks with a specified angular tolerance of ±15′, 75% (1308) blanks were within ±10′ and 90% (1570) within ±15′. When the specification was reduced to ±10′, 94% (979) were within tolerance and 99% (1025) within ±15′.

It is also important to maintain a uniform thickness in cutting wafers. Too thick wafers are wasteful and when cut too thin cannot be used because the saw marks cannot be completely lapped off. Specifying 0.045″ ±0.005″, 87% (14,554) blanks were between 0.041″ and 0.051″ (Fig. 10).

Direct Wafering. Not only are the direct wafering single mount set-ups undesirable from the standpoint of orientation and yield as described in an accompanying paper, but they also are unsatisfactory because of the poorer blade performance obtained in cutting. The crystals are generally mounted on jigs which cause instability. Due to the irregularity in the shape of the entering surface, smaller flanges and hence thicker blades are required to minimize drift. Most manufacturers using such methods must angle-correct a considerable percentage of the blanks in order to meet the rigid angular specifications. Since the mount is usually at an angle to the saw bed, the saw stop cannot be set for one stopping point and the operator must be careful not to cut through the mount into the jig. In the X-block method, the depth stop is fixed to the same point for all the crystals, and hence one operator can look after several saws. 8″ and 10″ diameter blades, 0.045″ to 0.060″ thick, 60 or 80 grit size, L25M concentration are recommended by Norton Co. for this operation. The exact blade to choose is dependent upon the arc of contact; the smaller the arc, the thinner the blade and finer the grit size. The minimum wafer thickness should be 0.045″ to 0.050″, depending upon the blade used. If a considerable amount of angle correction is required it may be advisable to increase the minimum wafer thickness by 0.005″.

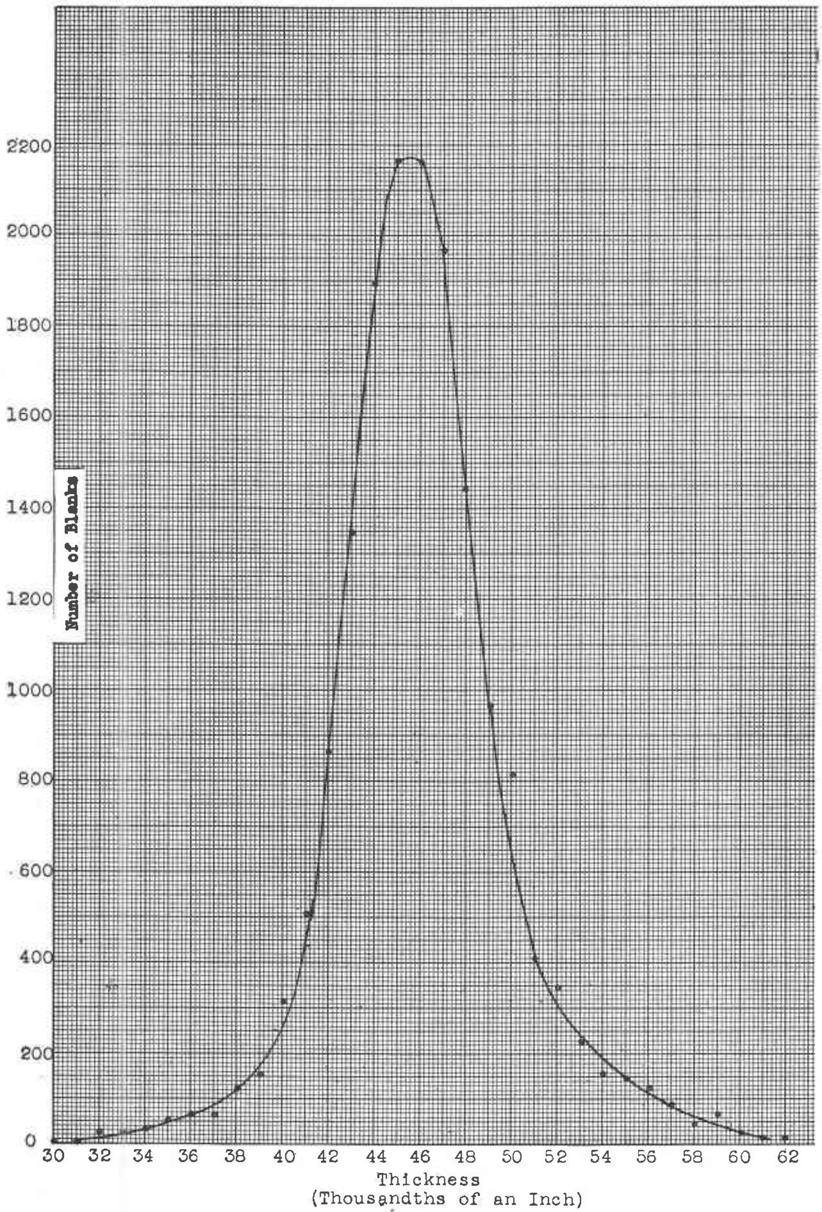


FIG. 10. Thickness distribution curve. Specified thickness 0.045 ± 0.005″.

Trim Sawing (Dicing)

The operation of cutting the blanks from the wafers is known as trim sawing or dicing. The wafers are etched, twinned and flawed areas marked out at the twinoscope, the usable portion of electrical twins determined, the wafer stauroscoped and the blanks laid out with a rubber stamp. The blanks are usually trimmed about 0.035″ to 0.045″ oversize to allow for squaring to final dimensions.

The usual method is to employ a trim saw of type shown in Fig. 11.[7] The blade position is fixed, the wafer held stationary by fingers on the

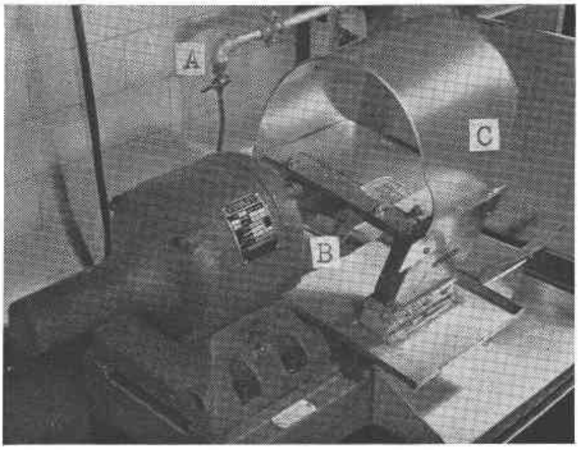


Fig. 11. Trim saw for dicing wafers. Table and wafer are rocked into blade. (A) Coolant system; (B) shallow felt filled reservoir for coolant; (C) coolant shield.

saw table and the latter rocked into the blade. This arrangement has proven more successful than sliding the table or the wafer into the blade. The saw table (Fig. 12) has a pair of adjustable reference edges and a wide slit for the blade which is about $\frac{1}{4}$″ above the surface of the table. The back reference edge is perpendicular and the side reference edge parallel to the blade. The distance between the latter two is fixed to the desired blank width; a special arrangement permits adjustments in steps of 0.001″ up to 0.020″ without disturbing the reference edges by moving the slit laterally with respect to the blade.

Wafers cut by the X-block method already have reference edges exactly perpendicular to X remaining from the X-planes. The reference edge permits maintaining the dicing angle parallel to the Z-axis. The

[7] Designed by T. W. M. Schaffers, N.A.P. and manufactured by Hammond Machinery Builders, Inc., Kalamazoo, Mich.

smoothest edge is placed flush against the back reference edge and a cut made perpendicular to it along the edge of the first row of blanks. The wafer is then shifted laterally until the cut edge is flush with the side reference edge and strips of blanks are cut. The strips are cut into blanks in a similar fashion. The cutting is rapid. A 2″ long cut in a 0.045″ thick wafer takes 15 seconds. The average time for cutting a ½″ square blank is one minute.

A 3″ dia. Norton metal bonded blade, 0.020″ thick, D180L50M is used at 3450 r.p.m. The coolant, a mixture of deodorized kerosene and trans-

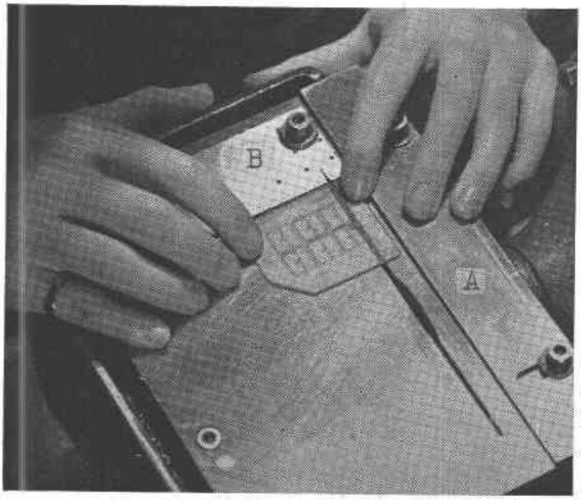


FIG. 12. Trim saw table. (A) Adjustable side reference edge set to desired blank width from blade; (B) rear reference edge perpendicular to side reference edge and blade. First cut is being made on wafer after which it will be translated to side reference edge to cut strips of blanks.

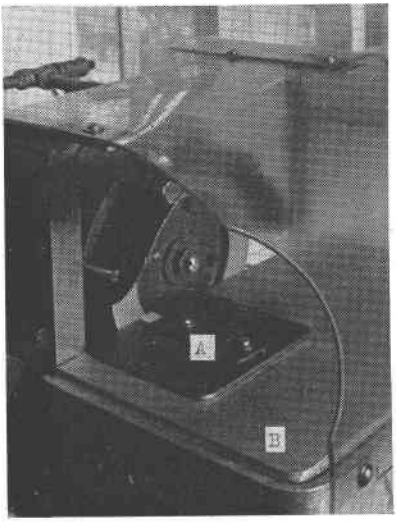
former oil, is supplied by a small circulating pump to a shallow felt-filled trough around the bottom of the blade. Other blades used for trim sawing include 4″ and 6″ dia. 0.035″ thick. Resinoid bonded blades are also used but must be operated at much higher speeds.

Another method of dicing is to cement the wafers, major face down, onto a large flat metal plate which has grooves a little wider than the diamond blade, spaced the trim-sawing distance apart. The plate is positioned on a saw table by means of pins on the under side of the plate and the wafers diced by cross-cutting. Although the method is faster than the one described above, the yield is much lower because there is no way of salvaging twinned and flawed areas.

SQUARING

The process of reducing trim-sawed blanks to approximately final edge dimensions is known as *squaring* or *edging*. It is one of the most difficult steps in the procedure. The blanks are often squared before the first lapping stage and the tolerance generally specified are $\pm 0.001''$; in predimensioning even closer tolerances are required and no completely satisfactory method has yet been developed for this purpose.

Crystals may be squared individually (when small quantities are required) or by loafing together (for production purposes). A machine



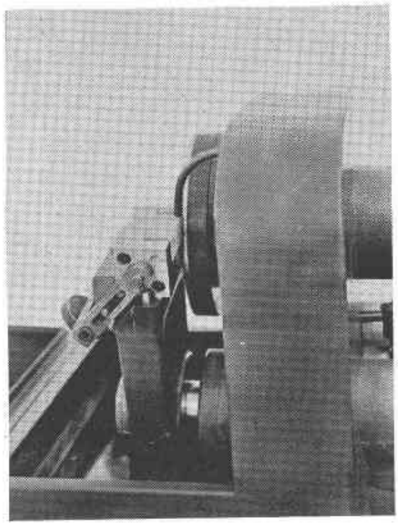
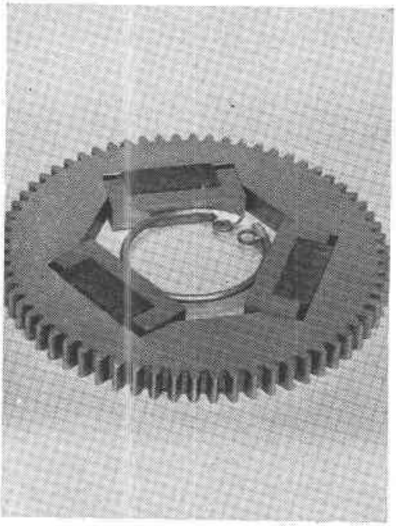


FIG. 13. Machine for squaring blanks individually. A 6″ dia. metal bonded cup wheel runs on an Excello precision grinder, 3450 r.p.m. The crystal is held in place in jig (A) whose position can be adjusted with respect to wheel. Large light weight table (B) runs on ball bearing races and is easily moved by hand. Micrometer screw working against stop permits setting to desired dimensions.

FIG. 14. New crystal edging machine manufactured by Volkel Bros. Machine Works, Los Angeles, Calif. Loaf of blanks carried by arm which oscillates over faces of Felker Di-Met resinoid bonded diamond abrasive wheel.

for squaring crystals individually is shown in Fig. 13. A 6″ diameter metal bonded diamond cup wheel such as the Norton D150N100M mounted on an Excello grinder was used for this purpose. Resinoid bond wheels are also used and the new vitreous bond is promising. Various diamond grit sizes are available; the finer the grit used, the slower the cutting but the better the finish. Two stages of squaring are often used to obtain maximum speed and quality of finish. The wheels are run at a relatively high speed (3450 r.p.m.) and must be mounted on a good spindle to keep vibration to a minimum. The jig which holds the crystal on the table must be accurately set with respect to the wheel to obtain perfectly square blanks. The width of the blanks can be set by means of a micrometer screw working against a stop. Tables for machines of this type must be carefully designed and built to obtain good results.

Various methods of squaring by waxing crystals together in a loaf on a V-block are used. In some methods the V-block is held magnetically to the base of a surface grinder and one edge of the loaf lapped with a dia-



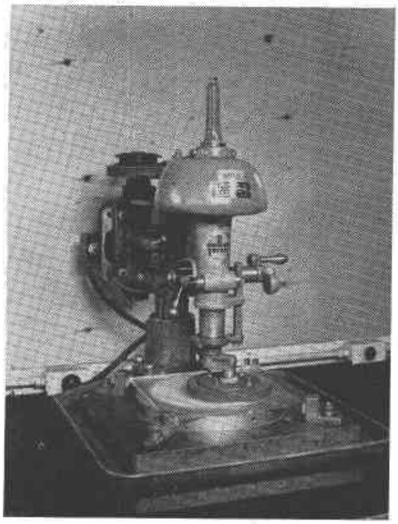


FIG. 15. Planetary lap gear for squaring crystals. Loaves of blanks are loaded in special gears and two surfaces lapped at once. Loaf is turned over for lapping other pair of sides. Method has extraordinary production capacity.

FIG. 16. Method of lapping-in diamond abrasive wheels. Backing plate screwed to wheel and lapped in a few minutes with drill press lap on glass plate with coarse silicon carbide. This "unloads" diamond points and sharpens cutting action.

mond wheel. After one side is finished the loaf is rotated 90° and the operation repeated. Some of the problems encountered are chipping of the blanks and difficulty of obtaining perfect right angles between the edges. The new Volkel crystal edging machine[8] was especially developed for this work. It is stated that one machine (Fig. 14) has a capacity of 2000–3000 crystals in eight hours. The crystals are mounted in a block on an arm which oscillates over a Di-Met resinoid bonded diamond cup wheel and automatically shuts itself off when the required size is attained.

[8] Manufactured by Volkel Bros. Machine Works, Los Angeles, Calif.

An excellent production method devised by E. F. Sheeder, N.A.P., employs the planetary lap.[9] Crystals are held in U-shaped blocks without waxing and are tightened lightly from one end by a set screw. Three blocks are placed in a gear (Fig. 15) properly machined and three gears at a time are lapped. A spring ring holds the three U-blocks in position. The crystals are lapped with #320 or #600 silicon carbide and a dial micrometer on the upper lap plate indicates when the proper thickness has been reached. After one pair of sides is lapped the crystals are rotated 90° for lapping the other pair of sides. One planetary lap has a capacity of about 5000 blanks per eight hour shift.

[9] Parrish, William, Machine lapping of quartz oscillator-plates: *Am. Mineral.*, this issue.