CHAPTER XVI

The Wire Mounted Crystal Unit

By WILLIAM F. DREWS and ANDREW E. SWICKARD

16.1 Introduction

A DISCUSSION of crystal theory, design and manufacture cannot be considered complete without a description of the manufacturing process for at least one unit. The unit chosen for that purpose should preferably be one which involves something unusual such as extraordinarily large quantity, or low cost, or both. Probably no type of crystal unit could be chosen for that purpose that would be more appropriate than the wire mounted unit, FT 241 type, of which upward of 10,000,000 were manufactured between the fall of 1941 and the end of 1944. Not only does this crystal hold the record for number to be made by a single manufacturer, but it pioneered the way to show how cheaply crystals could be made by the development of special equipment whose operation was simple, which utilized the ordinary grade of factory worker with a small amount of training and which permitted using the lower grades of quartz. It provides also a most excellent example of cooperation between the highly theoretical research man, the manufacturing development engineer, and the operating personnel to produce quickly an element vitally essential to military plans. It provides an example also as to how resourceful the native American can be. The research men spent several months right in the factory investigating troubles and suggesting solutions, and in many cases designing and constructing equipment that went directly into the production line. The development engineer suggested changes in crystal design and in operating techniques. The operating personnel also stepped from their chosen field and insisted on changes in machines, tools, and crystal design. Very often, to their own surprise as well as to the surprise of others, the suggestions and changes turned to be out successful.

The intensive effort to get this unit into production quickly brought results far beyond the expectations of the most optimistic. The actual manufacturing costs were as far below the costs that had been estimated as the latter had been below prewar costs on crystal units. In addition the rate of manufacture in a single establishment climbed so that the daily output was over twice the yearly output by the same company in prewar years. The design and the manufacturing processes that were involved in this unexpected achievement will take their places among the industrial efforts toward war preparedness that have made this country famous.

At the time of the outbreak of the war in Europe, the use of crystal control had become practically universal in this country for frequency control in radio transmitters. There was developing at that time a demand for quick and exact shift of both receivers and transmitters from one channel to another. The sets that would permit making the shifts by means of simple motions had been especially useful in aircraft where the pilot had so many things to do that customary tuning methods common to broadcast receiving were too time consuming and uncertain at best. The use of crystals for beating oscillator control in receivers had simplified the problem, and many aircraft had been so equipped.

With the initiation of preparedness in 1940 the military people wishing to secure the greatest possible tactical advantage from radio communication made plans to capitalize on the important developments that had occurred in radio up to that time. The use of crystals for controlling the transmitters should provide more channels than could otherwise be secured. Either automatic mechanical tuning or crystal control in the beating oscillator should permit tuning a receiver without preliminary testing. The tactical advantages of these simplified manipulations were so great that calm judgment dictated that they should be pushed to the limit. The result was that radio sets were ordered for all kinds of services and they were all to embody one or more crystals.

Among the sets ordered were those for tanks. Tanks were ordered in large numbers—hundreds of thousands. Such large numbers together with the need for channel shifting to reduce enemy interception called for provisions for each tank being able to work on a large number of frequencies. Provision was therefore made to include 80 crystals with each transmitter.

Later other sets for other purposes were designed to employ as high as 120 crystals in each transmitter. The number of crystals needed therefore climbed to formidable proportions.

A decision to utilize frequency modulation in the tank sets brought with it the requirement that the crystal operate in the low frequency range (350 to 550 kc) rather than the high frequency range (5 to 10 mc) as used for most of the amplitude modulation sets. Such a crystal could best be made to operate at a frequency determined by its larger dimensions rather than its thickness. This introduced a new complication. The crystal units developed for and largely used in radio applications previously were of the thickness vibration type, were held in a clamped holder, and their frequencies were in the higher range. The types of holders thus in most common use could not be used with the new crystals, the frequencies of which were around 350 to 550 kc. It became necessary therefore to develop a new crystal mounting. Point clamp mountings had been developed for several lower frequency filter types of crystals, and for 100 kc frequency standard units. Such types of mountings were hardly suited to the vibratory tank service. Other filter crystal units had been developed for filter purposes in which the crystals were supported by wires soldered to platings on the crystal. They had also been tried experimentally for radio. This type of support seemed to be more feasible. Though development work was done on both kinds of mountings, the wire mounted crystal came to fruition quicker, and has maintained its lead in satisfaction of performance.

16.2 The Crystal Cuts

The crystal cuts utilized in these wire mounted units are the *CT* and *DT* cuts. They are described in Chapter 1, paragraph 1.5 and Figs. 1.9 and 1.13, and in Chapter VI, paragraph 6.24 and Fig. 6.6. The vibration occurs in the form of a shear in the plane of the large faces as indicated in Chapter VI, Figs. 6.4 and 6.6. The frequency-temperature curves for the crystals are indicated in Fig. 1.14 of Chapter 1. The location of the apex of the frequency-temperature curve in these crystals is not an invariant, but is a function of orientation. *CT* and *DT* crystals designed for various operating temperatures may, therefore, be cut with orientations varying slightly from the figures given. These crystals in the main were oriented at 38° 0′ for the *CT* and −52° 30′ for the *DT* having in mind temperature range use of 20° to 70°C and −30° to +55°C respectively. For a temperature range of −40° to +70°C, *CT* crystals are oriented at 37° 45′, 200 kc *DT* crystals at −52° 00′ and 500 kc *DT* crystals at −52° 30′.

16.3 Supporting

The crystal, with electrodes plated on its two sides, is supported in its mounting by two wires soldered to the electrodes on opposite sides, at as near the center of each face as practical. The wires not only support the crystal physically but provide the electrical connection to the electrodes. The supporting wires were in turn soldered to larger conductors that make connections with the mounting terminal pins. These larger wires were designed and proportioned to take up most of the shock from normal handling. A photograph of one of these mounted units is given in Fig. 8.5, Chapter VIII.

Since the earliest use of crystal control, the mounting of the crystal plate has been a problem. As much work has been done on crystal holders or mounts as upon the crystal element itself. The crystal element, to be vibration free, must be held in such a way that the necessary vibration can occur freely. It is very impractical to cut the crystal element out of the mother crystal with a "handle" of crystalline material as an integral part so placed as to have no inhibiting reactions. On the other hand, attempts to hold a crystal loosely have usually resulted in frequency variation or other undesirable characteristics. Clamping of the crystal at substantially quiescent points has worked well in radio for high frequency crystals (thickness vibration type) but for low frequency crystals, such points reduce to a single central point or line. Rigid clamping at such points is very satisfactory for the low frequency crystals that receive little or no handling after installation and are used in places having little vibration. The provision of a "handle" by attaching a conductor to the crystalline plate solves many problems, but the details involved in the solution, both design and manufacture, are large in number and determine the performance as well as the cost. The more important of these details will be discussed.

16.4 The Crystal Element

The crystal element, cut from the mother crystal, is assumed to have a proper angular cut before consideration is given to the other physical characteristics necessary for this unit. The crystal is made square largely for convenience. One pair of edges of a large face is specified as parallel to an electric axis, while the other pair is to be perpendicular to the same axis and inclined to the optic axis by the "angle of cut," viz. 38° 0′ or −52° 30′ as the case may be. The orientation of the face is specified as ±15′ from these angles. The crystal may actually be rotated within this plane up to about 2° with little effect. Upon departing from squareness, changes occur. If the X dimension is shortened, zero temperature coefficient occurs at a lower temperature and the angle of cut must be increased to restore it. If the Z dimension instead is shortened, the opposite movement of zero temperature point occurs within limits and opposite rotation of angle of cut is then necessary for restoration. The shift in temperature coefficient is not rapid enough to prevent adjustment to frequency without harm to the temperature coefficient by slightly grinding off one edge only after the crystals have been originally ground to convenient mechanical dimensions in the preparation of the blanks.

The thickness of the crystal plates has more than one effect upon performance. The impedance is lower with thinner crystals. The flexure vibrations of the crystal will have a lower frequency and have a greater number of harmonics if the crystal is made thinner. The flexure frequencies can couple with a desired frequency and give trouble both in activity and in temperature coefficient. However, all harmonics do not give equal trouble. The thickness of the crystal must, therefore, be chosen to produce a minimum of disturbance. The thicknesses being used as of the date of the preparation of this chapter are given in the table below although investigations under way were indicating that a reduction in rejects might be secured by a number of changes.

Frequency Ranges—Kc	*Thickness—inch*
370– 428	.0185–.0199
428– 475	.0160–.0175
475– 540	.0185–.0199
730– 875	.0120–.0140
875–1040	.0160–.0175

The *DT*'s are made around .017 inch thick.

The finish on the crystal blank can at times be important. The grinding process is basically one in which the surface of the material is shattered in minute spots by virtue of a particle of abrasive getting caught between high spots of the crystal surface and the grinding lap. The shattering not only knocks off pieces that are carried away, but produces minute cracks extending downward into the crystalline material. These cracks can be a source of loss when their sides rub together as the crystal distorts in shape during its vibrations. The activity may thereby be affected. Giving the crystal a finer finish will reduce the depths of these cracks and improve the activity. This phenomenon is of especial importance with DT plates of high performance requirements.

16.5 The Plated Electrodes

The electrodes are of silver, plated on the two sides of the crystal by the evaporation process of Chapter XI. Plated electrodes have several advantages over other electrodes. (1) The plated electrode is nearer the crystal than physical plates can be placed. The smaller distance increases the coupling and reduces chances of arcing between the electrode and the crystal surface. (2) The plated electrode always retains its position with respect to the crystal. Any movement of a crystal with respect to an electrode causes a change in frequency. (3) Plating the electrode on the crystal is the most practical method of holding an electrode near a low frequency crystal where any vibration or movement is present. (4) Plating assists in preventing aging as it protects the quartz surface from the erosion that causes aging.

The plating of the electrode on the crystal does have the difficulty that corrosion of the plating will affect the frequency.

Before the crystal element is plated, it is etched, and the silver spots to which the supporting wires are soldered are applied. The silver spotting, together with other information on plating is given in paragraph 13.4 of Chapter XIII.

16.6 Wire Soldering

The machine to solder the supporting wires on to the crystal plates is one of the most important elements entering into the successful manufacture of the wire mounted crystal. The machine as developed is shown in Figs. 16.29 and 16.30. Referring to both figures, a crystal element already plated and spotted is placed between self-centering jaws. Beneath the jaws is a hot plate, to assist in the soldering process. The wire made of bronze and electro-tinned is fed from a spool, but caution must be taken that the wire comes off the spool relatively straight without a short radius set. The amount of solder used is controlled by punching a pellet from a thin ribbon of solder. Easy handling of this small pellet is accomplished by spearing it with the guided end of the wire to be soldered to the crystal. The impaled pellet is dipped in rosin-in-alcohol flux, and then placed by the carrying arm exactly on the silver spot, where the solder is melted by a blast of hot air. Iron (with aluminum tip) soldering was used in the early stages of development, but better results are obtained with hot air. The soldering is watched through a binocular microscope so that the hot air can be cut off when the solder has taken the proper shape. The solder used is a 63% tin 37% lead eutectic solder with $\frac{1}{10}$% silver to prevent its removing silver from the crystal. This solder completely solidifies at a given temperature producing a more uniform cone. A scissors element then cuts the wire, the operator uses tweezers to turn the crystal over, and a wire is soldered to the spot on the opposite side. It has been found that the operator must develop a certain soldering technique, and that slight changes in operation are necessary from time to time because of variations in the silver spots, solder, flux and wire. A well made solder joint will withstand a pull of 700 to 1000 gms., for a .005-inch diameter wire.

The solder's physical properties, the amount, and the shape of the final solder cone all enter into losses affecting the crystal's activity. If the solder cone is too eccentric, the crystal is discarded, stripped and reprocessed. This subject is discussed to some extent in Chapter VIII, paragraph 8.2.

Tests on the silver spot and on the solder joint cannot be carried out without weakening or destroying their adhesions. A small percentage of the crystals coming through in a group are tested to destruction. If any fail before reaching a desired tension, the entire group is rejected.

16.7 Mounting

With a crystal element plated, and wires soldered to the centers of the two sides, the problems of mounting are not overcome. It seems to be physically impossible to manufacture the crystals so that the wires will be attached at points that are suitably quiescent. Generally there is no quiescent point.

The motion associated with this type of crystal element is composed of a face shear, the principal one, a thickness type shear, and a plate flexure. These motions if in phase sum up to determine the nodal points at or near the center of the plate. If not in phase, no quiescent nodal point exists. To locate the nodes or points of minimum motion in each individual case before attaching the wires would not be practical. The wires, therefore, are attached to the physical centers of the plates and it is assumed that some movement will take place. The result of such movement is that mechanical waves are transmitted outward along the supporting wires. Such waves may absorb some energy. If the wires are soldered to other conductors comprising the base of the mounting, reflections of the waves will occur at such places and the energy returns to the crystal, probably not in phase with the crystal vibration. Such reflected wave will act like added inductance or capacity to a tuned circuit, and change the frequency, or like added resistance and reduce activity. Such effective inductance or capacity will vary with temperature, producing a frequency change that may destroy the low temperature coefficient performance expected. To eliminate this trouble, it is necessary to control the length of wire between the crystal and the solder connection out along the supporting wire. This is accomplished in a practical manner by placing a ball of solder, or other mass at such a position as to minimize the reaction on the crystal of the length of wire between it and the crystal. Fortunately, the minimizing is not a critical matter. A given distance of location will do for a range of frequencies. The theory of this is given in greater detail in Chapter VIII paragraph 8.4 and its Appendix D and in Chapter XIV, paragraph 14.34.

The mass of metal may be a separate piece of metal or, as found convenient in practice, it may be the solder that holds the wire to a supporting frame or other conductor.

The mounting for the crystal consists of a molded bakelite base containing two pins that are both support and external contacts. Formed pieces of tinned piano wire are soldered to the pins to act as support for the crystal. They are shaped so as to provide under impact a minimum of twisting and bending of the wires soldered to the crystal, and of such strength as to provide good cushioning.

16.8 Adjusting to Frequency

The crystals, after mounting, are thoroughly cleaned and then placed in a test oscillator circuit for frequency adjustment. This operation is performed by removing quartz from one edge of the plate by hand-lapping with fine emery paper.

The units after adjusting are again washed, baked four hours at 70°C and sealed. For sealing, a molded cap with neoprene gasket is held on with two screws extending through the base. Neoprene is used instead of rubber as the sulphur in the rubber will attack the silver electrodes. After the crystals are aged over four 2-hour cycles of heating to 70°C, and cooling, they are ready for inspection.

16.9 Increased Frequency Range

The crystal units of this type as first manufactured were for frequencies between 350 and 550 kc, and utilized the *CT* cut. A request for a unit for 200 kc coming after manufacture was under way resulted in the development of a modified unit with the *DT* cut of crystal. By using the *DT* cut, it was possible to use the same size of holder where it would have been necessary to construct a larger holder if the *CT* cut were used. Also it permitted meeting a lower frequency tolerance over the temperature range.

Later requests for higher frequencies resulted in developing crystal units of the same design, *CT* cut, going up to 1100 kc. This resulted in crystal plates smaller than $\frac{1}{8}$ inch square. The same general process of manufacture was used, but many refinements were necessary to get satisfactory crystal units. The higher frequency crystals were more difficult to make than the lower frequency units as it was not feasible to reduce all dimensions of wire, solder, etc., in exactly the same proportion. The margin of activity was smaller and a number of other problems arose that gave no trouble in the lower range.

An interesting example of the conservation of quartz came about in connection with the manufacture of these higher frequency elements. During the first year and a half of manufacture of the 350 to 550 kc range units, all crystalline blanks or "dice" as they have been termed too small for use in that range were saved although no plans had been made for their use. This "junk" material has furnished all the blanks for the units for the extended frequency range thereby obviating the use of any new quartz for that purpose.

16.10 Shop Operations

The design of the crystal unit and the entire manufacturing process are the result of cooperative development between the crystal design engineers, the manufacturing engineers, and the operating department whose cooperation was necessary to do experimental work with shop help and equipment. The urgency of the war situation did not allow of following the usual procedure of fully developing and designing the unit in the laboratory and then placing it in the factory. It was necessary to make tentative models and designs, securing suitable operativeness on a number needed for developing the radio sets by application of techniques known in the "art" by the engineers, and then approaching the factory engineers to see to what extent the tricks of the "art" could be utilized in the factory with the intention that the more expensive or impractical methods would be studied and reduced to simply controllable operations or eliminated. The most difficult or troublesome problems from the manufacturing standpoint received first attention. The manufacturing engineer took steps to make better machines, tools, or jigs. The research man took the crystals that were rejected after such processes and determined just what was the trouble with such elements that caused them to be rejected. At times a new machine or tool solved the problem. At other times a change in design either solved the problem or pointed the way to a solution. This cooperative effort resulted in a design that could be manufactured cheaply, and in a manufacturing process that required much less space, personnel, and time than was considered possible when the manufacture was initiated. It yielded greater production from the space assigned than was originally planned, and it resulted in a lower cost than would have been prophesied by the most enthusiastic crystal engineer.

Development in the manufacturing process was enforced for other reasons. When manufacture of these units was started, the procedures were based upon raw crystals of approximately 3 pounds weight. As the demand increased, such sized raw crystals became scarce and it was necessary to utilize smaller and smaller crystals. In addition early processes utilized natural crystal faces to assist in first orientation cuts. Later it became necessary to use pieces that showed no natural faces. As devices for using such crystal material were developed in a form suitable for factory use, they were included in the equipment. Such devices, described in the figures, made it possible to use raw quartz that a few years ago was considered useless.

Inspection of the manufacturing process outlined in the attached pictures will indicate that a considerable use is made of X-rays for orienting the crystal plates. X-ray determination of orientation is not a simple and easy matter, as evidenced by Chapter III in this book on the subject alone. The Western Electric Company was probably the first user of X-rays and ionization chambers in factory production of crystals, their use going back to 1932. In the intervening years many improvements in equipment and technique have been devised. The equipment was developed so that a simple and easily operable machine was available for each operation. The ionization chamber was preset, and simply adjustable jigs were provided so that an operator could quickly be taught to manipulate the adjustments and controls.

Advantage was also taken of improvements by others outside the organization in blades, wheels, laps, and machines wherever they could be found on the market.

From an historical point of view, it would be interesting to cover the developments in detail describing the difficulties encountered and the solutions evolved. However, such narration would be of questionable benefit to the reader. It appears preferable to describe only those points that are known to be of use to an engineer. The points involving design have been covered in the text. All of the points in manufacture have not. To that end a series of photographs of the more important steps and machines are given herewith together with explanatory captions that go into considerable detail. These figures show equipment used in the process at the time this material was prepared. It is very possible that by the time this material appears in print, modifications may have been made.

16.11 Auxiliary Instruments

Fig. 16.1—The inspectoscope

Crystals, before processing, require inspection. The crystals as they come from the quartz mines often contain unusable parts caused by cracks, inclusions, and coloring matter. The inspectoscope, whose theory of operation is described in Chapter IV, paragraph 4.7, is used to detect these flaws. The crystals, which at this stage in the processing are called "stones" are immersed in the oil in the inspectoscope and illuminated by the powerful beam of light through the circular opening only part of which can be seen above

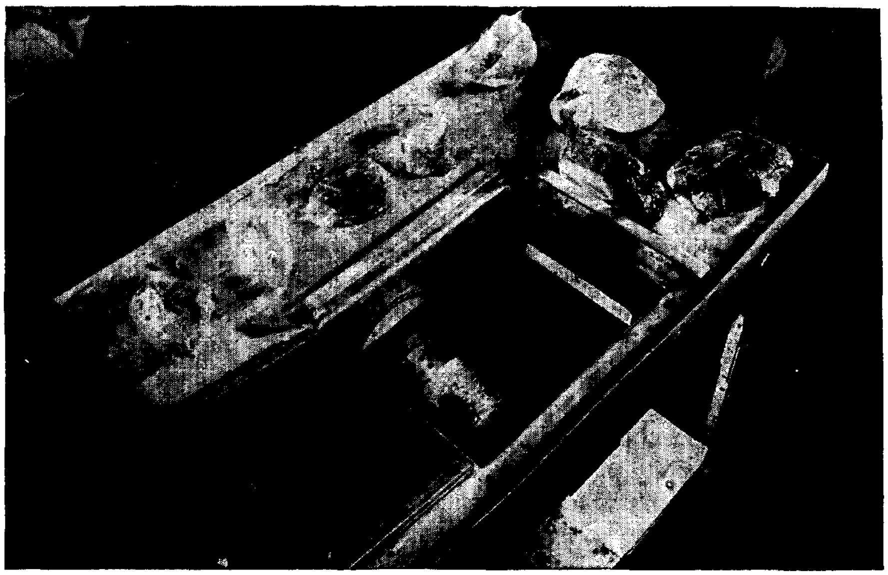

Fig. 16.1

the oil in the picture. Unusable stones or parts of stones may be discarded or otherwise suitably marked to show the usable parts.

Most stones also have few natural faces. They have been subjected to erosion for thousands of years and the outer surfaces have been largely chipped away. Some of the stones have no natural faces and it is necessary to use optical means to learn the direction of one of the principal axes. The inspectoscope provides for this also. Diffused polarized light from the rectangular end window passes through the stone and is observed visually as it is reflected from a 45° mirror in the left hand compartment. The stone is rotated until suitable rings appear at which time the Z or optic axis is parallel to the direction of light through the stone.

The diffused polarized light is also used to detect optical twinning, which is undesirable so far as crystal manufacture is concerned.

Fig. 16.2—Lap wheel

A suitable flat spot is then ground on such a side of a stone that it will lie on the bottom of the inspectoscope in the position that gives the indication that the optic (Z) axis direction is parallel with the bottom.

Another flat spot is then ground on the opposite side of the stone, and while the stone is properly oriented within the oil, a line is drawn on this upper flat surface perpendicular to the optic axis using a straight edge pro-

Fig. 16.2

vided in the inspectoscope oil bath. The first step in orientation is then completed.

Fig. 16.3—Diamond saw

The stone is now cemented to a rectangular glass plate using a thermal setting cement, with the first mentioned flat side down, and the mark on the top flat spot oriented to be parallel with the saw position. The glass plate is clamped in a diamond saw and a small piece cut off one end of the crystal. The plane of the cut is now approximately perpendicular to the direction of the optic axis.

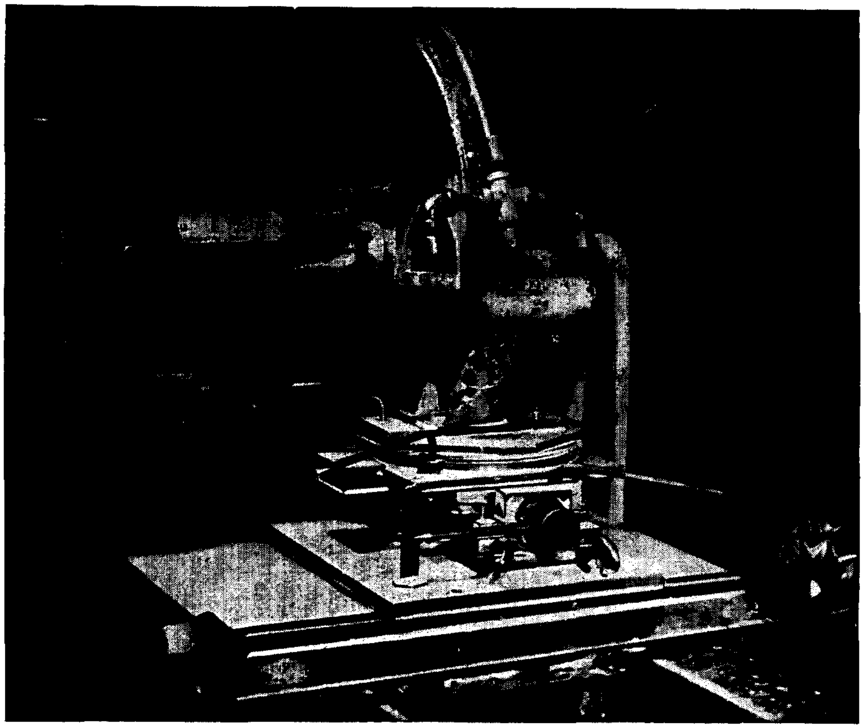

Fig. 16.3

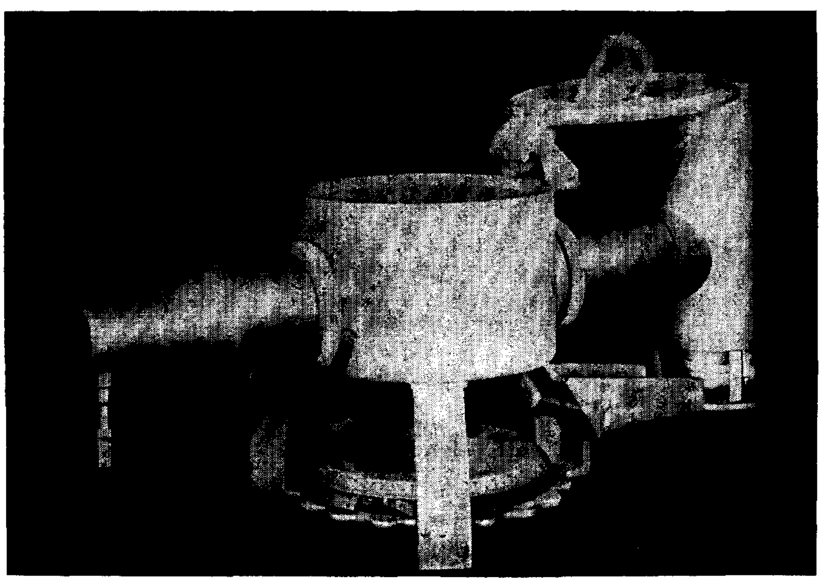

Fig. 16.4

Fig. 16.4—The conoscope

The sample is now inserted in the conoscope which will indicate with much greater accuracy the direction of the optic axis. The error in positioning the optic axis of the stone from the plane of the saw is thus determined.

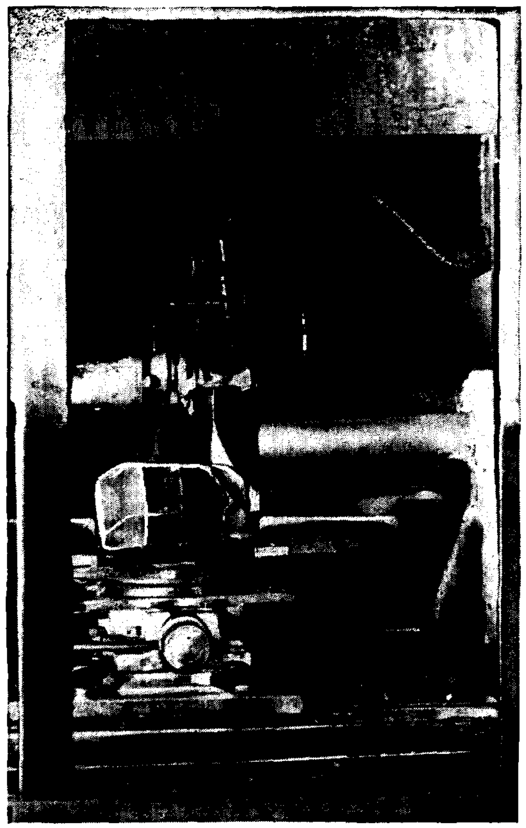

Fig. 16.5

Fig. 16.5—Sectioning

The fixtures on the saw are readjusted to correct for the misorientation of the optic axis, and the stone is sawed into sections with faces perpendicular to the optic axis.

In this picture the left hand end has been cut off the stone for orientation test. Two saw cuts have been made for sectioning and the third is being started.

Fig. 16.6—Correcting a section's face

Each section is then tested in the conoscope of Fig. 16.4 and the misorientation, if any, of one of the faces determined and marked on the section in a suitable manner. The sections are then ground on the lap wheel by holding the crystal by hand, and applying pressure over the side requiring the most grinding. In a short time an operator acquires enough experience to estimate the amount of grinding necessary. This grinding operation establishes a "corrected surface" normal to the Z axis within 15.′ One edge of the

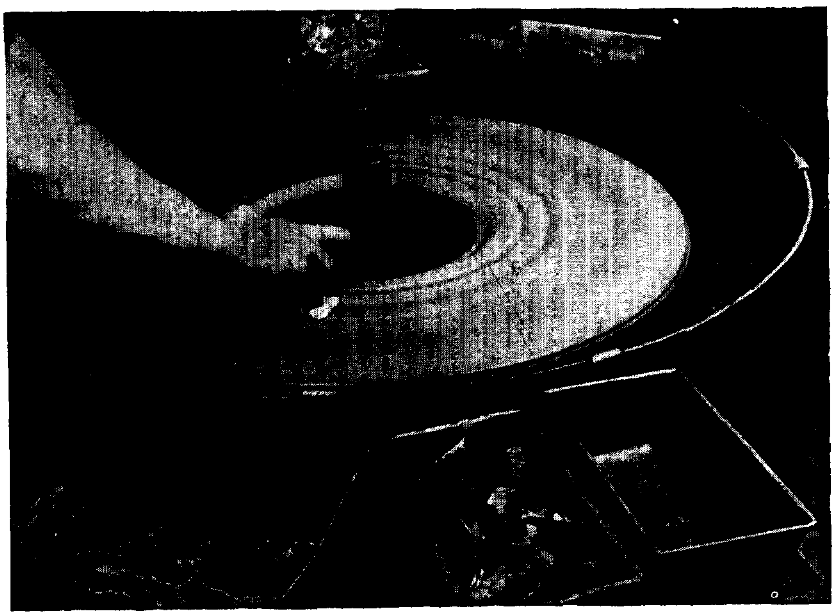

Fig. 16.6

completed crystal plates cut from this section will lie parallel to the X axis which lies in the plane of the surface just ground.

In this picture, the markings on some of the sections may be seen.

Fig. 16.7—Etching bath

The sections are now retested in the conoscope, this time to determine whether the section is of right-handed or left-handed quartz, and suitable identifying notches are ground in the section.

The sections are then placed in a container and lowered into a bath of about 30% hydrofluoric acid to etch the surfaces. Sections are contained in the left hand container shown in the picture. Slabs from a later operation appear in the right hand container.

Fig. 16.8—Pin-hole oriascope

The etched section, after washing, is now placed on the pin-hole oriascope to determine the sense and approximate direction of an electrical axis. The section is also analyzed from the standpoint of twinning to determine the parts that cannot be used. A place around the periphery of the section is selected to be ground flat. This place is selected to provide a minimum

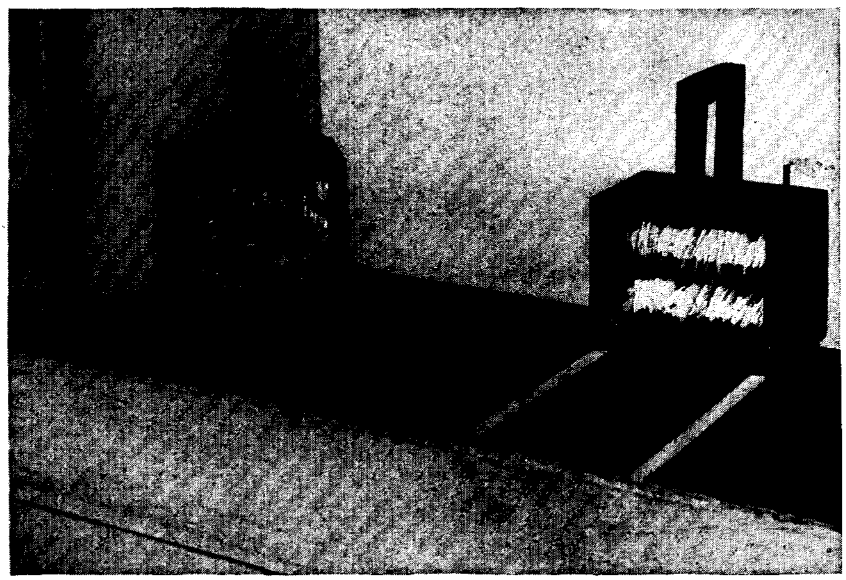

Fig. 16.7

amount of grinding necessary to obtain a plane surface approximately parallel to a natural prism face and at the same time be parallel to the X axis selected for slabbing. The section is then held on a lap wheel until a spot at the selected place has been ground.

Fig. 16.9—X-ray determination of the X axis

The location of the X axis by the Pin-Hole Oriascope is insufficiently exact for cutting but is mainly carried out to facilitate the more exact location using X-rays. The section now undergoes two successive X-ray operations one of which is also a preliminary determination. The section is placed on a flat plate in the position appearing in this figure with corrected face down and rotated by hand until indications of proper orientation are secured. The direction of the X axis and its positive or negative end are now marked upon the upper surface. This mark is suitably accurate for the first step in preparing for the next operation.

The corrected Z face of the section is now painted with a colored lacquer to designate the angle of cut of slabs to be cut from the section. The

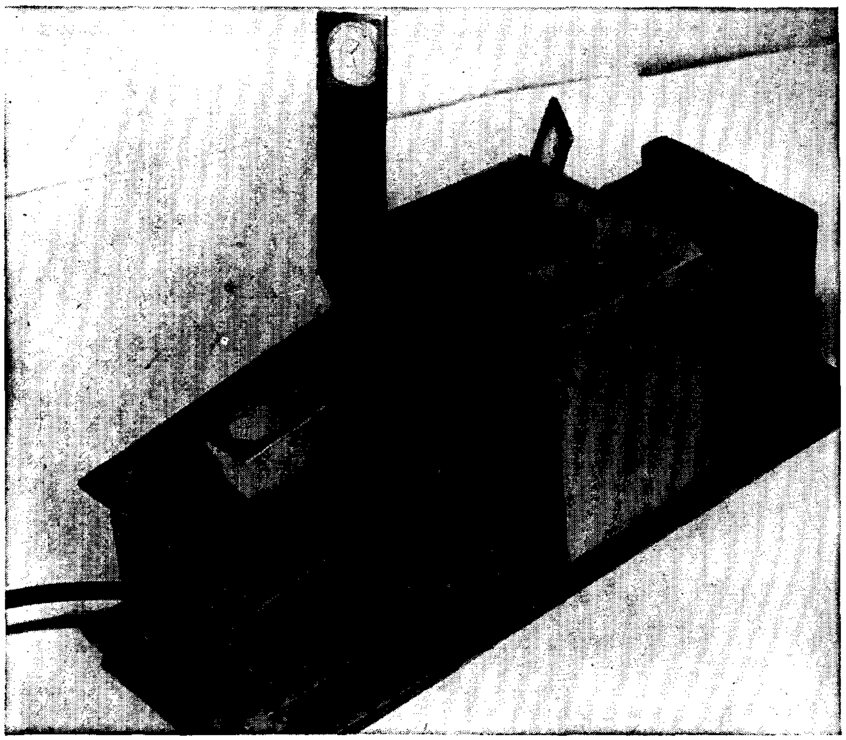

Fig. 16.8

colored lacquer will appear on one edge of all except the first two slabs cut from a section, and will serve as an indicator of an edge with proper and known orientation parallel to an X axis. As an added precaution, all bevelled edges are lapped flat except the edge having the proper orientation.

The markings of this X axis are still of insufficient accuracy for use in actual cutting but they are of sufficient accuracy to fall within the range of adjustment in the supporting element of the saw. The section is therefore cemented to a glass plate according to the markings and the glass plate is placed in the sub-base supporting element from the saw, and both are placed in the X-ray machine as shown, in a fixed position having a definite relation with the position it takes in the saw. Adjustments in the sub-base now are made that rotate the crystal section to give a maximum deflection of the indicator. The sub-base is then locked. The sub-base with section is now transferred to the saw, and the saw will cut off slabs with desired orientation.

Fig. 16.9

In the figure, the X-ray tube lies in the cylinder between domes A and B. The X-rays come out a slit C, are reflected at a glancing angle off the far side vertical side D, and enter opening E of ionization chamber and amplifier F and correct orientation occurs when a maximum deflection is observed on instrument G.

Fig. 16.10—Cutting slabs

The sub-base, with the oriented section now goes into a fixed position on the saw, and the section is sawed into "slabs." Each slab, which is to

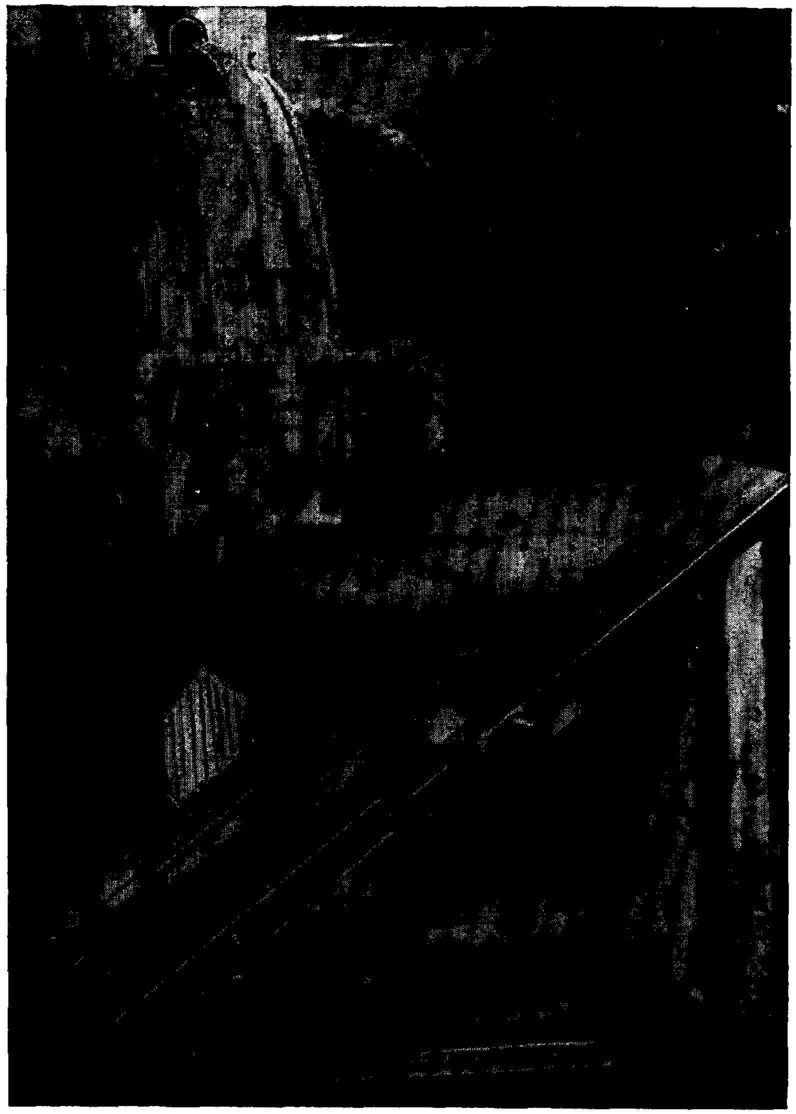

Fig. 16.10

become one or more crystal plates, is of suitable thickness for finishing, and has its proper orientation within the mother crystal form except for inaccuracies inherent in the saw as a machine.

The photograph shows the slices of crystal section, or "slabs" as they are called after cutting, standing in position and adhering to the glass plate.

Fig. 16.11—Twinoriascope

The slabs, removed and cleaned, are etched in hydrofluoric acid, as shown in Fig. 16.7 and the etched slabs processed in the twinoriascope. The twinoriascope utilizes light reflected from the etched surface to obtain further information about the quartz. The first operation shows the areas

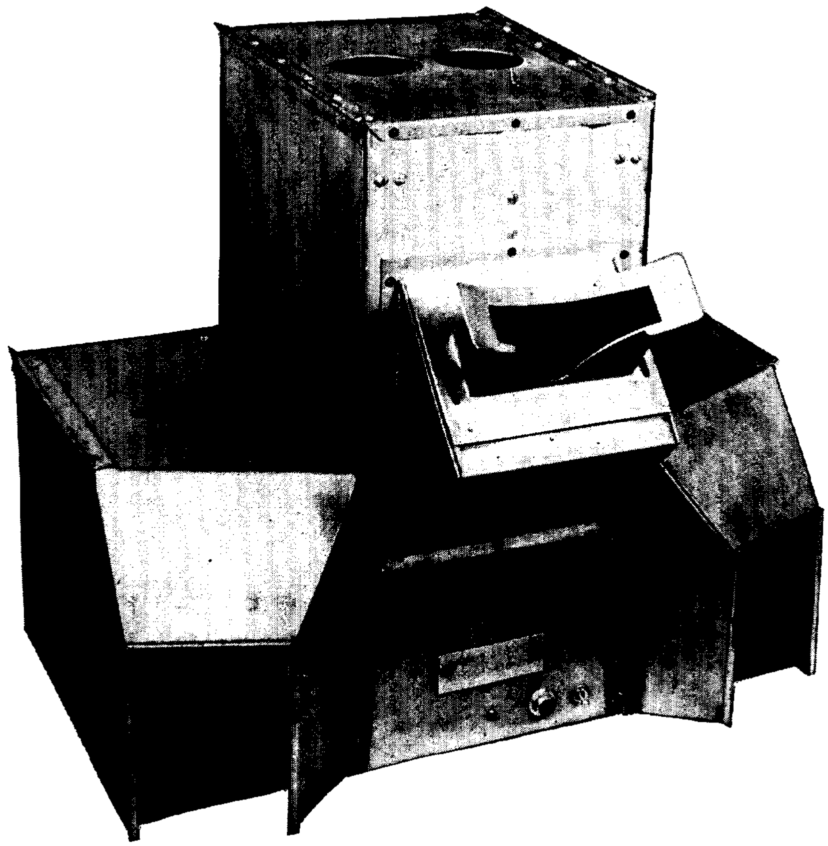

Fig. 16.11

of twinnings with boundary lines indicated clearly. An example is given of the appearance of a crystal in Chapter V, Fig. 5.14, Test 1. The boundaries of the twinned parts are marked on each slab by the operator. The second operation performed by the twinoriascope is brought about by swinging a translucent screen into the line of vision which automatically switches to a second source of light, thus producing a pattern on the screen from a small area in any part of the slab. Such a pattern will be one of the four marked "Test 2" in the same figure. The parts of the slab having desired and undesired orientations are suitably marked, and undesired parts, if conveniently located, are cut away in a diamond saw arranged for this purpose.

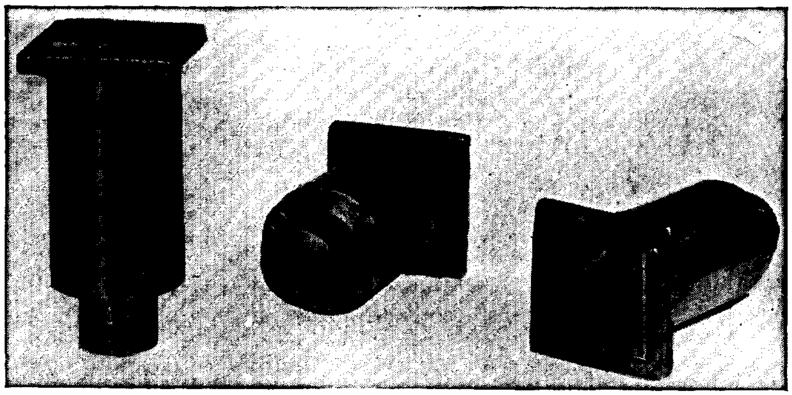

Fig. 16.12

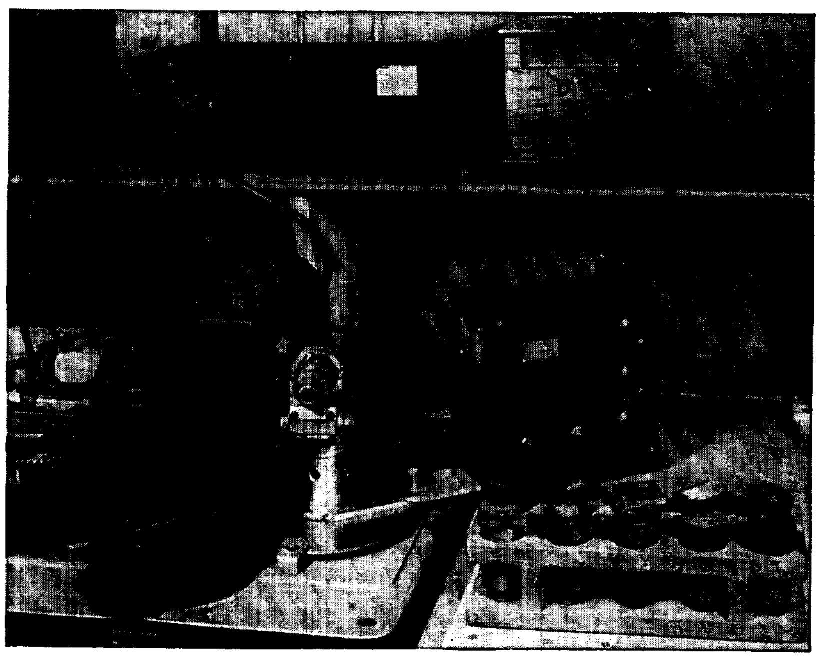

Fig. 16.13

Fig. 16.12—Holder for final orientation

Each slab, with etching ground away, is now cemented to the cap of a barrel holder to get final orientation. The face of the holder can be rotated slightly about two perpendicular axes in its plane by adjustments of two screws showing at the rear end.

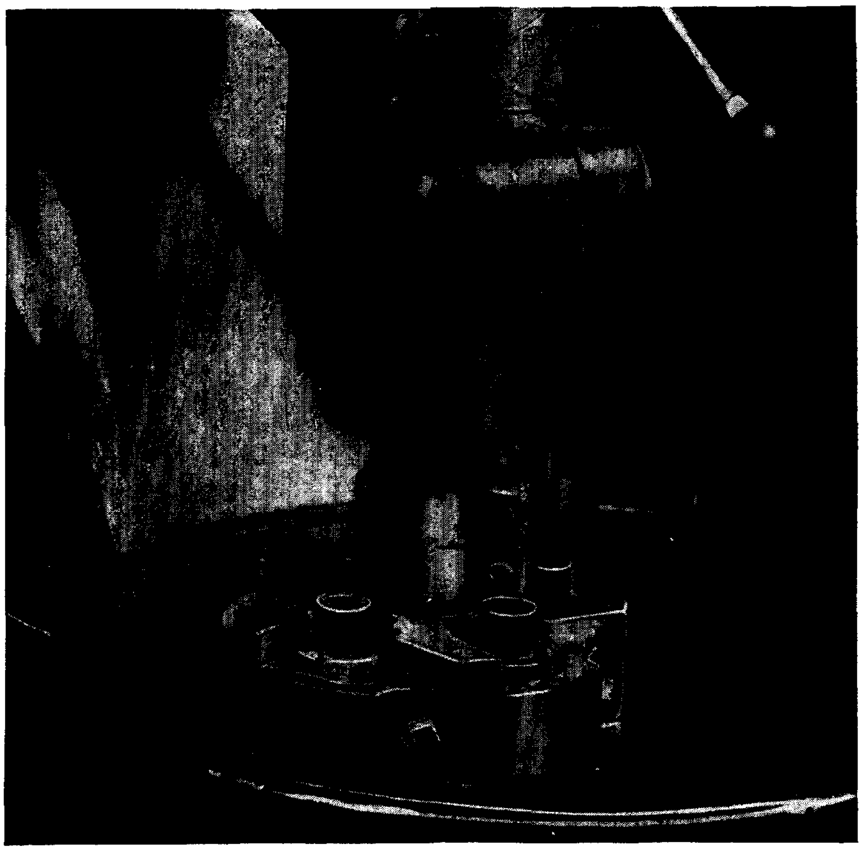

Fig. 16.14

Fig. 16.13—Final orientation

The holder, with slab cemented on the face, is placed in a jig on an X-ray machine. By screw driver manipulation of the two adjusting screws showing at its rear, the slab is given the necessary orientation to produce a maximum deflection on the indicating instrument on the shelf. The screw at the center of the rear is then tightened locking the face plate in position. The desired plane near the outer surface of the slab is now perpendicular to the axis of the slab holder.

Fig. 16.14—Lapping one side of slab to desired orientation

A number of adjusted slab holders are now placed in a jig on a lapping machine. The jig holds the holders so that their axes are parallel to the axis of the shaft onto which the jig is attached. The faces of the slabs are in contact with a lapping plate upon which No. 400 Carborundum is used. The two shafts are parallel, not in line, and rotate in opposite directions. The faces of the slabs are thus lapped flat and perpendicular to the holder axes. These lapped faces are now of the orientation desired for the crystal plates.

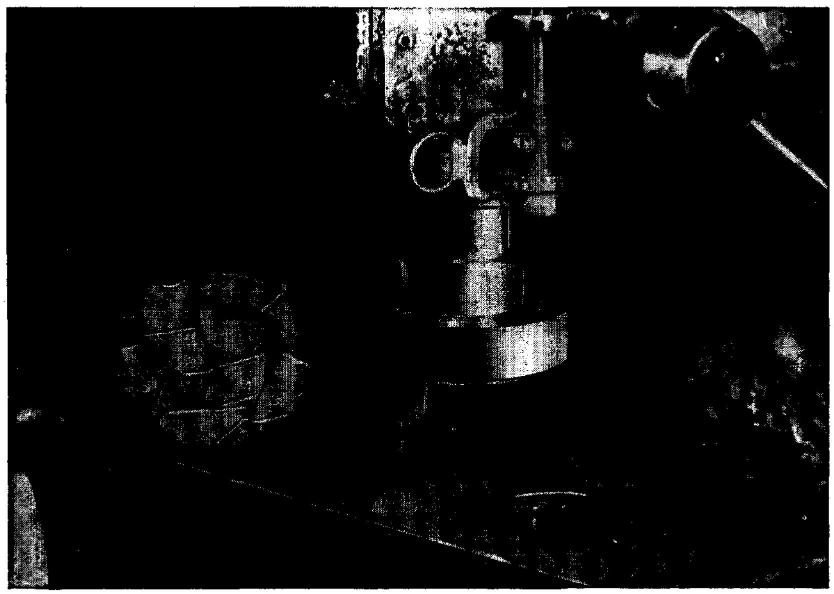

Fig. 16.15

Fig. 16.15—Grinding to thickness

The slabs, removed from the holders and cleaned, are now cemented to a large face plate with the corrected faces against the plate. The plate is placed in another lapping machine and the uncorrected faces are ground to parallelness with the corrected face, and to give the slab a specified thickness.

The slabs, thus ground are now called "wafers."

Fig. 16.16—Diamond dicing saw

The corrected wafers, now of proper orientation, are cemented to glass, using the bevelled edge surviving from the section's painted surface for alignment purposes. The slabs are sawed into squares, or "dice" as they are called.

Fig. 16.17—Finish lapping

Some of the dice are cemented to a face plate and ground to final thickness and finish in a lapping machine as is done with the slabs in Fig. 16.15. No. 400 Carborundum is used for this purpose. Other dice that require more control of thickness or a finer finish as discussed in design are ground to desired thickness and finish in this nest type lapping machine.

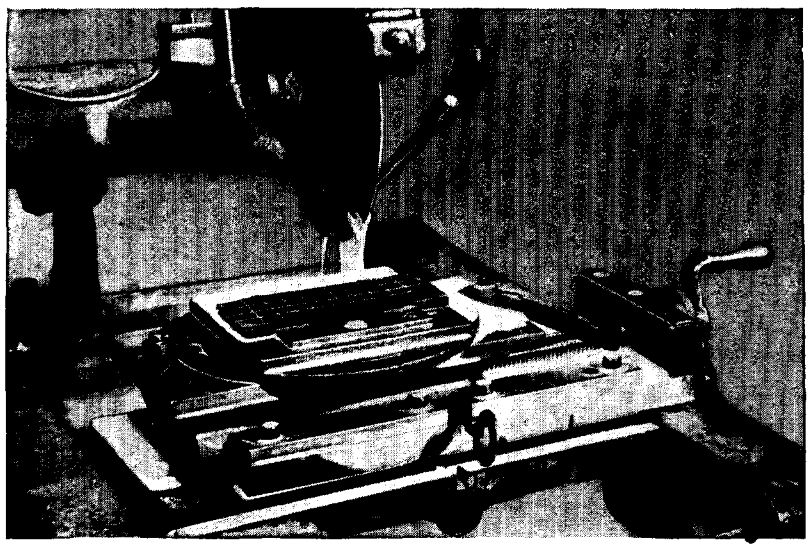

Fig. 16.16

Fig. 16.18—Edge lap fixture

A stack of dice is clamped into a fixture grooved with two 90° locating surfaces. In the first position, both exposed edges of the dice are ground parallel to their respective locating surfaces, then the stack is reversed and the two remaining edges are ground to square the dice to the desired dimension. The grinding is done on the machine shown in the following figure.

Fig. 16.19—Grinding dice to size

A number of fixtures holding dice are fastened to a rotating disc in a grinding machine and held against a diamond charged disc rotating at a higher speed in the opposite direction. The spindles supporting the discs are parallel with one another but one is off center in relation to the other.

Fig. 16.20—Spotting tool

A crystal plate, after a 20 minute etch in 30% hydrofluoric acid, and washing, is placed in position on the spotting tool. The spotting mandrel is wetted with silver paste by immersing it to the bottom of the paste well on the end of the tool in the operator's left hand. The mandrel is immedi-

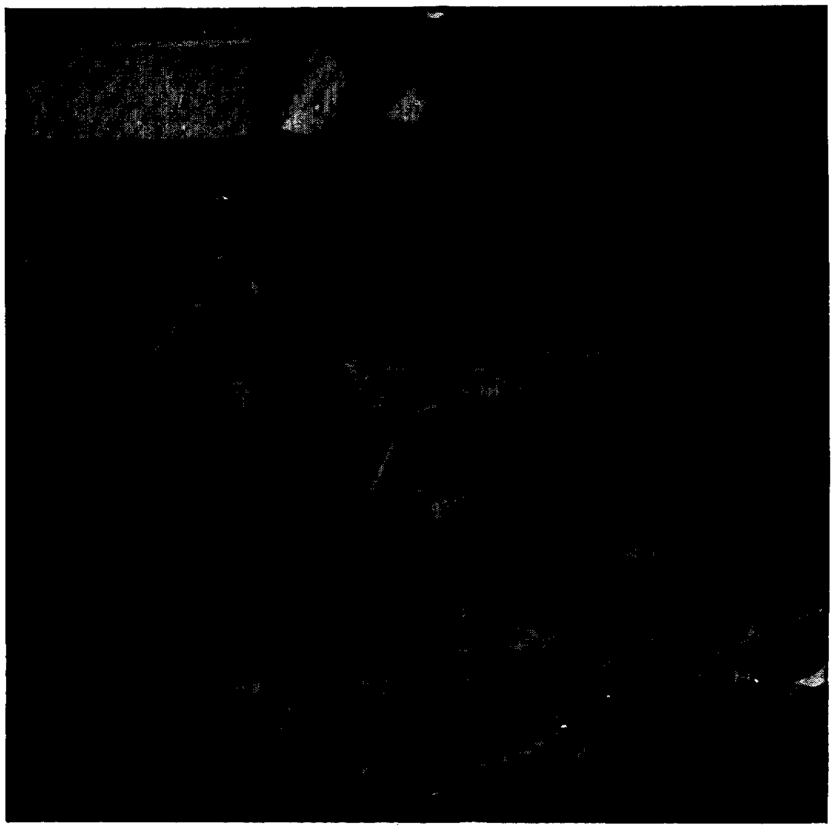

Fig. 16.17

ately lowered so that it touches the surface of the crystal, guidance being such that it touches the plate at its center. The crystal plate is then turned over and the operation is repeated.

In order that the silver spots will be uniform, a number of routines are carefully followed. Each bottle of liquid silver as received from the manufacturer is agitated on a commercial paint shaking machine for at least 6 hours to secure uniformity throughout, and then the entire contents is

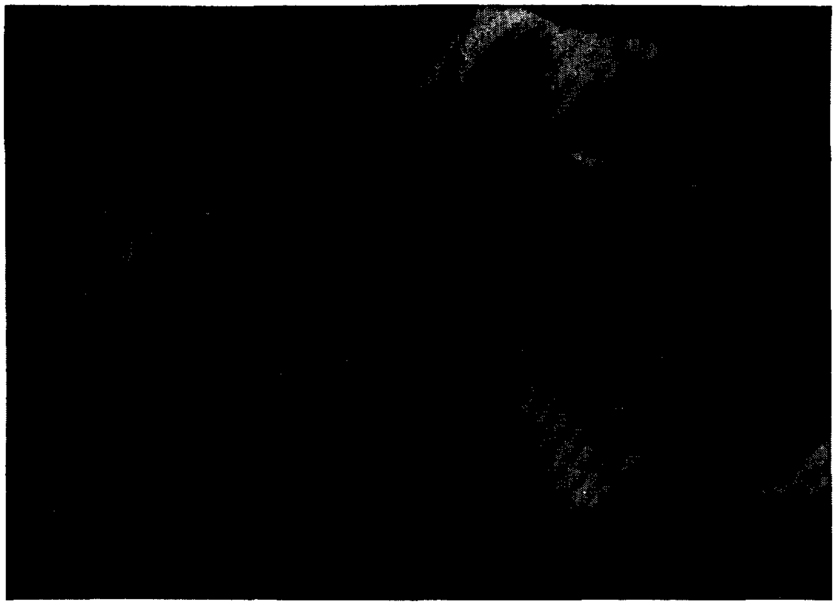

Fig. 16.18

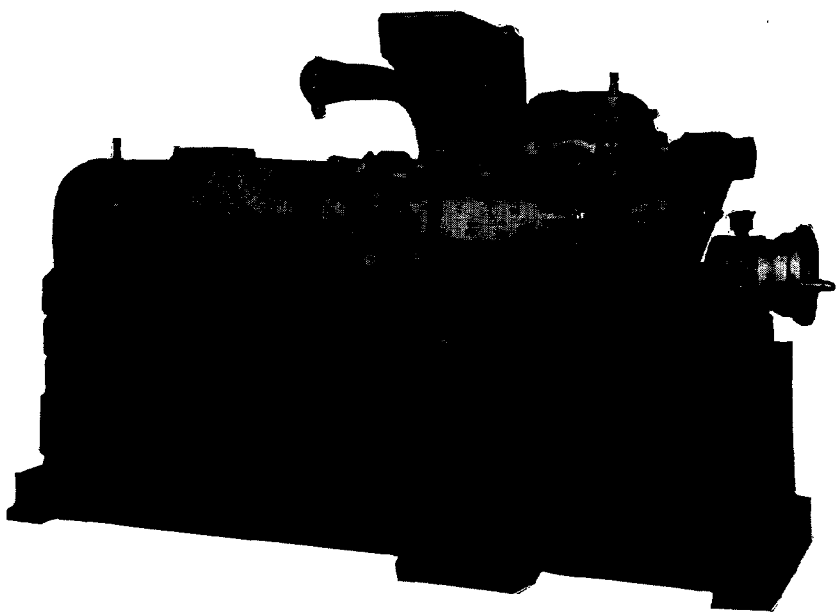

Fig. 16.19

transferred to 20-cc bottles which are used in the spotting positions. These small bottles are constantly shaken on a special tool (blurred parts shown in the figure) to maintain the solids in uniform suspension. Shaking is inter-

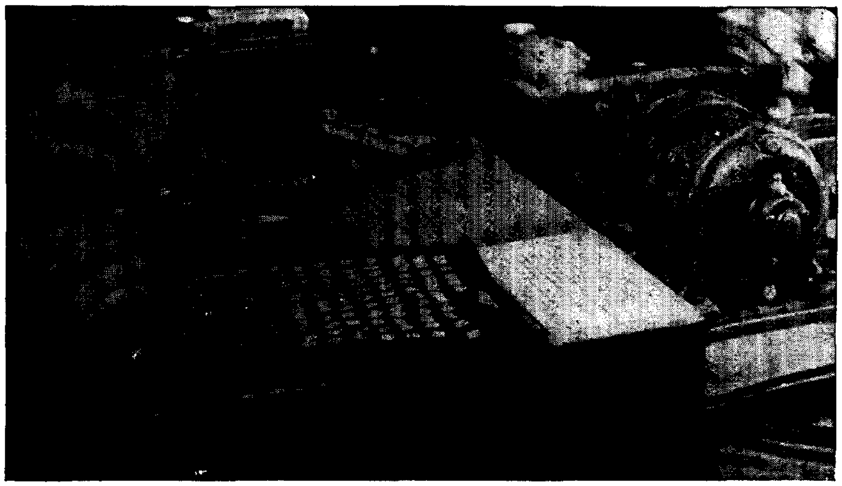

Fig. 16.20

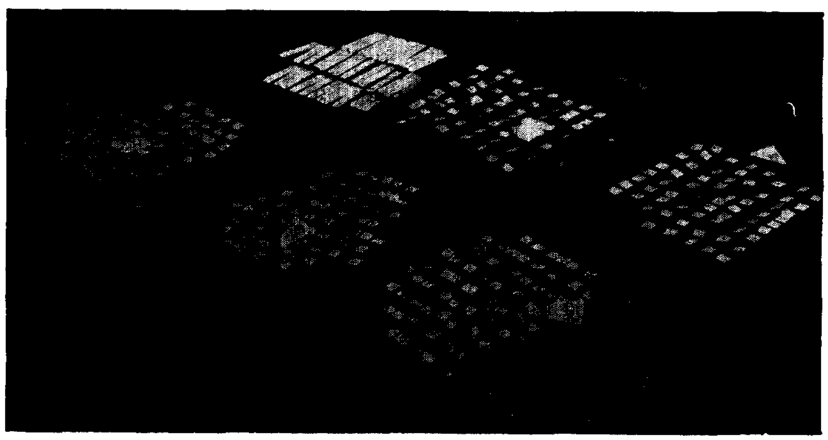

Fig. 16.21

rupted only long enough to refill the shallow well in the spotting machine. A total of 10 crystals is spotted from a filling of the well after which evaporation of the solvent and settling of the solids causes nonuniformity in spots to become too great. The well is wiped clean after each 10 crystals, and is refilled from the 20-cc bottle.

Fig. 16.21—Spotted crystals on drying screen

The spotted crystals are placed on nichrome screens and are heated over a 700°F hot plate for 5 minutes.

Fig. 16.22—Spot compressor

The spots, after the solvent has been driven off, are compressed in a special tool to reduce porosity, and improve their strength.

Fig. 16.22

Fig. 16.23—Spotted crystals ready for baking

The spotted crystals are given a fire-bake on the hot plate for 30 minutes, and are then placed in echelon in pyrex petri dishes and baked in an electric oven at 980° ± 10°F for 20 minutes to reduce the solids in the spot to a molten glass with admixture of silver. They are allowed to cool in closed dishes to room temperature after withdrawal from the oven.

Fig. 16.24—Silver plating

The spotted crystals are placed edge to edge on the plating tray, and the heater wire is loaded with little pieces of silver wire. The tray is slid into its chamber, in the plating machine (Fig. 11.13, Chapter XI) vacuum pumps started, and after a suitable vacuum is secured, the plating is started. The crystals are plated to between 3 and 5 mg per square inch. After plating is completed, the crystals are allowed to cool for 20 minutes before air is admitted to the plating chambers. The crystals are turned over, and the process is repeated.

Fig. 16.23

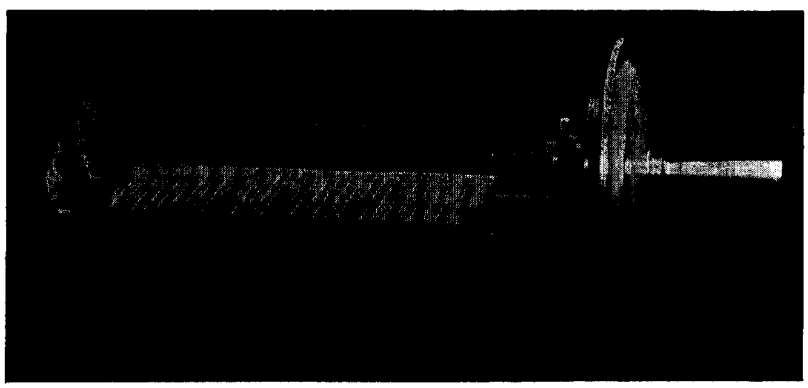

Fig. 16.24

Fig. 16.25—Cleaning edges

Some silver gets on the edge of some crystals, and must be removed. This may be done by rubbing the edge on a piece of emery paper. The crystal is held in a special rubber faced tweezers during this operation. An electrical test is made to determine the effectiveness of the silver removal.

Fig. 16.25

Fig. 16.26—Holder for sand blasting

For the certain crystals, removal of the silver from the edge by rubbing on emery paper is insufficient. The removal of the silver from the edges must be thorough. Sand blasting is resorted to in this case. A special tool holds a stack of crystal plates so as to expose two edges of the crystals at a time for sandblasting.

Fig. 16.26

Fig. 16.27—Sand blasting silver from edges

The crystals in the holder are then sandblasted on the exposed edges. The crystals in the holder are reversed and again sand blasted. The crystal edges are thus thoroughly cleaned of silver, providing sufficient insulation between the two sides to stand the required voltage tests.

Fig. 16.27

Fig. 16.28—Burnishing the spots

The spots are burnished by giving them several strokes on a hardened and ground steel plate as an aid to soldering.

Fig. 16.29—Soldering machine

The soldering machine is the most important development made for the manufacture of this crystal unit. The soldering of a wire to the center of

Fig. 16.28

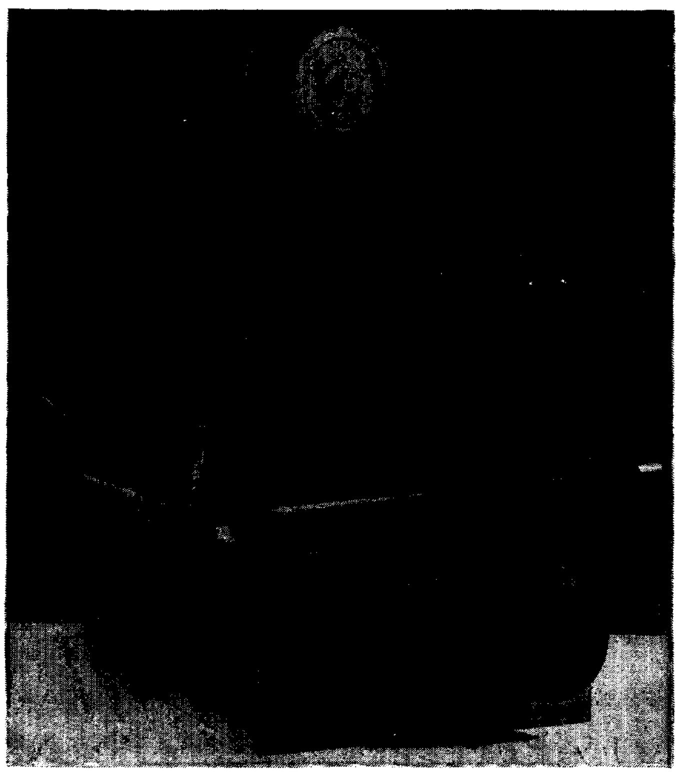

Fig. 16.29

each side of a crystal is a delicate job. The soldering machine made it possible for an operator with a little training to do a better and more uniform job than an expert could do without it.

The wire used is an 8% tin bronze electrotinned to 6 M.S.I. The wire must be straightened to a minimum radius of curvature of 12 inches before plating. The wire is held on a spool above the machine and is fed through a holding head whereby it is manipulated and soldered before cutting off to the correct length. The holding head is on the end of a long arm. The arm, partially counterbalanced, is hinged in a gimbal type support. This

Fig. 16.30

support, together with suitable guides and stops, insures the mechanical manipulation and placement to the necessary degrees of accuracy. A binocular microscope focused on the soldering spot allows the operator to control the soldering operation.

Fig. 16.30—Soldering operation

The soldering head A on the end of arm *B* contains a clamp on the underside that clamps the wire coming from the spool through the head. The crystal is placed between self-centered jaws *C* having a base thereunder held at 210°F. to assist in soldering. The arm and head are swung so as to fall between the guides *D* in which case the end of the wire projects into a small hole *E*. Pressing handle *F* punches a disc of solder out of a ribbon and impales it upon the end of the wire. The ribbon of solder after the discs are punched, moves out and is shown at *G*. The head is now lifted and swung so the arm falls between guides *H*, and is lowered. The disc of solder is dipped in rosin-alcohol flux in a cup inside *J* which is a tank of flux in which the cup hangs, the tank lowers under pressure from the head until the surface of the flux falls below the cup leaving the cup full. The head and arm are now swung to guides K where they are lowered until a stop is reached that just lands the solder disc upon the silver spot. The operator now looks through the binoculars (removed for this picture) and watches the subsequent operations. A spotlight *L* illuminates the soldering area. The soldering is done by means of a blast of hot air from the nozzle *M* which is put into action by placing a finger over a bypass opening *N* from a continuous air supply. When the solder has melted and reached the desired shape, the removal of the finger from the bypass stops the hot air blast and the solder solidifies. The wire clamp in the head is released by movement of lever *O* on the head and the head is raised against an upper stop in *K* allowing a length of wire to pass through. A special scissors *P* is pushed in by pressure on knob *Q* and when it reaches the wire, jaws automatically close cutting the wire off. The head and arm are returned to the normal rest position shown, knob *R* is moved opening the jaws holding the crystal, the crystal is turned over, and a wire is soldered to the other side.

Fig. 16.31—Mounting fixture

The base assembly is prepared by soldering two supporting springs to the tops of the pins that were moulded into the bakelite base. The springs are adjusted so as not to apply tension to the crystal lead wires, and pellets of solder about .02-inch diameter are soldered to each spring about $\frac{1}{8}$ inch from the free end and then dipped in rosin-alcohol flux. Jigs, not shown, are used in these three operations.

The base assembly and the crystal with wires attached are now placed in the mounting fixture, with a spacing element so placed that the soldering of the lead wires to the supporting springs will occur at the right distance from the crystal. An aluminum tipped soldering iron melts the solder permitting it to be rolled along the supporting spring to the junction with the lead wire. The completed assembly is carefully removed from the fixture.

In this picture, the operator is shown about to insert a crystal and a base assembly in the fixture. The fixture with base and crystal in position for soldering are shown in the insert in the lower right-hand corner. The spacers that insure placing the masses of solder at the right distances from the crystal are seen as partially hiding the crystal.

The aluminum tipped soldering iron is seen through the magnifying glass. It is fixed in position. The fixture with the crystal and base is brought up to the iron for soldering.

Fig. 16.31

Fig. 16.32—Cleaning mounted crystals

The mounted crystals are sprayed with hot tricloroethylene for ½ minute. A rack holding 20 mounted crystals is slid into the side of the spraying enclosure. After spraying, the rack of crystals is placed on a drain board.

The trichloroethylene removes grease, rosin and many other possible contaminations. The crystals must be thoroughly clean which means that the trichloroethylene with which they are finally washed, must contain no foreign materials that would be left behind by the evaporation of any adhering liquid from the washing stage. Numerous washing stages and continual changing of baths of the trichloroethylene are avoided by installing at this position a continuously operating purifying still. An adequate supply of the purified liquid is thus always available at small cost and effort.

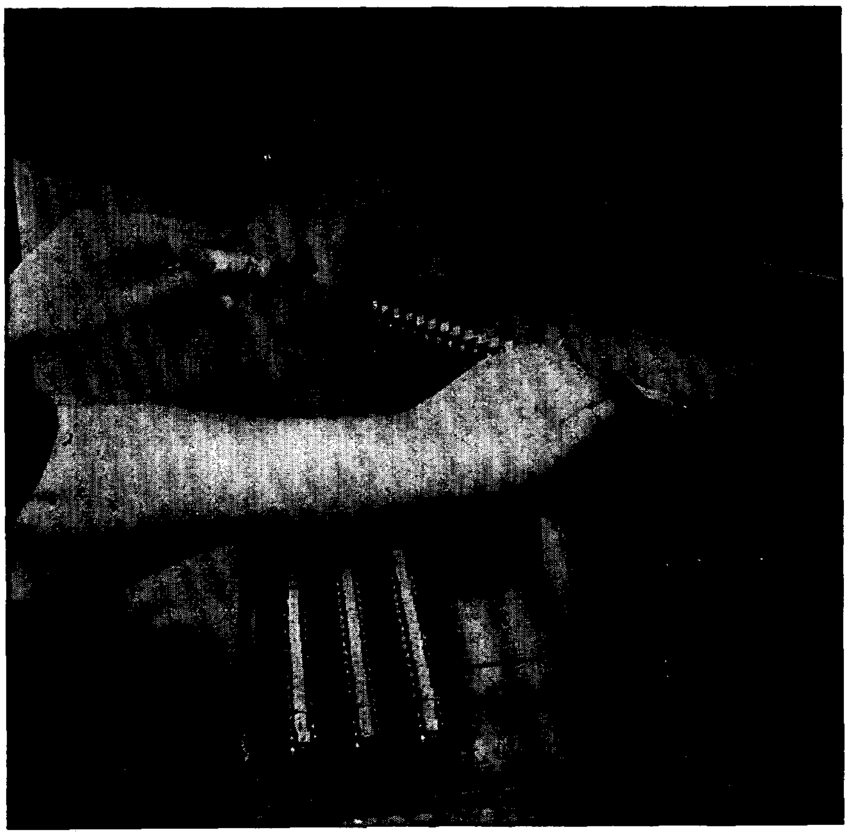

Fig. 16.32

Fig. 16.33—Calibrating

The crystals are adjusted to frequency by removing quartz from one edge with emery paper. The mounted crystal is placed in a special fixture connected to the frequency comparator. After an observation showing the frequency is too low, the operator grasps the fixture with her left hand, moving a lever by the second finger which causes a pair of jaws to sieze the crystal by its two vertical edges and hold it firmly while she rubs the emery paper over the top. The emery paper is fastened to one side of an element that is also the handle of a brush. She brushes off the dust, releases the fixture, and retests.

A comparator of the general type described in Chapter X is used in measuring the frequency.

Fig. 16.33

Fig. 16.34—Aging

After cleaning, and baking, the crystals have their covers sealed on. After an aging period of alternate heating and cooling, they are ready for final test and inspection. An oven shown in this picture is electrically heated and temperature controlled. Refrigerators and dry ice are used for testing purposes.

Fig. 16.35—Leak test

Some types of wire mounted crystals are called upon to undergo a test to determine the effectiveness of the seal. For this purpose, equipment was developed that operates on the principle of conduction through gases, reaching a maximum in conductivity at certain degrees of vacua. The leak test equipment is arranged to place a large number of crystals simultaneously under vacuum for a certain length of time. While under vacuum, they are individually tested.

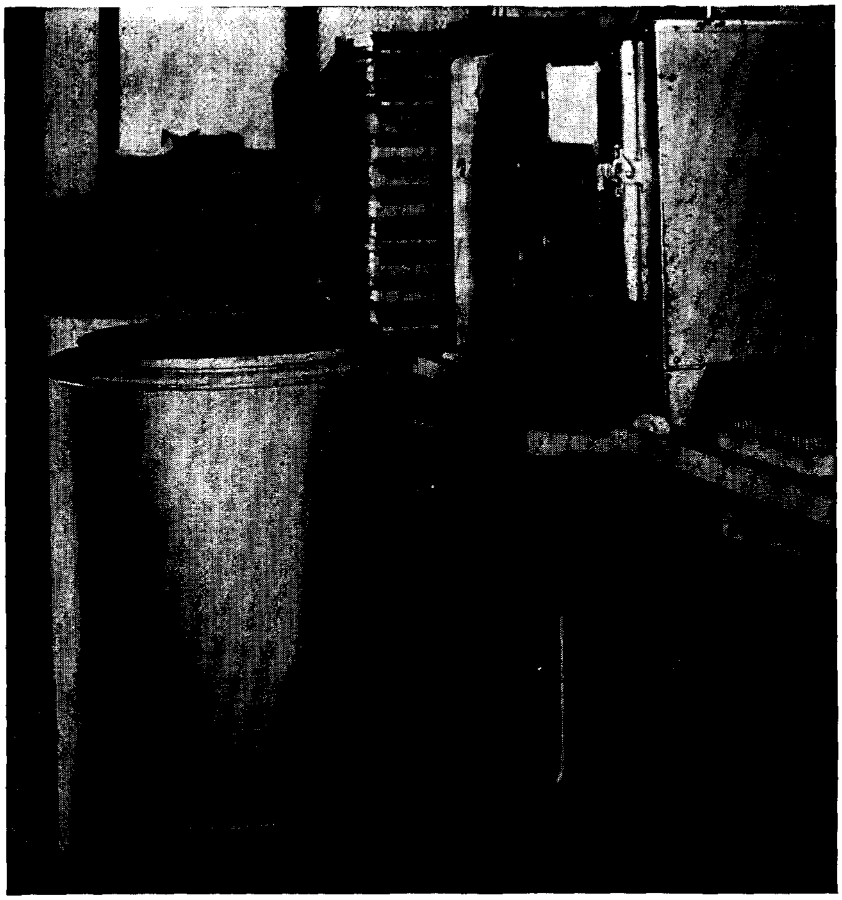

Fig. 16.34

The figures through 16.35 show what would be called "production line" instruments and machines. There are a number of other instruments used in the shop for special purposes, or were used in the production line in the past. A number of these devices might be mentioned.

This list of special equipments is given to indicate the scope of the development of apparatus which was found desirable or necessary for properly and efficiently processing the one type of crystal unit. The special equipment in many cases allowed of saving large numbers of crystal units that would otherwise have to be thrown away or whose orientations would have to be ascertained using much more expensive equipment and requiring a

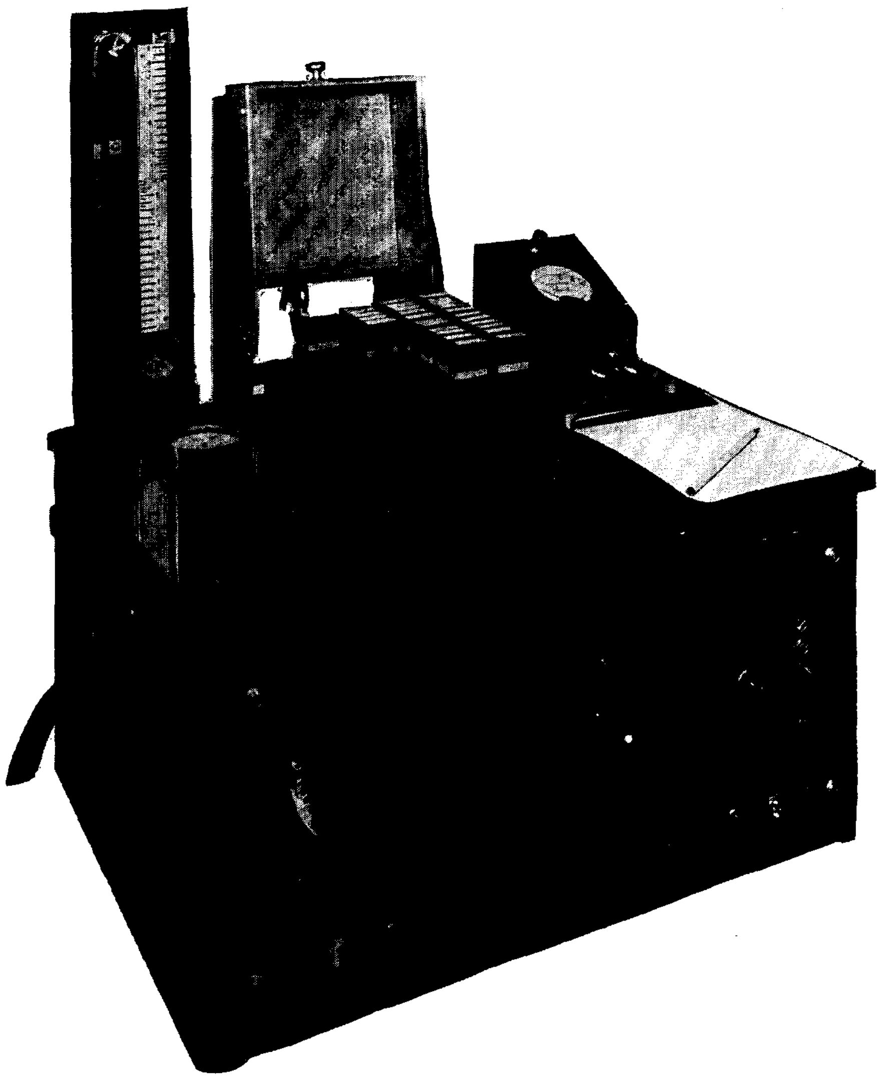

Fig. 16.35

much greater amount of time. This range of equipment would probably not be justified where the production was not large, but in this case they have rendered very useful services and have resulted in definite savings in material, cost and time.

Fig. 16.36—Oriascope

The oriascope is diagrammed in Figs. 5.11 and 5.12 of Chapter V. It operates somewhat as the pinholeoriascope of Fig. 16.8 does, but it uses only one side on a section so that it can be used where two cut surfaces are not available, such as an end section. This instrument was used in the production line until the pinholeoriascope was developed.

Fig. 16.37—Refractoscope

The refractive fluid used in the inspectoscope is a mixture of two ingredients to get a refractive index the same as that of quartz for one of the

Fig. 16.36

mercury lines. This fluid may become contaminated in time or one ingredient evaporate faster than the other and the index of refraction change. To determine if a change occurs (as well as in mixing the original ingredients) a refractoscope described in Fig. 4.4 of Chapter IV was developed and is a part of regular shop equipment.

Fig. 16.38—Normascope

A normascope, diagrammed in paragraph 2.7, and Fig. 2.27 of Chapter II, is an optical instrument for distinguishing between the direction of the electric and the other axes in crystal plates before they are placed in X-ray equipment for final orientation. Some crystals may have lost any markings

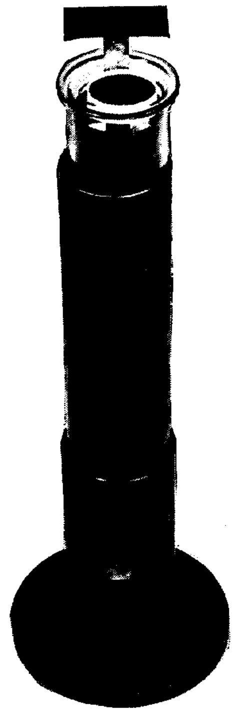

Fig. 16.37

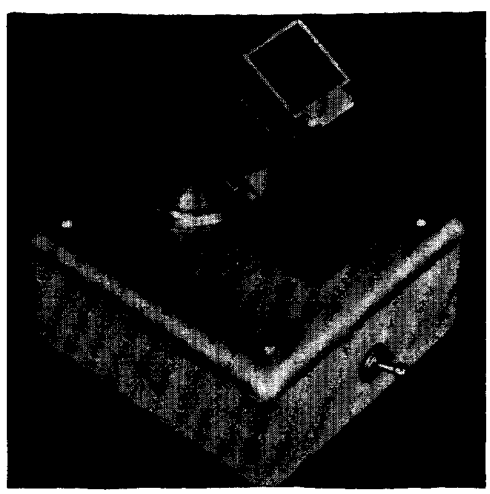

Fig. 16.38

they possessed, and being square will have no characteristic in their shape to indicate their orientation, they will be useless unless the necessary information can be secured. This device will quickly determine the major orientation. It can also be used to distinguish an AT from a BT plate.

Fig. 16.39—Stauroscope

This instrument described in paragraph 2.7 and Fig. 2.22 of Chapter II is used to measure the deviation of the X axis of a crystal from an edge. It can indicate to within reasonably close limits the error existing between the reference edge of the quartz element under test and the X axis. In the

Fig. 16.39

factory it is used to reestablish the X axis when the edges of quartz elements have poor or no reference edges. In the figure, a fixture using a rectangular plate is placed on the stauroscope table using two holes near the ends of the plate (only one showing) for alignment. The quartz wafer is placed over a large hole near one side of the plate and rotated by hand until colors in the microscope match. A holding element over the wafer is then tightened by means of the thumb nut. The wafer extends out the upper side. The fixture is then removed to a saw, and the edge of the wafer is cut off. The alignment of the fixture on the saw by means of the holes insures that the cut edge is parallel with the X axis.

Fig. 16.40—Crystal sorter

A large amount of crystal material in the form of dice properly and improperly oriented, and with small areas of defects, need to be sorted in order that the usable material can be reprocessed. An oscillator and associated sorting fixture was constructed to quickly accomplish sorting. Dice or blanks within a certain thickness limit are tested at a time. Crystals are fed into a chute in which a solenoid operated trip finger allows one crystal at a time to enter the sorting fixture. The oscillator operates at the crystal frequency. If the activity is sufficient, and the frequency is in the region which would be expected of plates of that dimension, a relay operates throwing the crystal into a certain container. If the frequency should be that

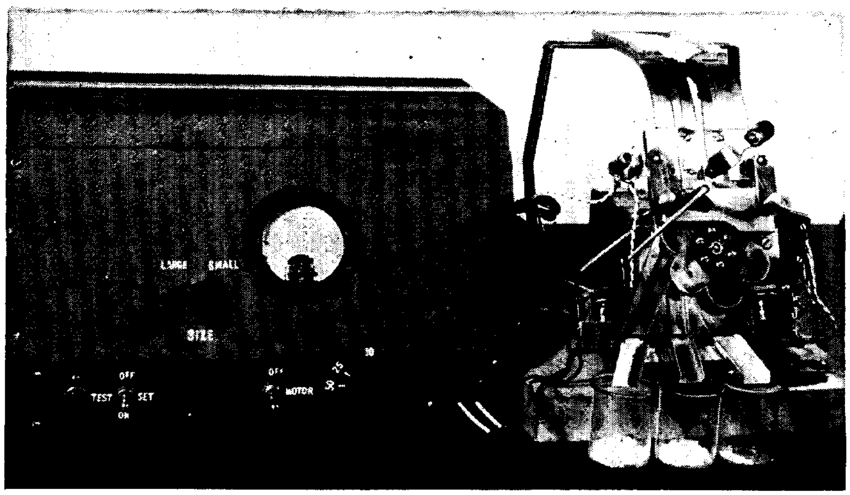

Fig. 16.40

expected with the wrong sense of orientation, a relay operates throwing the crystal into a different container. If the crystal fails to operate at all, or with insufficient activity, it is dropped into a third container.

Fig. 16.41—Acid test equipment

In Chapter V, paragraph 5.6, there is described a method for measuring the strength of hydrofluoric acid solution used in etching using a photometer to determine the opacity of a microscope slide which has been inserted in the acid to be tested for a certain number of minutes. This figure shows the instrument. It consists of a photometer originally developed for other purposes modified to take the etched slides. Calibrations are made of

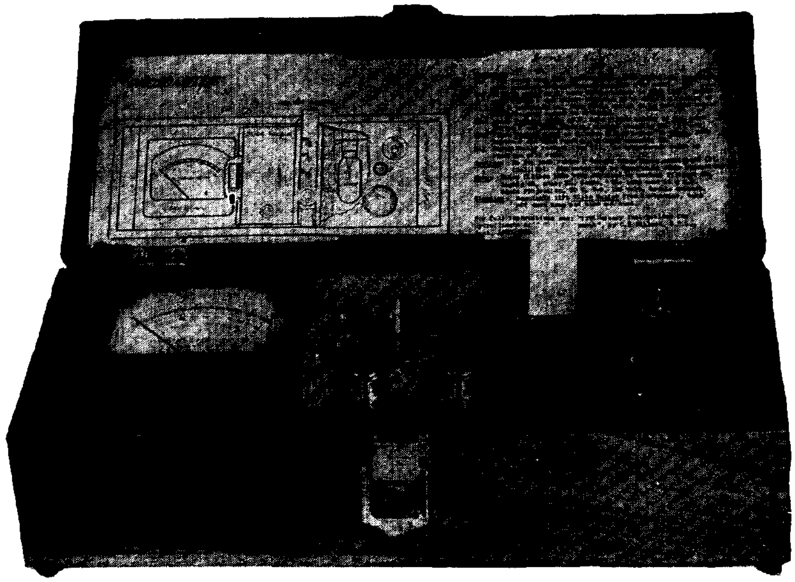

Fig. 16.41

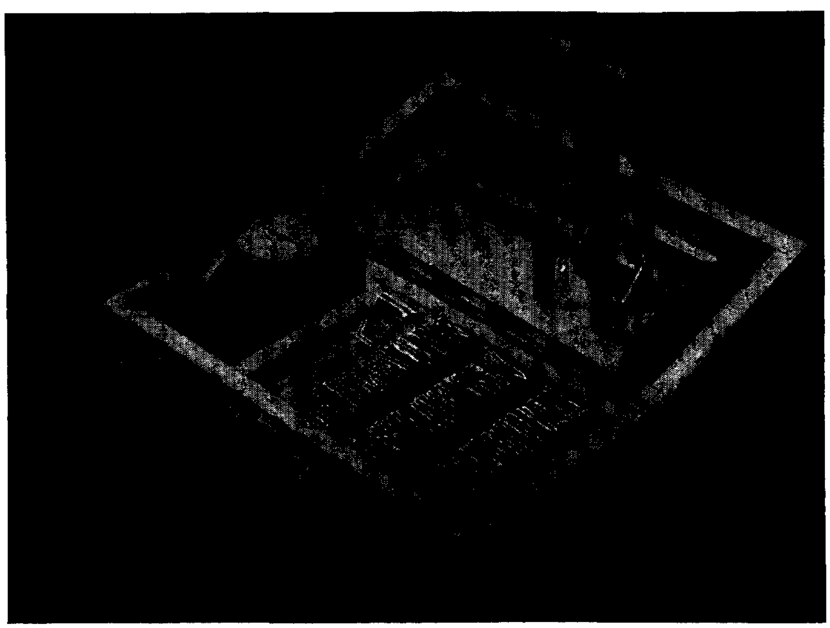

Fig. 16.42

opacity readings versus necessary etching times for satisfactory etched patterns. This permits of converting a reading directly into needed etching time without knowing at all the percentage of hydrofluoric acid.

Fig. 16.42—Acid test equipment

A second acid test equipment was later developed operating upon a simpler principle. Pieces of pyrex glass are etched for a certain length of time in the acid to be tested. After rinsing, the change in thickness is measured giving an indication of acid strength or of required etching time for quartz. Pyrex glass is used as ordinary glass forms a coating in the etching process

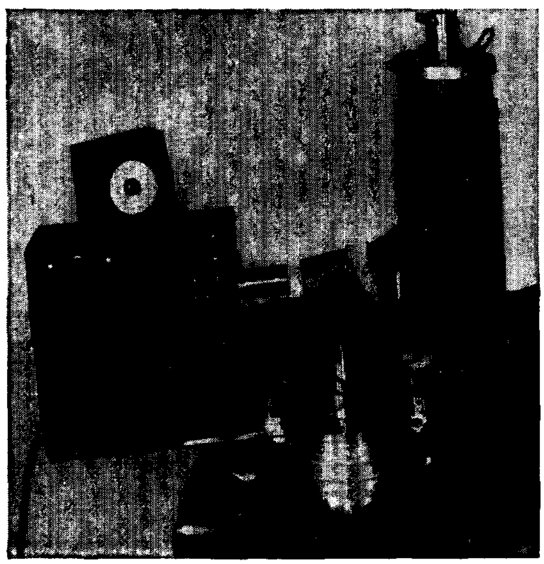

Fig. 16.43

which interferes with both further etching and with mechanical measurement of the thickness of the remaining glass.

Fig. 16.43—Interlocking goniometer

This special goniometer to be attached to X-ray equipment was developed for quickly checking crystal plates in case there is any question as to their orientation. Two large discs rest upon a circular base. To the middle disc is attached the ionization chamber and amplifier, and to the top disc, the holder for the crystal. Alignment holes through the two discs and into the base, allow of pre-setting the crystal and the ionization chamber at angles that should give reflections from known orientations. Absence of an indication indicates a wrong cut. Slight movements from normal of the crystal can be made to determine the magnitude of slight misorientations.