CHAPTER XIII*

The Mounting and Fabrication of Plated Quartz Crystal Units

By R. M. C. GREENIDGE

13.1 Introduction

THIS paper is one of a series on piezoelectric quartz plates and deals primarily with the methods employed in mounting crystal plates operating up to approximately one megacycle for practical utilization in communication equipment. The theoretical aspects of mounting crystals have been covered in Chapter VII. The discussion is confined to plates[1] having definite nodal lines or points, such as $+5°$ and $-18° 25'$ X cuts, GT, CT, DT, MT and NT cuts. The mounting of high-frequency crystal plates such as AT and BT cuts, which vibrate in thickness shear modes, is not included. It should also be noted that the subject matter is treated descriptively and that no attempt is made to go into the more intricate details of design or to give performance characteristics. These matters will be dealt with fully in a later paper. The designs and methods outlined are up to date for each type of unit, the results of many years of development on the part of Bell System engineers to evolve practical designs for commercial manufacture and use. Expanding on the contributions of the early investigators mentioned by W. P. Mason in Chapter I,[1] these engineers had, in the ten years prior to 1939, worked out practical designs and developed suitable tools and processes for wide commercialization in telephone applications. In the last five years, under the impetus of war, further improvements have been made in the design and manufacture of crystal units, particularly those for use by the Armed Forces.

The term "Crystal Unit", originally adopted by the Bell System to designate the complete assembly of a crystal plate in its mounting and case, has now been standardized quite generally in the art, replacing a variety of names by which these devices were formerly called. The basic design features of a crystal unit involve the use of:

1. Electrodes, on or near to the crystal surfaces for impressing voltage across the plate,

* Chapters IX, X, XI and XII, which will be included in a forthcoming volume are omitted from the *Technical Journal* because they deal largely with details of manufacturing operations.

[1] "Quartz Crystal Applications", W. P. Mason, *B.S.T.J.*, Vol. XXII, Page 191, July 1943.

2. Supports for holding the crystal plate in its mount, and
3. A sealed outer case having the necessary terminals, and provisions for incorporating the unit electrically and mechanically into the apparatus.

Two distinct types of crystal units have been evolved, one embodying the use of pressure pins or anvils for supporting and holding the crystal plate and the other involving the suspension of the crystal plate by means of fine wires.[2] These designs are known, respectively, as the Pressure Type and Wire Supported Type, and will be discussed later under these headings. However, there are several details of fabrication common to both types which can best be discussed at this point.

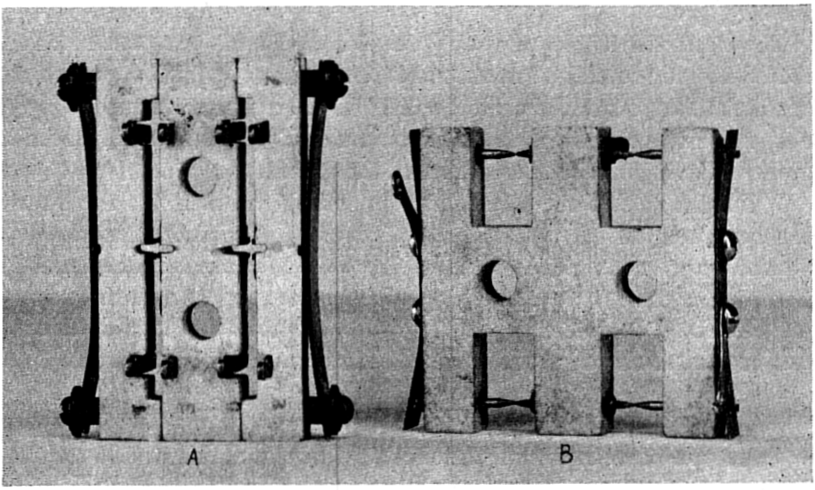

Fig. 13.1—Pressure-type holders.

Irrespective of the type of mounting, realization of the desired performance in a crystal unit depends to a considerable extent on the processing of the quartz plate itself. Previous articles[1, 3] have brought out the significance of such factors as the precision of angular orientation and linear dimensions on the fundamental characteristics of the plate. The plate must also be virtually free of impurities or imperfections.[4] In the preparation of a quartz plate it must be lapped using increasingly finer abrasive materials until the final dimensions are reached. Depending upon the type of crystal unit, No. 400, No. 600 carborundum or finer abrasives are now

[2] A. W. Ziegler, Patent 2,275,122, March 3, 1942.
[3] "The Use of X-Rays for Determining the Orientation of Quartz Crystals", W. L. Bond and E. J. Armstrong, *B.S.T.J.*, Vol. XXII, Oct. 1943.
[4] "Raw Quartz, Its Imperfections and Inspection," G. W. Willard, *B.S.T.J.*, Vol. XXII, Oct. 1943.

employed for the final stage grinding. Following this, the plate is thoroughly cleaned by acid treatments or by the use of solvents and detergents followed by copious washing. It is then etched in commercial hydrofluoric acid to remove all loose particles of quartz that might have remained on the surfaces or in the crevices after cleaning. Etching also smooths off the roughness of the ground surfaces. The effect of this treatment reduces energy dissipation in the plate itself and increases by many times the efficiency of the crystal units. Etching also improves the stability of performance of the crystal unit. Standard designs of crystal units require etching of the plates, uniformly on all surfaces, for a period of thirty to forty minutes. For units of highest precision and efficiency longer etching periods are employed.

The electrodes employed with types of crystal units being described consist of metallic coatings, generally aluminum, silver, or gold deposited over the major surfaces of the crystal plate. These coatings are applied by the evaporation process which results in an extremely thin and uniform coating of metal having excellent adherence to the quartz.

With reference to the mechanical supporting members for the plate, it has been brought out that such supports should be confined as closely as possible to the nodal points or nodal lines where the motion for all practical purposes is zero. It is common practice for the supporting members to be made of metal so that they will serve also as a means of making electrical connections to the electrode coatings on the surfaces of the plates.

13.2 Pressure Type Crystal Units

This type of crystal unit was initially developed for use in telephone filters. Up to about five years ago it was employed in virtually all commercial designs of filters. Depending upon the mode of vibration and size of the crystal plate the design of the mounting varies. However the principles employed for clamping are essentially the same in all cases. Where small longitudinal or face shear plates are involved one pair of pressure pins is used unless two are required for electrical reasons as explained later. For medium size plates of the same type or for face flexure plates, two pairs of pins are employed. In the case of large low-frequency longitudinal plates double anvils are used instead of pins in order to obtain firmer clamping of the plate to prevent translation or rotational movement which might cause wear in the electrode surface at the pressure point with resultant variations in frequency and resistance. The blocks are usually composed of molded steatite and the springs for exerting the necessary pressure are of phosphor-bronze.

Figure 13.1 (B) shows a pressure mounting for holding four crystals which have single coatings on each of their major surfaces. The main require-

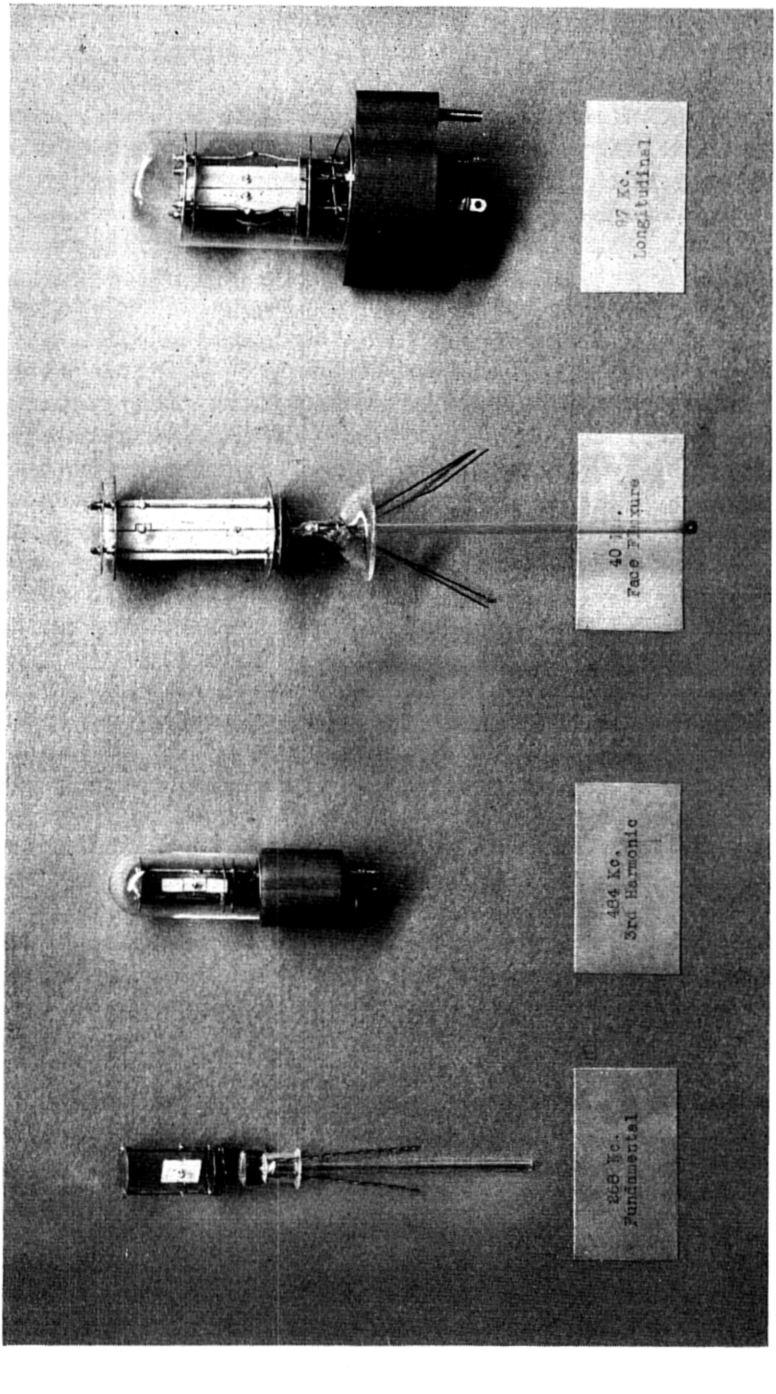

Fig. 13.2—Wire-supported crystal units.

ments which must be met for such a mounting are small areas, accurate alignment, and adequate pressure to hold the plate in place. Some designers make slight indentations in the quartz at the point of contact to improve the mechanical stability of the plate. For crystal plates of the order of one-half inch square or smaller, points having an area of about 10 mils in diameter are employed and the pressures used for holding the plate range from one to two pounds. For larger plates correspondingly larger areas of points and increased pressures are employed. The accuracy of alignment required for ten mil points is of the order of two or three mils. This is obtained in the mountings shown in Figure 13.1 by using concentric sleeves for holding the points which are brought into alignment by means of a straight rod and then cemented in place. One of the points is fixed while the other point slides in its sleeve and the pressure required is obtained by the spring which presses on the outer end of the sliding point. In balanced filter structures it is desirable to use crystal plates with the coating on each side divided into two equal areas. This reduces to one-half the number of plates that would otherwise be required. In mounting plates with divided coating, it is necessary to provide a mounting which makes double contact on each side of the plate. Figure 13.1 (A) shows a pressure type mounting which accomplishes this. This is the mounting which has been used for several years in holding the plates used for the 75-type crystal channel filters[5] for the standard terminal common to all broad-band telephone systems. The crystal is mounted in the holder in such a way that the two pairs of points clamp the crystal along the nodal line. The rectangular dimensions of the points used for this type mounting for crystals operating in the frequency range from 60 kc up to 120 kc are about 35 mils long in the direction of the nodal line and from 10 to 15 mils wide. A very important requirement for such a mounting is that the flat area of the points on each side of the plate fall in the same plane. This is accomplished by a precise milling operation after the points are assembled in the mounting. The pressure applied to the pair of points is furnished by the flat spring shown and is equalized by the action of the roller centrally located under the springs. The pressure employed is of the order of four to five pounds for each pair of points.

The most commonly used coating for crystal plates held in pressure-type mountings is aluminum.[6] Aluminum has been found to be most satisfactory for this type of unit because its hard surface is more resistant to wear at the points of clamping than other metals such as silver, or gold.

Except for a few designs, which are mounted in sealed metal or glass

[5] "Crystal Channel Filters for Carrier Cable Systems," C. E. Lane, *B.S.T.J.*, Vol. XVII, Page 125.

[6] The details of processing aluminum-coated crystals are similar to those described for silver-coated crystals in paragraphs 13.42 and 13.43.

containers, pressure-type crystal units are not sealed in individual containers. However, the entire filter in which they are employed is dried and sealed off after filling with dry air.

In pressure-type units of this type, variations in frequency of the order of .01% may be expected if crystals are transferred from one mounting to another or relocated in the same mounting. Consequently, if high-frequency precision is desired, it is necessary to make the final frequency adjustment with the crystal located in its final position. Due to the inherent difficulties of adjustment, coupled with the close manufacturing tolerances on parts, and precision adjustments necessary for the holders during assembly, these designs have been virtually discarded in favor of wire supported designs. However, more recent developments by J. F. Barry on pressure-mounted-type units have brought forth some new ideas which might prove in for wider future application.

13.3 Wire Supported Crystal Units

This type of mounting is being used extensively on crystal applications and has superseded the earlier pressure-type units. Various designs of this type of crystal are shown on Fig. 13.2. The wire-mounted crystal possesses the definite advantage in that after the supporting wires are attached to the plate, they remain fixed in position throughout the subsequent manufacturing process thus facilitating adjustment of the frequency or the frequency-temperature characteristic. Moreover, the supporting wires can be formed so as to provide a spring mounting for the crystal plate which protects it from any shocks or vibration it may encounter in shipment or use. In the wire-supported design the suspension wire is also employed as a means of connecting the electrical circuit to the electrode plating on the crystal. By virtue of the solder bond between the wire and the electrode, this type of unit is free from the possibility of instability in frequency performance due to slight changes in position and variations in contact resistance prevalent in pressure type designs, and for this reason the stability and frequency precision of wire supported crystals is superior.

From a manufacturing standpoint the wire-supported unit involves a greater number of processing operations than the pressure-type unit, but the adjustment operations are considerably easier. Moreover, it is possible to realize greater precision of frequency adjustment by a factor of at least two or even three. The crystals are also more uniform in their effective resistance. Since the mount or cage in which the crystal is suspended is comparatively inexpensive, there should in general be little difference in the manufacturing costs of the two types. Consequently, in the wire-supported crystal units a very appreciable improvement should be gained in performance without increasing the cost of the unit.

13.4 Fabrication of Wire Supported Unit

13.41 Silver Spotting

13.411 Application of Silver Paste

Starting with the crystal plate, the first step in manufacture is to apply silver spots to the surfaces of the plate. These spots serve as footings to which the supporting wires are ultimately soldered or sweated. They are placed on the nodal points or along the nodal lines of the plate in order to detract as little as possible from the intrinsic characteristics of the plate itself. The areas of the silver spots cover the range from about 40 to 90 mils in diameter depending upon the amount of solder to be used in attaching the wire to the plate. Before spotting the plates it is essential that they be free from any contamination such as grease or organic material that might affect the fusion of the silver spots into the surface of the quartz. One of the best methods to ensure cleanliness is to boil the plates in aqua regia, followed by copious rinsing in water. Detergents such as sodium meta-silicate are also employed followed by a rinsing. The plates may finally be boiled in distilled water and carefully dried. Throughout the subsequent processes the plates should be handled with clean tweezers or gloved fingers and kept away from any source of contamination. Prefiring of the plates at 950°F prior to spotting has also been used as a positive way of ensuring freedom from any contamination that would affect the fusion of the spots, but this process is not necessary if the first mentioned process is properly controlled.

In spotting, small quantities of a prepared silver paste are placed on the areas of the plate to which the wires will ultimately be attached. The paste consists of a compound of finely divided silver and low melting point glass (lead borate) thoroughly mixed with a suitable vehicle to facilitate application. For spotting purposes it has been found that a paste having a specific gravity of between 2.3 and 2.6 gives best results. In use, the materials must be constantly agitated or stirred in order to prevent the solid ingredients from settling out. This is important, for, unless the concentration of silver is maintained around 90 to 95 per cent of the solid matter, it will not be possible to obtain good wetting of the solder in making the wire attachment.

The placement of the semi-liquid material on the plate is accomplished by means of a small stylus, the crystal plate being held in a clamp or vise and the stylus guided so as to place the material at the exact location on the plate as desired. A typical tool for doing this work is shown in Figure 13.3. The point of the stylus should have a slightly rounded end. With the rounded point the tendency of the paste to spread out is minimized and consequently the diameter of the spot is substantially the same as that of the stylus. The rounded stylus also results in a more uniform distribution of the material. The material is applied to the end of the stylus by spreading a small amount of the paste on a glass plate from which it is transferred to the stylus and then deposited on the crystal. The material on the glass plate should be wiped off and replaced quite often due to settling and drying out of the mixture, in order to insure uniformly good spots. Generally speaking, anywhere from two to six spots at the most should be possible from one loading of the transfer plate depending upon the speed of the operator.

Regarding the character of the crystal surface, aside from cleanliness, and its effect on the ultimate strength of adhesion of the silver spot, experience

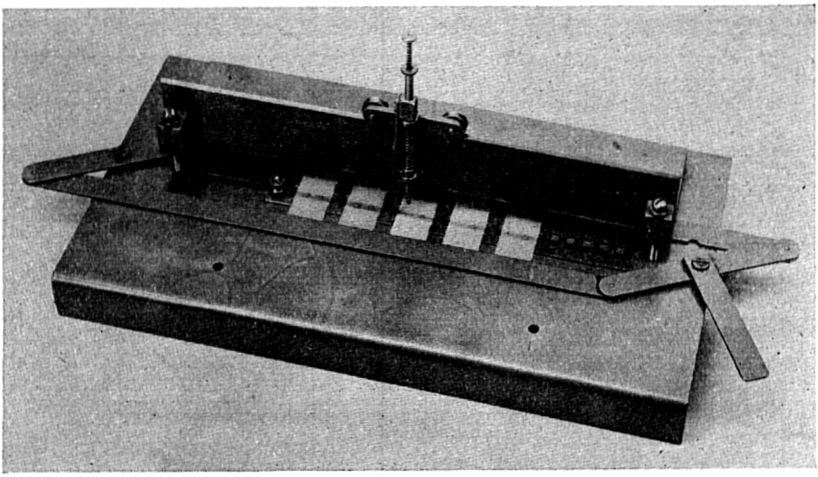

Fig. 13.3—Tool for applying silver spots.

so far with all the various cuts of plates does not indicate that this is a factor. Spots have been found to adhere to polished surfaces as well as ground and etched surfaces with about the same degree of strength.

13.412 *Firing of Silver Spots*

Following the application of the paste to the plates it is desirable to pre-dry the spots in order to remove the low volatile constituents of the vehicle prior to firing at high temperature. This may be done in a ventilated oven or over a hot plate at approximately 300°F for about 15 minutes. The plates are then placed in a furnace and heated up to between 975 to 1010°F and held at that temperature for a sufficient length of time to obtain good fusion of the spot to the plate. Ordinarily this reaction takes only a few minutes after the plate has reached the proper temperature. After firing, the plates are allowed to cool in the furnace to the point where they can be removed without danger of the crystal cracking due to cold shock. It is essential to control the temperature of the furnace so that the temperature of the crystal plates does not reach 1063°F, otherwise the crystals may become electrically twinned and consequently useless. In order to avoid shattering of quartz plates due to thermal shocks while heating up and cooling, fairly long cycles have heretofore been specified. However, more recent experience has shown that much shorter cycles can be employed especially where small crystals are involved. Moreover, there are indications that the faster heating, particularly during the last two or three hundred degrees temperature rise, results in better spots. During the firing

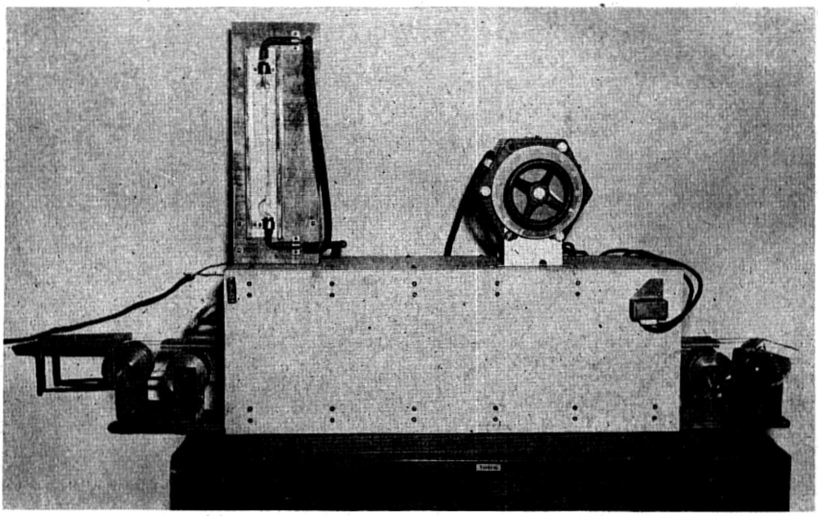

Fig. 13.4—Continuous-belt furnace for firing silver spots.

operation the crystal plates may be placed on nichrome wire mesh trays or Pyrex dishes provided ample provision is made for air to circulate around the spots. This precaution is essential with the types of pastes employed as the baking reaction must take place in the presence of oxygen so that the lead borate will not be reduced to lead, leaving only a partially bonded mixture of silver and lead on the plate. This type of spot when encountered usually has a dull appearance after burnishing as compared with the bright surface obtained with a good silver spot, and is quite difficult to wet with solder. For firing silver spots, ventilated continuous-belt-type furnaces with open ports are being used with very satisfactory results. Figure 13.4 shows a furnace of this type developed by C. J. Christensen for this purpose.

After the firing operation, the spots should be examined to ensure that they are satisfactory. Besides a visual inspection, it is desirable that a small percentage of the plates be used as a control sample to which mounting wires are attached and pull tested. Satisfactory spots should withstand for a few seconds a force of at least two pounds. The average pull-off strength of commercial attachments using 6-mil hooked or headed wires is between three and four pounds. Unsatisfactory plates can be reclaimed at this stage by stripping off the spots by means of aqua regia and ammonium hydroxide, and reprocessing in the manner described.

13.42 *Silver Plating*

At this point of the process the surfaces of the plates are coated with silver electrodes by the evaporation process previously mentioned. Four milligrams per square inch of silver is the weight of coating generally employed, which amounts to a thickness of .024 mil. Except for harmonic and other special types of crystal units, these coatings are required only on the major surfaces of the plates. However, during the evaporation process, the silver is deposited to some degree on the minor surfaces or edges as well, and it is necessary to remove it. This process called "edge cleaning", is done by lapping the edges of the crystal on a flat plate covered with a mixture of pumice or a finely divided abrasive such as No. 600 carborundum and water or kerosene in the form of a paste. Rubbing the edge of the plate lightly over very fine abrasive cloth is also satisfactory. The pumice is preferable, however, since while it readily removes the silver, it is much softer than quartz and consequently does not remove any material from the plate. The use of harder abrasives has a tendency to chip the edge of the quartz unless the operation is performed very carefully. After the edge cleaning is completed the plates are washed, dried and inspected by testing for insulation resistance at 500 volts d.c. to make certain that no conducting material remains between the silver coatings on the major surfaces.

13.43 *Division of Coating*

For circuit reasons all but a few types of crystal units require a balanced pair of electrodes on each side of the plate. Division of coatings along the longitudinal axis is essential on flexure mode crystals in order to make the plate vibrate in flexure. Typical divisions of coating can be noted on the crystals shown in Figure 13.2. In the case of the flexural crystal the dividing line is carried around the wire attachments in such a manner that each of the divided surfaces is connected to one of the wires. One method for dividing coating involves the use of a low voltage (two to three volts) impressed between the coating to be divided and a stylus.[7] When the fine point of the stylus is brought in contact with the silver plating and moved along the desired line of division, the silver is burned away, leaving a small

[7] W. L. Bond, Pat. #2,248,057.

gap in the plating between 8 and 18 mils wide depending upon the point of the stylus. Following the burning operation, the plate is immersed in a photographic hypo solution to remove all traces of the burned residue after

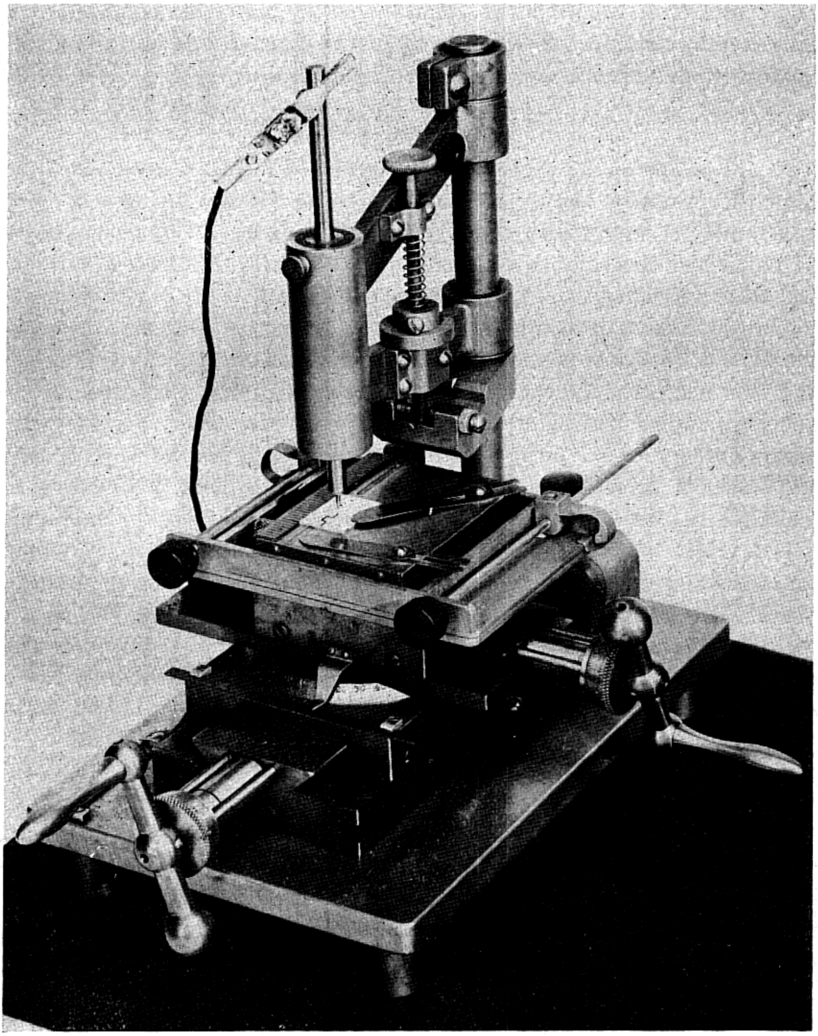

Fig. 13.5—Tool for dividing plating (electric stylus).

which it is carefully washed and rinsed in water and dried. In this process it is important that the plates are not kept in the hypo solution for longer than two or three minutes, otherwise discoloration of the silver coating will result. The gap in then tested for presence of metallic particles by gradually impressing voltages up to 1000 volts a-c across it. If no flashover occurs the division is satisfactory. If flashover occurs the voltage is maintained until the slivers are burned out. The hypo and burning treatments are repeated until a good division is obtained. Figure 13.5 shows an electric dividing tool developed for this purpose. In using this method it has been found that the arc at the point of the stylus may cause twinning of the quartz to a minor extent along the dividing line. This effect is usually insignificant although it may be objectionable especially where precise values of crystal inductance or frequency-temperature performance are required. Where more complicated divisions are necessary, as in the case of face flexure and harmonic plates, the electric stylus method is employed, although methods and tools for performing this operation by other means to avoid twinning are being developed.

13.44 Attachment of Wire Supporting Leads

Phosphor-bronze wire is employed in wire supported crystal units primarily because of its high tensile strength, and excellent fatigue resistance characteristics. Five- and six-mil diameter wires are the most widely used sizes, depending upon the mass of the crystal plate, the desired electrical performance, and the severity of treatment it is likely to encounter in use. To facilitate soldering the wires to the spot on the crystal plate and to the crystal support system the phosphor-bronze wire is given a heavy electrotinned finish. 59.5–34.5 per cent tin-lead eutectic solder saturated with approximately 6 per cent silver at 570°F is employed for attaching these fine wires to the silver spots of the crystals. This solder solidifies at approximately 360°F with practically no mushy stage. The reason for saturating the solder with silver is to discourage migration of the silver in the spot to the solder during the soldering operation. Even with this solder it is advisable to limit the time for heating of the joint to a minimum.

One method of attaching the wires to the crystal plate is by means of a special machine developed for the purpose. Such a machine is illustrated in the photograph on Fig. 13.6. The wire is fed from a spool through the head in the movable arm. The head contains a wire guide having a hole only slightly larger than the diameter of the wire and a small vise for firmly clamping the wire. The crystal plate is clamped in the vise on the hot plate which is thermostatically controlled at approximately 240°F. The position of the arm carrying the wire is lined up with respect to the crystal plate by means of guides so that the wire will be placed exactly on the nodal point or line of the crystal. In making the attachment, with everything lined up, the wire is fed through the guide until it touches the spot on the plate and the vise closed. Since the curvature of the wire can never be entirely eliminated the distance between the tip of the guide and the crystal plate is kept as small as possible. A small disc of solder is then punched in the press at the left, the little disc remaining in a round slot whose position is also lined up with respect to the arm carrying the wire. The movable arm

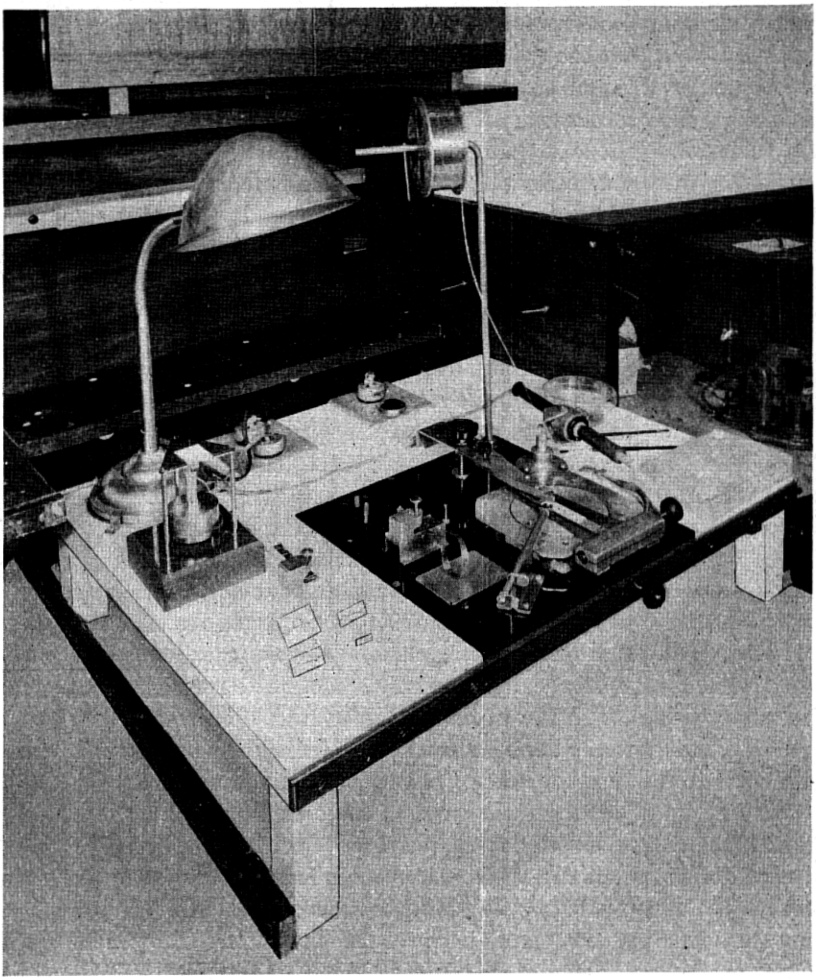

Fig. 13.6—Wire-soldering machine for straight or hooked wires.

is then rotated until the wire is directly over the solder disc at which point it falls into a guide and comes down and spears the disc. The arm is then lifted, picking up the solder at the end of the wire. The solder and the end of the wire is then wetted with rosin-alcohol flux and the arm rotated until it falls into its original position over the crystal plate. The solder is then fused to the wire and plate by means of a special aluminum tipped soldering iron as shown in the illustration or by a controlled hot air blast focused on the joint to melt the solder. In this operation a fillet or conical button is formed around the wire attaching it to the silver spot. To promote good wetting of the solder, the spot should be clean and well burnished. Rubbing the spot on a hard polished metal surface or burnishing with a blunt pointed tool of agate, are the best methods found so far.

The hot air blast has now replaced the iron entirely in commercial use. It consists of a tube through which air at about one inch water pressure is passed over a hot filament and through a nozzle directed at the solder. The head of the filament is adjusted so that the temperature of the blast is just hot enough to melt the solder and complete the attachment in 10 to 15 seconds time. In using this method with large plates care must be taken to insure that the temperature of the crystal has reached that of the hot plate and that the blast is brought up to the plate slowly, for otherwise the heat shock of the localized blast may cause the crystal to crack. For very small plates the use of a hot plate may be dispensed with if the hot blast is brought up slowly enough to preheat the crystal plate. Other means of melting the solder such as a hot radiant wire or ribbon or the use of a minute flame have been considered, but so far no extensive trials of these methods have been made. The advantage of the hot blast over the other methods mentioned is that it can be better controlled since little is left to the judgment of the operator. If an iron is used it must actually be touched to the solder with the possibility of displacing the position of the wire. Moreover, as already mentioned, the iron must be equipped with a special aluminum tip to prevent removal of solder from the joint on withdrawal of the iron. Considerable maintenance is required to keep such irons in satisfactory operating condition.

13.45 Type of Wire Attachments

The type of attachment described above wherein the part of the wire embedded in the solder cone is straight was used in the first designs of wire-supported crystals. However, it was found that with such attachments vibration of the crystal plate caused breakage of the bond between the solder cone and the wire with resultant failure of the attachments, especially in large plates. Because of this the use of straight wires is recommended only for small size plates. In order to eliminate the above difficulty a little hook has been placed at the end of the wire embedded in the solder in order to obtain a better anchorage. The hook is formed in the wire by means of a special tool affixed to the soldering machine. The basic methods described for straight wires are otherwise used for this type of attachment. Instead of spearing the little solder discs as with the straight wire, the solder is punched in the shape of a horseshoe and squeezed in place on the hook or positioned by tool with the hooked wire in place on the spot. Hooked wire attachments will withstand pulls of the order of three to four pounds before pulling off. Under severe vibration hooked-wire attachments have the same tendencies as straight wires towards breaking away of the wires from the top of the solder cone forming a small crater in the latter. However, the crater does not progress deeply enough into the solder cone to impair their strength or cause failure under ordinary conditions.

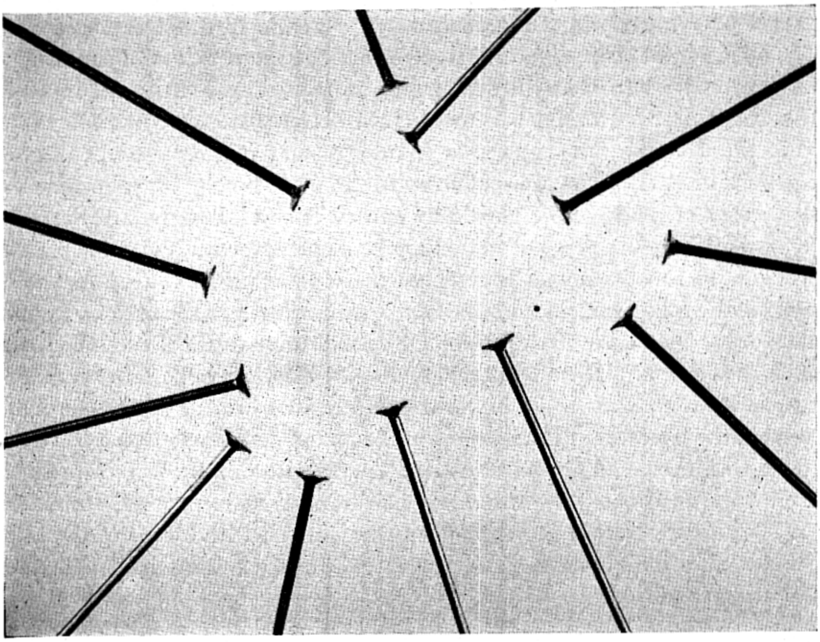

Fig. 13.7—Examples of headed phosphor-bronze wire.

The most recent development for wire supports involves the use of headed phosphor-bronze wires as worked out by A. W. Ziegler. In this procedure individual wire lengths are cut and one end upset in a cold heading tool which provides a little cone-shaped head with a base of about 22 mils as shown in Figure 13.7 for 6-mil diameter wires. The head is carefully pre-tinned, leaving a small globule of solder at the end. Depending upon the size of the crystal plate, globules of 1000, 3000 or 7000 cubic mils of solder are used. The attachments are made in a wire soldering tool which attaches the wires to both sides of the plate simultaneously. This tool is illustrated in Figure 13.8. The prepared wires are fed into positioning guides, which

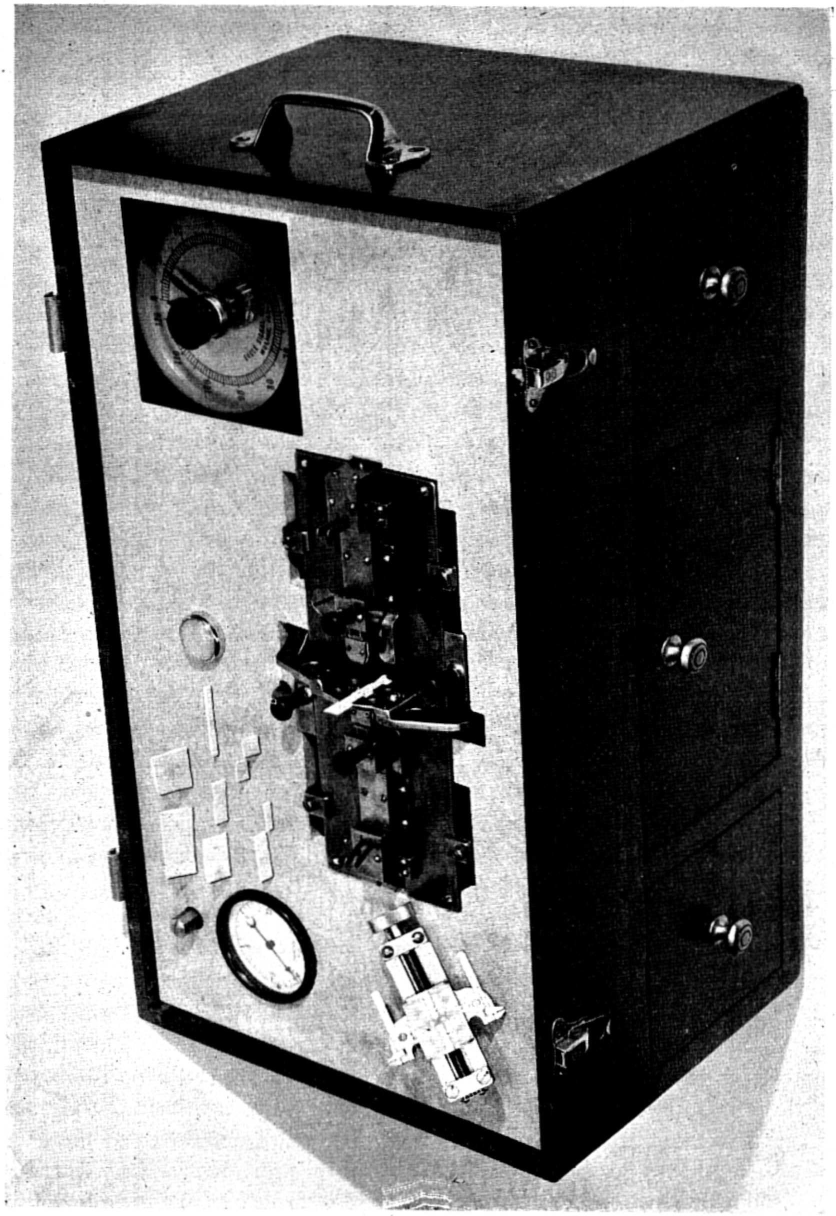

Fig. 13.8—Machine for attaching headed wires.

are aligned with respect to the crystal plate, which is properly located and held between sliding jaws as shown. Prior to the operation the silver spots are burnished and fluxed. The wires in their guides are then slid into contact with the plate. The hot blasts are raised from below so as to aim directly at the work. The solder is melted and the attachment completed in about 10 seconds when the blasts are withdrawn. Slight pressure is maintained on the wires during this operation by springs in the guides to force the head of the wire to seat on the spot. A small fillet is obtained around the head making the solder cover an area of about 35 to 40 mils diameter.

Crystal units using headed wire attachments have many advantages over those made with straight or hooked wires. The pull-off strength is more uniform and averages slightly better than that of hooked wires, despite the fact that only a fraction of the amount of solder used with hooked wires is employed. With this type of attachment the cratering effects encountered with previous methods have also been eliminated. The reduced quantity of solder on the face of the crystal plate effects a decided improvement in the temperature coefficient of the crystal unit as well as in its efficiency and stability. Although the heading of the wires and the subsequent cleaning and tinning operations involve more work, the process of making the attachments is simpler and quicker, since the use of individual wires is better adapted to making all the attachments in one operation. Headed wire attachments are more uniform in size and shape and give a more workmanlike finish to the job. This type of attachment has now replaced those using straight and hooked wires in virtually all designs of telephone type crystal units using wire supports. While the potential advantages of a headed wire type of attachment for crystal support wires had been known for many years, the practical exploitation of the idea depended on finding commercial means for producing the headed wires. The development of a suitable machine for this purpose was carried out by the Western Electric Company in close collaboration with the Laboratories. Figure 13.9 shows such a machine. The fine wire is fed through the lower mechanism to a die in which it is firmly clamped with a predetermined amount extending above the plate. This part of the wire is then cold-worked by multiple punches in the head of the machine until a conical shaped head is formed in the die cavity. As the individually headed wires are formed they are cut off to a definite length and expelled as the vise is released and the next wire brought into position. Cold heading of the wires is necessary in order to retain the elastic properties of the phosphor-bronze springs employed in the suspension. The operation of the tool is simple after the precise alignments of the die and punches have been made.

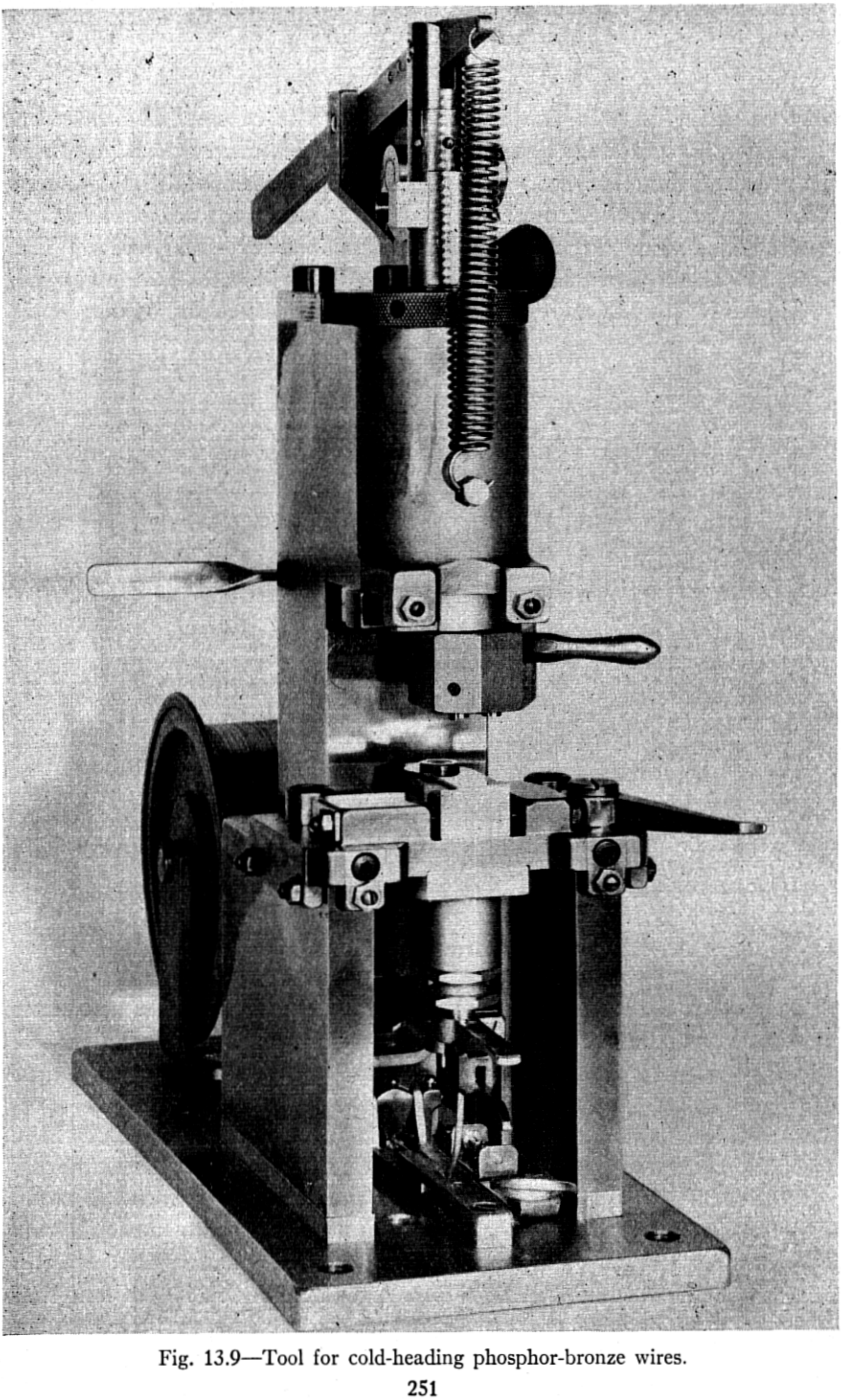

Fig. 13.9—Tool for cold-heading phosphor-bronze wires.

13.46 *Mounting the Crystal Plate*

After the suspension wires are affixed to the plate, they are then bent to serve as springs and to permit soldering into the cages as illustrated in Fig. 13.2. Two different types of springs are used, one of them involving one bend and the other two. The direction of the bends and the distances between them have been worked out so that the crystal will be displaced to about the same extent in all three directions for equal forces. The cages are of simple construction being made up of mica stampings and metal rods. The assembly of these parts is performed by welding little

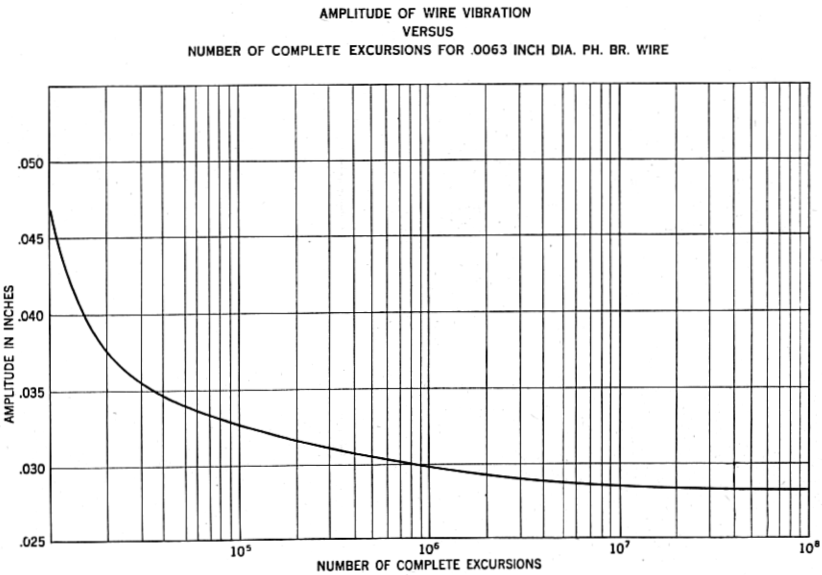

Fig. 13.10—Characteristic performance of phosphor-bronze spring wires.

eyelets, which are staked into the micas, to the rods. In the structures shown, the inside micas are provided with rectangular slots which limit the sidewise movement of the crystal plate from 25 to 30 mils. The end micas are spaced so as to limit the movement of the plate in the lengthwise direction by the same amount. Aside from being used as parts of the cage, the micas therefore serve as "bumpers" to prevent excessive displacement, and possible breakage of the wires or plate if the crystal units are subject to extreme vibration or shock. Figure 13.10 is an experimental curve showing the minimum number of excursions made by wire-mounted crystal plates vibrated at different amplitudes before wire failure occurs for 6.3 mil phosphor bronze spring wires with single bends. On the basis of these data, the chosen spacing of 25–30 mils between the crystal plate and the bumper should ensure against any service failure of the unit in this regard. In order to center the crystal laterally and longitudinally in the bumper system, the plate is assembled first in the cage by means of spacers. The fine wires are then soldered to the vertical rods or "straights" as they are called, and the spacers removed leaving the plate suspended in position. In order not to set up any strains in the junctions of the wire to the straight which might tend to displace the plate after this operation, the spring wires are usually pre-formed to come within about 5 to 20 mils of the straight. The junction is made by immersing the intersection of the wire and straight in a ball of molten solder. As the wires are withdrawn the ball of molten solder comes with them, solidifying in the air and thus joining the fine wire to the straight without strain.

It will be noted from Fig. 13.2 that the wires to the longitudinal crystal are equipped with little weights close to the plate. This practice has been found desirable on virtually all types of crystal units to alleviate problems of wire resonance[8] which arise in occasional units thereby causing high resistance as well as a shift in the frequency of the plate. Initially, while these effects were noted to some extent in the course of laboratory developments, it was not thought that they would be prevalent enough to warrant taking precaution to eliminate them by loading the wires, since they can usually be corrected by refloating and resoldering the crystal plate thereby changing the effective length of the wire. However, it has turned out that in manufacture a large enough percentage of crystals contain resonant wires to warrant the use of weights. For low-frequency crystals (up to 200 kc) solder balls are placed on the wire at the desired location using a method worked out in conjunction with the Western Electric Company. The process is performed in somewhat the same manner as that described above for connecting the crystal support wires to the straights, except that the weight of the solder deposited and the distance from the plate is more critically controlled. For higher-frequency crystals above 200 kc in which more precise positioning of the weight is essential, small metal discs are employed. They are threaded onto the mounting wire and held in the correct position by a definite amount of solder on the back to obtain the desired loading. Since the free length of wire must be accurately controlled, the manufacturing aspects of this job have been greatly simplified by the use of headed wires in which the variation in height of the solder cones is very small. The chart shown in Fig. 13.11 shows the weights of solder balls or discs and the position they should take on crystals having frequencies up to about one megacycle. It should be noted that the chart covers .0063″ phosphor

[8] "Principles of Mounting Quartz Plates," R. A. Sykes, *B.S.T.J.*, April 1944.

bronze wire. For any other diameter, d, of phosphor bronze wire, the new distance

$$X' = X\sqrt{\frac{d}{.0063}}.$$

Earlier, it was mentioned that the supporting wires for the plates were formed with one or two bends. In addition to the function of suspension these bends also introduce changes in impedance along the wire thus mini-

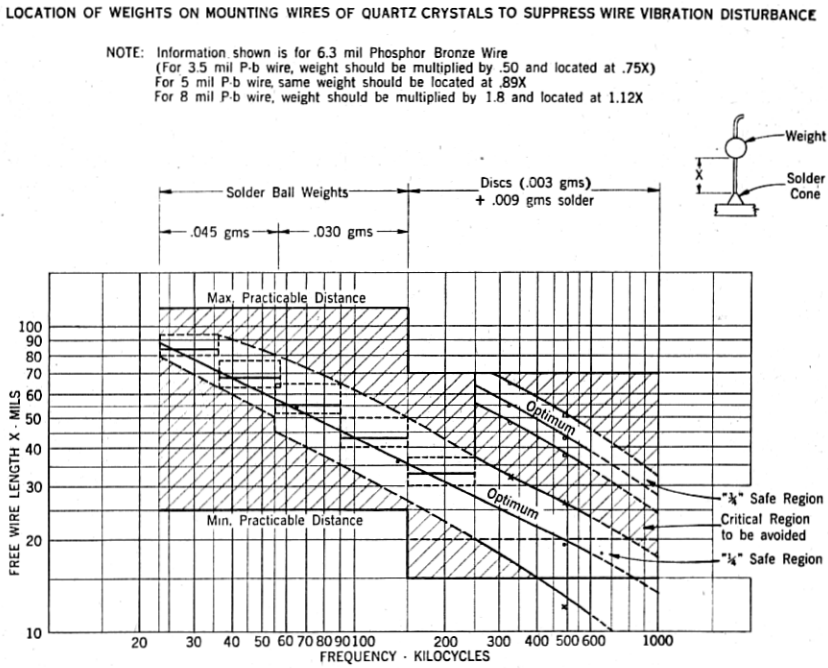

Fig. 13.11—Graph for determining placement of weights on wires for damping vibration.

mizing the possibility of trouble due to wire resonance. The use of a greater number of bends in the wire would tend to accomplish the same result as that of weights. However, the use of weights is considered more practical and has been adopted. As a result of this change, it is possible to employ wire supports having only one bend in virtually all crystals. In low-frequency crystals (below 2 kc) where the wave-length of the flexural wave in the wire is relatively long it is unnecessary to use weights since the wire length can be controlled adequately by the termination of the support wire at the straight. Depending upon the frequency, the desired length of wire is obtained by using either two or three direction bends.

13.47 Housing of Crystal Units

For the pressure-type units first discussed no provision was made for protecting or sealing them other than the hermetically sealed containers in which all the other associated components of the filter were enclosed. However, the wire-supported designs have been worked out so that each unit is sealed in its own individual container. Fortunately, the sizes of virtually all crystal units are in the range which permits the use of relatively inexpensive radio tube parts for these housings. There are many obvious advantages to the individually sealed unit. After adjustment and sealing it can be handled more readily in subsequent assembly operations. It is not subject to variations due to changes in ambient humidity and consequently does not restrict the assembly of apparatus to conditioned space. It can be made up and stored or shipped as an individual unit. It has a higher degree of stability. There is one small effect, however, in the case of units which are sealed in vacuum. Due to the absence of any gaseous medium around the crystal, a slight change in frequency is encountered when the tube is evacuated. However, this change is always the same for each particular type and size of crystal and can be allowed for in the final adjustment before sealing.

Most designs of crystals can be sealed in an atmosphere of dry air although better performance results from the use of vacuum. Some crystals must be sealed in vacuum for this reason. A decided advantage in favor of vacuum-sealed crystals is the elimination of acoustic effects from air resonance.

Both metal and glass tubes are used for housing crystal units. Initially it appeared that metal tube radio parts were ideally adapted to crystal use, and it was felt that, instead of welding the stem to tube, this sealing operation could be done by soldering. However, it was found that while sound solder joints could be obtained, extreme precautions were necessary to protect the button-type glass seals, through which the leads emerge, during the pre-tinning and soldering operations. Even with such precautions, it would have been essential to include in every vacuum type tube a means of detecting whether or not a leak had developed. For air-filled tubes at atmospheric pressure this would not have been necessary since minute leaks can be tolerated with little likelihood of the crystal being affected over a long period of time. The possibility of welding as is done in the case of radio tubes was considered but did not appear justified on the basis of equipment cost. Moreover, even with welding there still appeared to be problems from leakage and outgassing of the metal since, after the crystal is enclosed, the assembly cannot be exposed to high temperature to drive off adsorbed gases during the evacuation process. In view of these drawbacks the use of metal tubes has been discarded in favor of glass tubes except in the case of a few special designs.

The procedure of mounting a crystal unit on a stem and sealing it in glass is much the same as for a radio tube. Figure 13.2 shows crystal units mounted on stems ready for sealing and also shows units sealed in glass and based. The extensions of the straights through the bottom micas are welded to the formed wires emerging from the glass seals. In the glass-sealing operation care must be taken not to heat up the assembly to the point where the solder attachments will be melted or even softened enough to permit the crystal to change position. To accomplish this it is necessary to use hot, sharp-pointed fires localized to the region where the seal will be made. The use of oxygen-gas flames is virtually essential to accomplish the seal quickly. Having the fires strike the bulb at tangency is also desirable. The ordinary type of glass-sealing head for use with gas-air fires is not well adapted to this work since the rotating pillars require the fires to be held too far away from the work thereby necessitating larger flames and consequently more heating up of the crystal unit assembly. The screening effect of the pillars as they revolve also slows up the work of the fires thus increasing the over-all heating of the assembly. A special glass-sealing machine developed for sealing crystal units is shown in Fig. 13.12. Immediately following the sealing operation the glass units should be placed in a suitable annealing box or leer where they can cool off very slowly. A large wooden block equipped with holes to admit the individual bulbs is convenient. The holes may be covered with a cloth to prevent air circulation.

After the units have cooled they are placed on a vacuum pumping station and evacuated. During the first half hour of pumping they are enclosed in a heated oven in which the ambient temperature is maintained at about 240°F. This drives off any traces of moisture that might have entered the tube prior to sealing. Following the heating interval, the tubes are pumped for another half-hour during which time they will have cooled down to room temperature. At this point the pressure in the tubes should be at the minimum of which the pump is capable of attaining. This value should be at most 20 microns and preferably less. However, with a six- or eight-tube station better than 15–20 microns is not likely to be attained unless a liquid nitrogen trap is employed in the system for eliminating moisture.

After the pumping period, vacuum-type units are sealed off, with pump running, by melting the glass tubulation with a fine-pointed oxygen-gas flame as close to the stem as possible. If air is to be admitted, the pump is closed off from the system and dry air admitted to the tubes after which they are sealed off. After testing the crystal unit to see that it meets its requirements, the unit is equipped with a base in the same manner as followed for radio vacuum tubes.

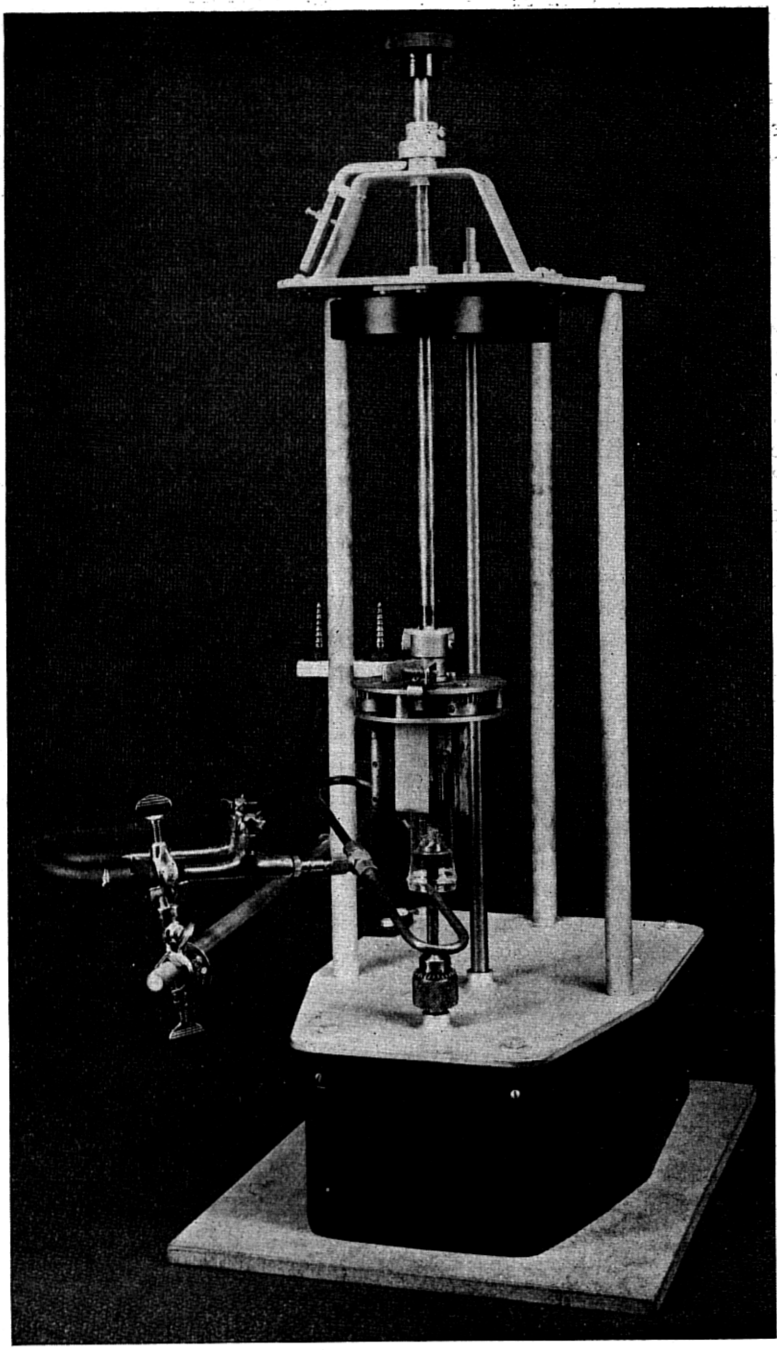

Fig. 13.12—Glass-sealing machine.

13.48 *Stabilization of Crystal Units*

Despite the close dimensional tolerances applying to the manufacture of the individual crystal plates, the exact frequencies are rarely realized in the mounted crystals. To bring the crystal to frequency it is therefore necessary to grind off minute layers from the lengthwise or widthwise edges of the plate depending on the mode of vibration. This adjustment, which causes superficial disruption of the quartz areas affected, results in unstable operation of the unit with respect to frequency and resistance. Unless the crystal plate is properly treated after these operations, considerable drift in these characteristics will take place, particularly during the initial service life of the unit To alleviate this condition, the crystal units are first rough-adjusted to the approximate frequency and then heat-aged in an oven which subjects the units to several heating and cooling cycles between 240°F and 75°F. The units are then mounted in their cages as previously described and fine-adjusted after which they are again aged. This operation also tends to drive off any moisture which might be troublesome. With this type of accelerated aging the crystals are stabilized to the point where changes in performance can be detected only by the use of the most precise measuring equipment over long periods of time. Crystals so stabilized may generally be depended upon, at any one temperature, maintaining their frequency indefinitely within two or three parts per million provided they are not subjected to excess voltage.

13.49 *Cleaning of Crystal Units*

Throughout the manufacturing process it is essential that every precaution be taken to keep the crystal plate and associated parts absolutely free from contamination and dirt. The rigorous cleaning necessary before the spotting operation has already been discussed. In all the subsequent operations care must be taken to prevent the plates coming in contact with substances that might tend to cause corrosion. Any particles of foreign matter that may have accumulated on the plate or wires before rough and fine adjustments should be carefully washed off. Otherwise the performance and life of the crystal may be adversely affected. A suitable method for cleaning crystal units before sealing consists of washing and rinsing in chemically pure carbon-tetrachloride or other suitable solvent to remove grease, followed by washing and rinsing in hot distilled water at about 150°F. To facilitate removal of unwanted substances, the parts should be scrubbed gently with a soft brush or agitated in the solution during this process. The use of pure alcohol (95%) in addition to carbon-tetrachloride is also good for this process, but is not essential. The cleansed crystal units should be carefully dried out and protected from further contamination prior to the sealing operation.

13.5 Conclusion

In ending I should like to acknowledge the aid and useful suggestions given me by Mr. C. E. Lane and my other associates in preparing this article. I should also like to reiterate the fact that the status of the art as described was reached after many years of pioneering development by many engineers. In some cases the names of individuals associated with specific contributions of a major nature have been mentioned.