Certain crystalline substances develop a voltage upon their surfaces when they are subjected to a mechanical stress and, conversely, when a voltage is applied, a mechanical deformation of the crystal takes place. This phenomenon, discovered by the Curie Brothers in 1880, is known as the piezoelectric effect. The crystal phonograph pickup functions upon this principle.

The crystalline substance most commonly used for crystal cartridges is the crystalline form of Rochelle salts (sodium potassium tartrate). These crystals exhibit piezoelectric properties far greater than any other known material, being approximately 1000 times more active than quartz.

The crystals are first grown from a Rochelle salt solution in the form of large, clear homogeneous bars. These bars are cut into slabs from which the final crystal plates are cut.

The properties of these crystal plates may be expressed in the terms of the axes X, Y, and Z, as shown in Figure 1A. In the Rochelle salt crystal plate, the electric effect is greater along the X axis and, consequently, the plates are cut perpendicular to the X axis as shown in Figure 1B. The two fundamental "X-cut" plates, the expander and shear plates, are shown in Figures 1C and 1D. The expander plate is cut at an angle of forty-five degrees to the Y and Z axes and the shear plate is cut with the edges parallel to the Y and Z axes.

When a voltage of a given polarity is applied to the two faces of the plate, the mechanical motion developed will be at a forty-five degree angle to the Y and Z axes. As the expander plate (Figure 1C) is cut at a forty-five degree angle to the Y and Z axes, the mechanical motion developed by an applied voltage will increase its length and simultaneously decrease its width. On change of polarity of the applied voltage, the length will decrease and width increase. The cut of the shear plate as noted in Figure 1D is such that

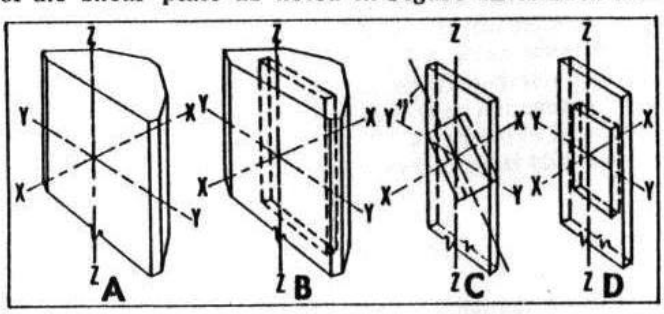

Figure 1. Cutting Angle of Expander and Shear Plate Phono Crystals Showing X, Y, Z Axes.

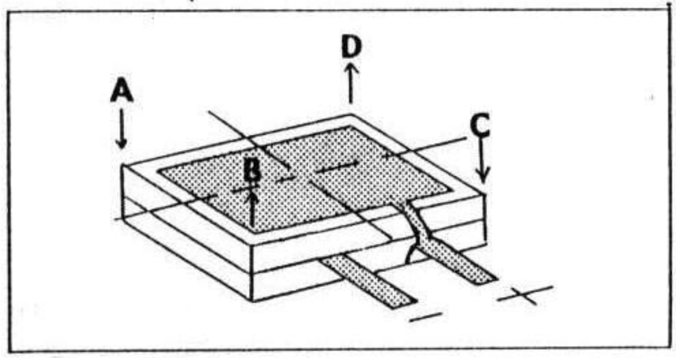

Figure 2. Movement of Corners in a "Twister" Element with a Potential Applied.

mechanical motion developed by an applied voltage will cause an expansion and contraction approximately along the diagonals of the plate.

Bender and twister elements, made commercially under the trade name "Bimorph," utilize two or more X-cut crystal plates cemented face to face.

In the "bender" type, the X-axis of two or more expander plates are so oriented that as one plate expands in either direction the other contracts. An applied electric potential tends to make one plate longer and narrower and the other shorter and wider and as a result, an unconstrained bender element tends to become saddle shaped. If one end of the element is clamped and an alternating voltage is applied, the other end moves to and fro. If both ends are clamped, the curvature in the breadth direction is largely suppressed and the central portion of the element vibrates like a diaphragm.

"Twister" elements consist of two or more shear plates cut in square, rectangular, or trapezoidal shape. When a voltage of given polarity is applied to the twister element, the shear plates tend to expand and contract along the diagonal. The plates are so oriented that the diagonal of one plate is expanding as the corresponding diagonal of the other plate is contracting.

The resultant motion of the twister element is such that corners A and C of Figure 2 have a downward motion while corners B and D have an upward motion. This action is reversed on change of polarity of the applied voltage. If the element is clamped at one end, as at BC, then the end face AD tends to rotate in its own plane. Twister elements are often mounted in this way in crystal cartridges.

Rochelle salt crystals operate safely from -40° to +130 degrees Fahrenheit. Their greatest piezo-

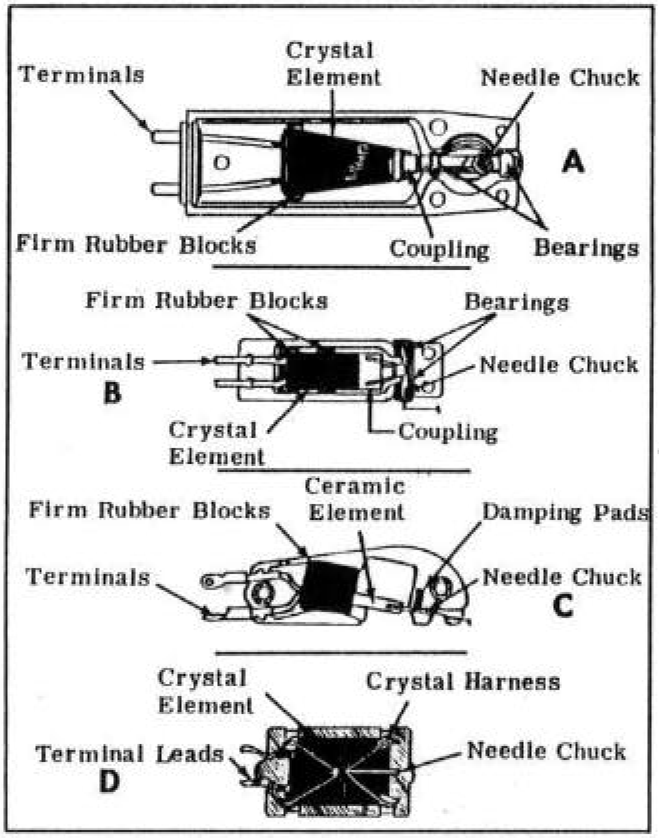

Figure 3. Examples of Various Types of Crystal Harnesses.

electric activity is at normal room temperature. When the crystals are subjected to temperatures above 130° Fahrenheit, they lose their piezoelectric properties permanently. In storing Rochelle salt crystal cartridges, care should be taken to insure that the cartridges are placed in relatively cool places. Exposure of the cartridge to the sun, as in window displays, should be avoided. If necessary to use a soldering iron on the cartridge when making an installation or servicing, the soldering iron should not be applied for a longer period than necessary to make a good joint. In climates of high relative humidity and temperature, the Rochelle salt crystal has a tendency to take on excessive moisture.

PN CRYSTAL

Another type of crystal element sometimes used in phono cartridges is the PN Crystal (Primary Ammonium Phosphate). This crystal is capable of operating at a higher temperature than the more common Rochelle salt crystal. The PN element will temporarily withstand temperatures as high as 212° Fahrenheit and will operate at temperatures as high as 140° to 160° Fahrenheit for a considerable period of time without permanent damage. Slightly higher open circuit output voltages may be obtained from the PN crystal as compared to a Rochelle salt element of the same size and in the same assembly.

The capacity of a PN crystal is approximately one-tenth the capacity of a Rochelle salt element of the same dimension. Because of the comparatively low capacity of the PN element, it should not be used to replace a Rochelle salt crystal cartridge directly. The lower capacity of the PN element makes it necessary to use a load resistance approximately 10 times the value used for a comparable Rochelle salt crystal cartridge, if the same frequency response is to be maintained.

A piezoelectric ceramic element is also used in phono cartridges. This element is especially adaptable for use in hot and humid climates. However, the output of the ceramic element is lower than for a comparable Rochelle salt crystal.

Drive Systems

Low mechanical impedance of the stylus in a phonograph pickup is very important in improving reproduction and in reducing record wear and needle talk. The high inherent stiffness of piezoelectric crystal elements necessitates the use of some efficient type of coupling between the crystal element and the needle if a high ratio of output voltage to stiffness is to be obtained. Considerable research and development have been devoted to the improvement of the coupling systems of crystal cartridges. The old, heavy, stiff-acting cartridges are being replaced by modern light weight cartridges that are much more compliant.

Several different methods are used to couple the torsional motion of the needle system to the crystal element. Some of the more common methods are illustrated in Figure 3. The crystal cartridge shown in Figure 3A uses a "twister" element. The twister element is clamped at the lead end by means of two firm rubber blocks. The needle chuck is mounted in two rubber or composition bearings. As the needle follows the groove of a record upon which sound has been recorded, the needle vibrates in proportion to the amplitude of the recorded sound. This vibration is transmitted to the soft rubber coupling between the needle chuck and the crystal element and this coupling is compressed in proportion to the torsional motion of the needle. The pressure thus developed acts upon the crystal, and a voltage is generated that is proportional to the amplitude of the recorded sound.

A crystal cartridge that uses a "bender" element is illustrated in Figure 3B. The same cartridge is shown in Figure 4A with the crystal, needle chuck, and coupling system shown separately. This cartridge

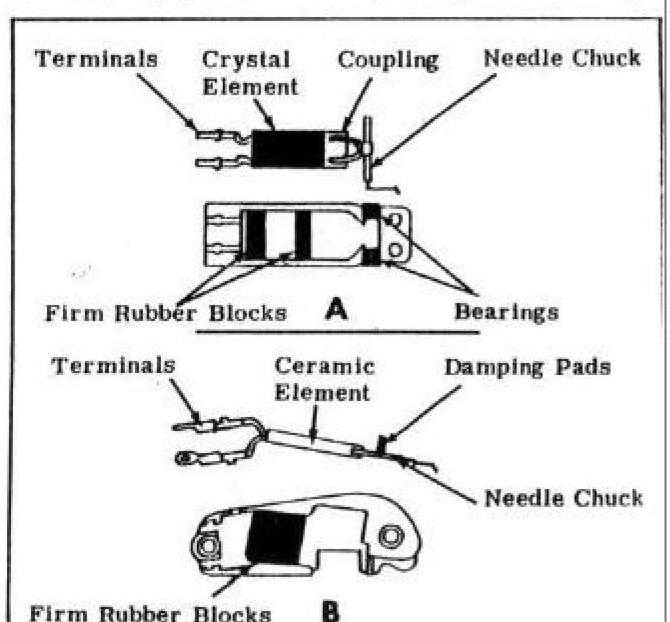

Figure 4. Crystal and Ceramic "Bender" Cartridges

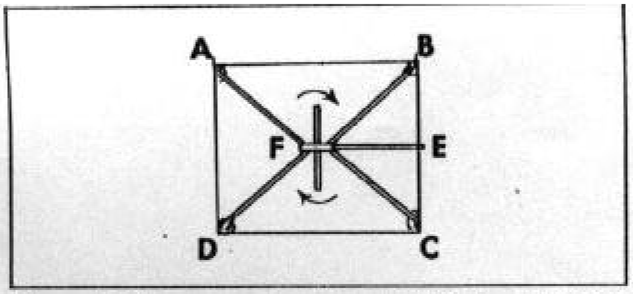

Figure 5. Harness Arrangement Employed with a Single Shear Plate Crystal.

has the crystal element clamped at approximately the middle as well as at the lead ends. The needle chuck is coupled to the crystal element in such a manner that any lateral motion of the needle applies a bending stress upon the crystal element proportional to the lateral motion. The vertical motion of the needle is absorbed by the rubber bearings of the needle chuck and produces relatively little if any bending stress upon the crystal element.

The cartridge shown in Figure 3C uses a piezoelectric ceramic element. Figure 4B is an illustration of the same cartridge with the ceramic element and needle chuck shown separately. The needle chuck is coupled directly to the ceramic element. This element is clamped at the rear portion by means of two firm rubber blocks. Any lateral motion of the needle exerts a bending stress upon the ceramic element causing a voltage to be generated that is proportional to the lateral motion of the needle.

A crystal cartridge that uses a single shear plate crystal is illustrated in Figure 3D. The harness that is attached to the corners of the crystal is composed of offset diagonals as shown in Figure 5. When a shear plate crystal is compressed along one diagonal and elongated along the other, a voltage is generated that is proportional to the applied force. If the needle chuck EF is rotated in the direction of the arrows, diagonal BD will be compressed while diagonal AC will be elongated. This distortion of the crystal produces a voltage between the faces of the crystal. Rotation of the needle chuck in the other direction compresses the crystal along diagonal AC and elongates it along diagonal BD, producing a voltage of opposite polarity between the faces of the crystal.

Another cartridge that uses a single expander plate crystal is illustrated in Figure 6. The expander plate is mounted in the harness in such a manner that when the needle chuck is rotated laterally in one direction the crystal is compressed lengthwise and expanded breadthwise, generating a voltage between

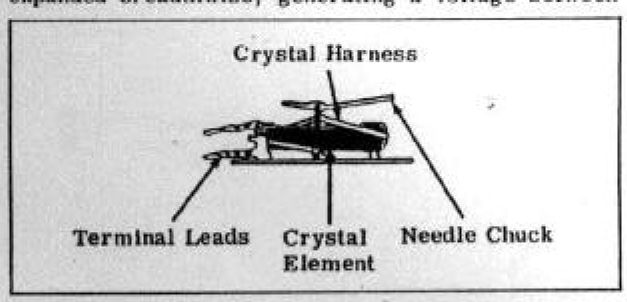

Figure 6. Crystal Harness Coupled to an "Expander"

cartridges may be replaced by an equivalent modern cartridge that will give a better reproduction of records as well as reducing record and needle wear.

the faces of the crystal. Rotation of the needle chuck in the other direction allows the crystal to expand lengthwise and contract breadthwise, producing a voltage of opposite polarity.

Lever Type Cartridge

The lever type cartridge shown in Figure 7 consists of a single lever formed of thin metal in a trapezoidal shape. The lever is slotted to allow entry of the crystal element. The rear portion of the lever and crystal assembly is held secure in the cartridge case by means of two firm rubber pads. The front of the lever is connected to the needle chuck through a composition pad which serves to provide a longitudinal shock isolation between the chuck and lever. Since the lever is rigidly coupled to the needle chuck, the lever will faithfully follow any rotary motions of the needle.

The torque transmitted from the needle chuck to the crystal by means of the trapezoidal shaped lever is built up several times. This permits decreasing needle-point stiffness without loss of output voltage.

Cartridge Replacement

Crystal cartridges are made in a variety of sizes and shapes as well as in a wide variety of electrical characteristics. The trend in recent years has been toward a lighter, more compliant cartridge with a wider frequency response. Typical old style cartridge cases were frequently cast of a heavy white metal and weighed approximately 30 grams. The modern cartridge using a stamped aluminum or bakelite case with a net weight of 4 or 5 grams is not at all uncommon. Improved needle design and more efficient drive systems have enabled manufacturers to produce a cartridge several times as compliant as the older models. The compliance or flexibility of the needle system allows the needle to more faithfully follow the modulated groove of a record and results in a more faithful reproduction.

Several million phonograph and record changers are still using the old, heavy, stiff model cartridges. This represents a potential source of income for the service technician. In many cases, these old model

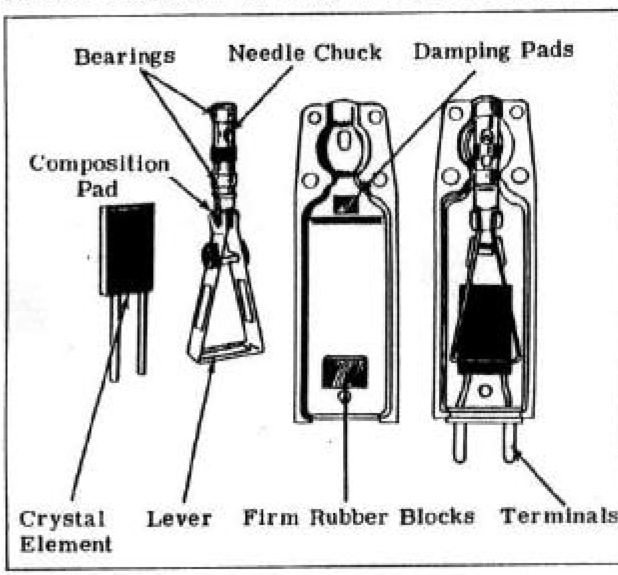

Figure 7. Details of Harness Employed with a "Twister" Element.