Pickups, Tone Arms, and Needles

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Sound-Chapter 5

Most music lovers think of a hi-fi system as, primarily, a top-quality phonograph. The first link between the groove and the listener's ear is the needle, followed closely by the pickup as the second link, and the arm as the third. Thus all three are important in the chain of equipment that translates grooves to music.

THE MODERN PICKUP, unlike the older "sound box" of the acoustical phonograph, is an electrical generator driven mechanically by the vibrations of the stylus. The pickup's output appears as an alternating voltage between two terminals; the extent to which this voltage faithfully represents the recorded signals is the degree of fidelity of the pickup.

Modern pickups that are in general use belong to one of two basic categories, with one exception. These two categories are the piezo-electric and the magnetic (there are variations within each); the exception is the capacitive pickup.

Magnetic pickups are by far the most common in high-quality installations. They may in turn be classified into two types: the variable reluctance pickup and the dynamic or moving-coil pickup.

The Variable Reluctance Pickup

In order to understand how the variable reluctance pickup works we must first briefly consider some of the fundamentals of electro-magnetic theory.

A magnetic "structure" refers to a system which includes a magnet, with north and south poles, and a magnetic path between the poles, in which magnetic forces exist. The structure is often referred to as a magnetic *circuit*, analogous to an electrical circuit in many ways. The magnet itself is like the electrical generator, and the magnetic path is like the load connected to the generator.

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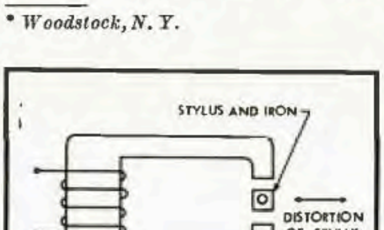

Fig. 4—1. Simplified diagram of the variable reluctance pickup.

In an electrical circuit the amount of current flow (within the power capability of the generator) is determined by the generator voltage and the circuit resistance. For a given voltage, the lower the resistance the greater the current flow.

In a magnetic circuit the strength of the magnetic field in the path between north and south poles is determined by the field strength of the magnet and by the *reluctance* of the magnetic path (analogous to *resistance* in electrical terminology).

Different materials have different reluctances. For example, air has a high reluctance, iron a low one. For the same magnet, then, a relatively strong magnetic field will exist if the path between magnetic poles is of iron, and a relatively weak one if the path is of air. Intermediate values will be associated with a path which is partly iron and partly air.

We need to discuss one more phenomenon before completing the theoretical background of the variable reluctance pickup. If a coil is moved with its conductors perpendicular to a magnetic field (as in an electrical generator), a voltage appears at the coil terminals. The appearance of this voltage is due to the *relative* motion of coil and magnetic field, and it doesn't make any difference which of the two does the moving. The same effect will be created if the coil remains motionless, and the magnetic field expands or collapses in such a way that its "lines of force" are perpendicular to the wires.

The design of the variable reluctance pickup is based upon the above phenomena. *Figure* 4—1 shows a simplified diagram of a coil and magnet in a pickup; the magnetic path consists of the U-shaped iron, the air in the gap between the ends of the U-shaped piece, and the iron held in the gap by the needle. The reluctance of the magnetic path will thus be at a minimum when the movable iron is fully in position in the gap, and will be at a maximum when the needle has moved its iron out of the gap.

As the needle is vibrated by the record groove, the reluctance of the magnetic path is continuously changed. The strength of the magnetic field will also be changing, inversely (the higher the reluctance the weaker the field). The magnetic field expands and contracts across the conductors of the coil, and since there is relative motion between the magnetic field and the wire a varying voltage appears at the coil terminals, which is to say at the output of the pickup.

It will be seen that the only work that the needle must do is to move the tiny piece of iron in and out of the gap (the energy required to change the field is negligible). The mechanical system of the pickup can be highly compliant, which contributes greatly to the fidelity that can be achieved with variable reluctance pickups. Low distortion and extended, relatively peak-free frequency response may be expected.

Another characteristic of variable reluctance pickups is low voltage output (low, at any rate, compared to the piezoelectric type). The General Electric pickup, for example, is rated as having 10 millivolts output at a given reference

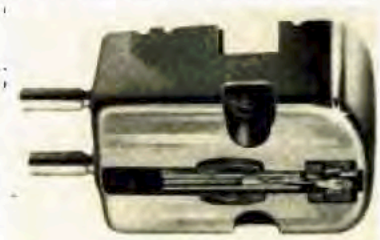

Fig. 4—2. The G. E. variable reluctance pickup. There are two gaps: when the iron in the stylus assembly is moved out of one gap it is simultaneously moved into the other.

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standard of groove modulation.

A further characteristic of variable reluctance pickups is that the output voltage is proportional to stylus *velocity*, not to the distance of needle travel. We have seen that the recorded signal is doctored before it is cut into the disc. A pickup whose output is proportional to needle velocity will present us with the doctored signal, not the original one. Therefore variable reluctance pickups must always work in conjunction with a preamplifier stage, which increases the signal voltage and, at the same time, compensates for the frequency equalization existing in the recording.

Figure 4—2 illustrates a commercial variable reluctance pickup. The needle assembly itself is the only moving element in the system.

The Moving-Coil Pickup

The moving-coil pickup works in an inverse manner to the variable reluctance unit. It has a coil, and the output voltage appears at the coil terminals, but in this case the magnetic path is fixed and the coil itself is the moving element.

Such a coil must, of course, be very light and small. There is no room for many turns of wire, and the output voltage is low even when compared to that of a variable reluctance pickup. The output may be as little as one millivolt. Compensating for this low output is the extremely high quality that can be realized. The moving-coil pickup is usually considered to have the highest potentiality for faithful reproduction.

The moving-coil pickup, like the variable reluctance type, requires a preamplifier to boost its voltage and to compensate for recording characteristics. (The moving-coil output is also velocity-dependent). The low output voltage calls for high amplification in the preamplifier, and the problems of hum pickup are proportionately increased.

If a given hum voltage x from, let us say, stray fields of the phonograph motor, is induced in a pickup system with 10 millivolt output (requiring a preamplifier gain of 100), the output hum will be $100x$. If substantially the same hum voltage is induced in a pickup system with 2 millivolt output, (requiring a preamplifier gain of 500), the output hum voltage will be $500x$. Another way of describing the situation is to state that the signal-to-hum ratio is much worse in the case of the pickup with low signal output. However, since any moving element in a pickup should be very light, the moving coil itself usually consists of a small number of turns of wire, which results in a low impedance and a consequent insensitivity to hum pickup. For this reason, moving-coil pickups generally have a comparatively high signal-to-hum ratio.

Figure 4—3 illustrates a commercial moving-coil pickup.

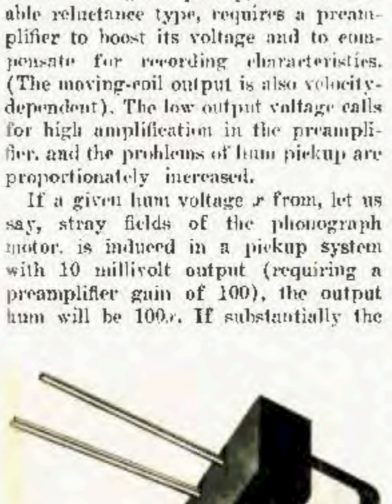

Fig. 4—3. A modern moving-coil pickup (ESL).

Piezo-Electric Pickups

The piezo-electric or "crystal" pickups generate their voltages in an entirely different manner from the magnetic units. Certain crystalline materials, such as Rochelle salt and barium titanate ceramics, have the property of producing voltages at their surfaces when they are bent or twisted. The stylus is harnessed to slabs of these materials through a system such as that illustrated in *Fig.* 4—4, and the modulations of the groove apply either a twisting or bending force to the slabs.

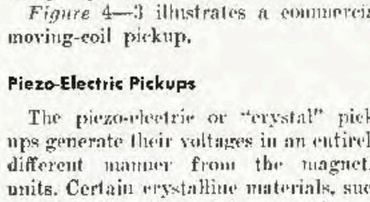

Fig. 4—4. Internal structure of a "bender" type of crystal pickup. (Courtesy Brush Electronics Co.)

The output voltage appearing at the cartridge terminals is much greater than that produced by magnetic pickups, and may be from ½ volt to as high as 4 volts. Furthermore the crystal pickup does not produce a voltage proportional to the stylus velocity, but to the amplitude of the stylus movement. The frequency characteristic of the output, however, is approximately the reciprocal of the typical recording characteristic used in modern records. Therefore the output of the crystal pickup is fed directly to the amplifier, without the use of a preamplifier. Both the voltage amplification and the equalization of the preamplifier would play havoc with the crystal pickup's output.

Modern crystal pickups are sometimes designed with a particular recording characteristic in mind (the advent of the standard RIAA characteristic makes this much more practical). Crystal pickups have not yet been designed, however, with as accurate a frequency compensation, as extended a range, or as low a distortion level as that of the best magnetics. The crystal pickup does have the advantages of significantly greater simplicity in installation, freedom from hum, and reduced cost.

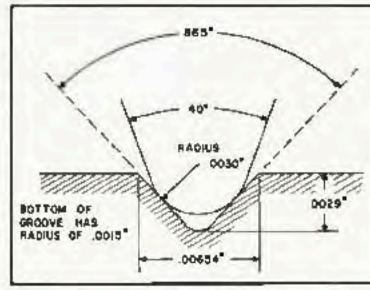

Fig. 4—5. A 3-mil stylus tip in the record groove. (After F. Longford Smith).

Some recently introduced ceramic and crystal pickups have been designed to work into a load impedance which decreases the low-frequency response so that the output is almost proportional to the velocity of the stylus. By properly adjusting the load resistance and the output voltage (usually with a voltage divider) these pickups can be fed into a preamplifier equalized for magnetic pickups with attendant flexibility of response curves.

Older crystal pickups had disadvantages which have been overcome to a large extent. Rochelle salt is subject to deterioration from heat and humidity, but the ceramics are not. The stiff mechanical system of the older units has given way to needle systems which move relatively easily, and which are designed in such a way as to largely suppress response to vertical motion caused by pinch effect. (Dynamic and variable reluctance pickups are readily designed to virtually eliminate any vertical response).

Electrical Connection of the Pickup

Pickups are normally connected to the input of the amplifier or preamplifier with low-capacitance shield cable. The "termination" of the pickup refers to the value of resistance that the amplifier input places across this cable, and is very significant in the case of both variable reluctance and crystal pickups.

Manufacturers' recommendations are usually the best guide to use when it is possible to adjust the value of resistance across the pickup (some preamplifiers allow for this), but a few general principles may be stated here:

1. With a variable reluctance pickup, too low a shunt resistance will attenuate the high frequencies; too high a resist-

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Fig. 4—6. One mil microgroove needles after 15 plays of a 12-inch Vinylite record, with 8 grams vertical tracking force. Left to right: diamond, sapphire, and osmium. (After Marcus).

ance may allow an excessive peak in the upper treble. Typical values of resistance for reluctance pickups range from 22,000 to 56,000 ohms.

2. With a crystal pickup, too low a shunt resistance will attenuate the bass; too high a resistance will over-emphasize the low frequencies and create a peak in the upper bass. Typical values of resistance for crystal cartridges are 0.47 meg. to 3.0 megs.

Needles

The type of contact established between the stylus and the record groove is illustrated in *Fig.* 4—5. It will be seen that the spherical tip of the stylus does not touch the bottom of the groove.

It is obvious that the stylus tip should be of such material that it maintains its shape in spite of repeated use. It is also important that the tip have a smooth, unmarred surface. Sapphire fulfills these conditions for a relatively short time, diamond for a much longer period. Estimates of the life of a sapphire stylus in a high quality system are rarely above twenty-five hours of playing time, while diamonds are normally good for more than a thousand. *Figure* 4—6 illustrates the relative wear of diamond, sapphire and osmium.

Although diamond needles may be, initially, as much as ten times as expensive as sapphire, one of their outstanding characteristics, at least in a high-quality installation, is economy. More important is the freedom from the danger of periodic degradation in reproduction quality and in record wear.

Vertical Force on the Pickup

The *vertical tracking force* on the pickup (rated in grams) is the force required to keep the needle in firm contact with the groove walls at all times. This is sometimes called "tracking pressure," but the latter is an improper term because units of pressure are in terms of force per unit area. The higher the vertical force the greater will be the erosion of the groove walls, but this does not mean that it is possible to arbitrarily decrease the weight on a given pickup. Only pickups with very high compliance —that is, pickups whose needles can be displaced with very little force—can afford to work under conditions of low tracking force.

Typical vertical tracking forces required by modern high-quality pickups range from one or two grams to about 8 grams. When the tracking force is reduced below its optimum value distortion, often severe, results. Therefore it is better to err in the direction of a gram too much than a gram too little. Pickup arms often allow the user to adjust the tracking force, by the use of an adjustable counterweight or by an adjustable retaining spring. The manufacturer's specifications should always be consulted carefully, but it must be remembered that the specified tracking force may be for an optimum installation, and more typical installations may require somewhat higher tracking forces. The way to really know when the tracking force is right is to note the point at which intermodulation distortion is reduced to an acceptable value. This is difficult to do without instruments.

Pickup Arms

The pickup arm holds the pickup in place over the groove. It should supply the proper tracking force, be free of significant resonances of its own, and always present the pickup to the record in a position tangent to the groove being played, or as close to this ideal as possible.

One method of subduing pickup arm resonances, and of stabilizing the arm so that it is less subject to the influence of outside shocks, is to use a pivot damped with a viscous silicone fluid. Although the sluggish characteristics of such a damped pickup arm might seem to be undesirable, the nature of the viscous resistance (coupled with the almost universal "side thrust" force toward the center of the record) is such that the slow sweep of the arm across the record is not hindered, while erratic and unwanted motions are suppressed. The needle hugs the groove in spite of record eccentricities and imperfections, or outside jars. The elimination of erratic pressure of the stylus against the groove walls is claimed to reduce record wear.

A rigid pickup arm which is pivoted at one point cannot keep the pickup parallel to all grooves. The divergence from tangency is called *tracking error*, and it results primarily in increased distortion, due to the fact that the vibration axis of the pickup is held obliquely to the groove that drives it.

It is possible, however, to keep the pickup within a few degrees of tangency at all points by mounting a fairly long arm, of bent shape, in a special way. The arm is mounted so that the needle would "overhang" the turntable spindle if it were swept past, as illustrated in *Fig.* 4—7. Such a mounting position, when calibrated properly to the length of the arm, keeps the cartridge-groove angle almost constant, although the absolute angle between groove and pickup would be far from correct with a straight arm. The cartridge is therefore mounted in the arm at an "offset" angle, to bring it back to tangency. The exact amount of overhang depends both on the length of the arm and on the offset angle.

It will be seen from the foregoing that the offset angle of a bent pickup arm does not correct for tracking error in itself. The most critical element is the amount of overhang, and this should be correct to at least 0.1 inch. A bent arm incorrectly mounted is at least as bad as a straight arm in the same mounting position, and very probably much worse.

The correct mounting position for a pickup arm relative to the record spindle is usually furnished by the manufacturer, often by means of a template, and this should be followed with painstaking care.

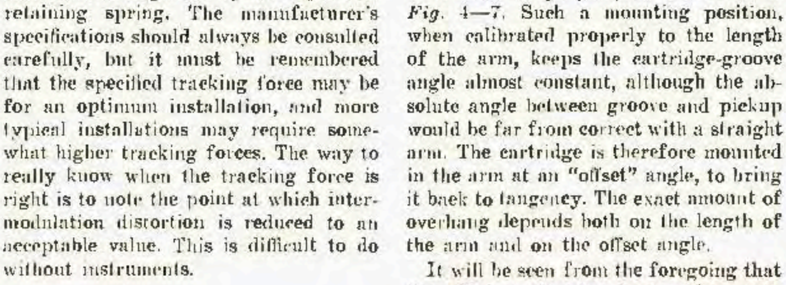

Fig. 4—7. Mounting position of the offset tone arm, showing overhang.

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