Toward an Optimum Stereo Cartridge

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The subminiature application of the ages-old principle of the gimbal results in an interesting and effective design for a stereo cartridge which comprises two d'Arsonval "meter" movements for its generating elements.

INDUSTRY AGREEMENT on the selection of the 45/45 cut for stereo disc recording, the release of demonstration discs, and the alacrity displayed by commercial recording companies in making stereo pressings available to the consumer, gave impetus and direction to engineering development of an optimum playback unit consistent with:

(a) the design previously used for monophonic pickups;
(b) feasibility of manufacture;
(c) eventual consumer cost; and
(d) a release target date—based upon a multiplicity of considerations, including: materials and components availability, required tooling change-overs, publicity timing, and established marketing channels.

These factors were undoubtedly accorded varying degrees of prominence in establishing organizational policy regarding the final product—consonant with the attitude of manufacturing, management, and sales divisions—toward what the public would accept. The prime motivator—consumer demand—had already, in large measure, been established.

Certainly, it had to be determined whether release was to be delayed until design effort had reached the *ultima Thule*, or limit engineering effort to the creation of a device adequate for the reproduction of present offerings by the recording industry—trusting that improvement in the quality of the recorded material would not obsolete the product within its probable life-span. Each manufacturing organization resolved the question according to its own experience and conscience.

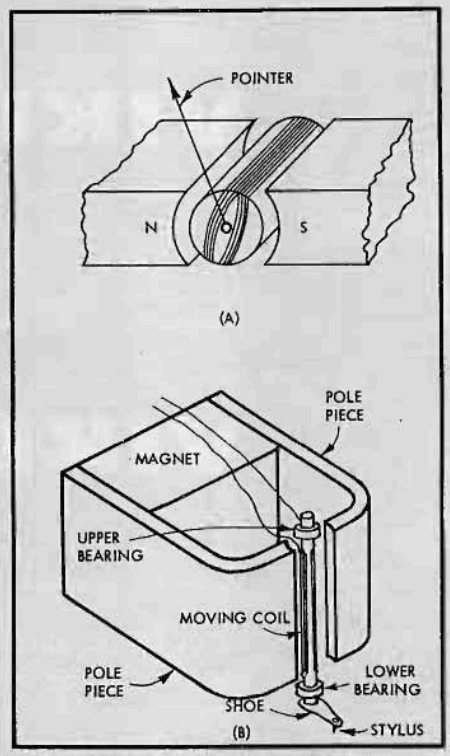

Fig. 2. (A) Diagram of a typical d'Arsonval meter movement, and (B) its adaptation as a phonograph pickup—the ESL C-60.

Although both aesthetic and technical criticism have been leveled at some stereophonic pressings released within recent months, the improvement in both areas is already apparent. With the many types of stereo playback cartridges now available to the enthusiast (piezo-electric, moving magnet, moving coil, moving vane), the consumer may select a pickup compatible with his budget, or reflecting his listening tastes.

Evaluating the Design

To evaluate justly the design approach and the subsequent performance of a stereophonic cartridge, one ought to begin with an inherently perfect recording. Any inadequacy in the test disc would invalidate the test results or require "allowance for" when comparing several pick-up units. Assume that by some engineering sorcery, a flawless test recording could be prepared. The following technical conditions will have been met:

(a) The material of the disc will have been infinitely plastic during cutting and will have attained surpassing hardness at the exact instant that the cutting stylus passed to the next point to be inscribed. The first condition is necessary to ensure that each miniscule excursion of the stylus is faithfully recorded, while the second requirement ensures that no subsequent distortion of the recorded undulation can ever result through stylus friction.
(b) There is no unwanted coupling between input channels in *any* portion of the recording equipment.
(c) As a corollary to item (b), no motion of the cutter stylus toward one groove wall has in any manner affected the opposing groove wall.
(d) Accurate and properly balanced depth of cut represents precise intensity of channel information supplied.

Now, given a recording, faithful in all

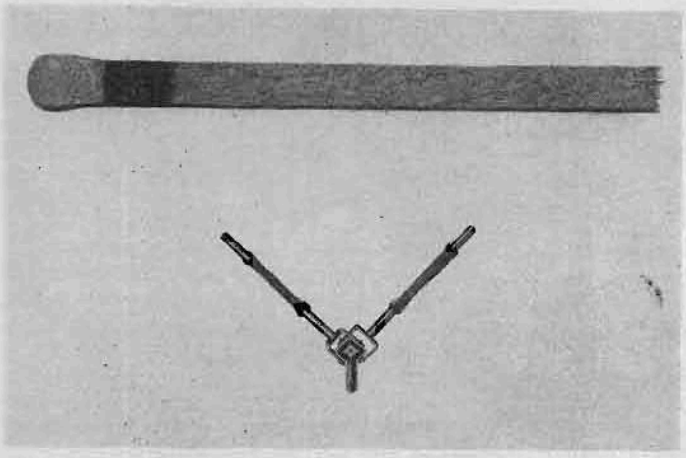

Fig. 1. Comparison in size between moving elements and book-type paper match, about 2-1/3 times actual size.

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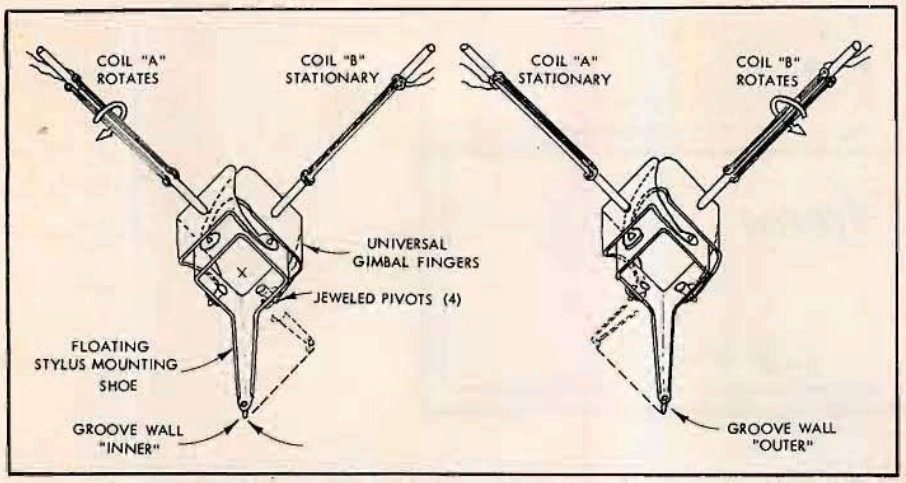

Fig. 3. Two d'Arsonval movements set at 45 deg. from the vertical and connected with the Gyro/Jewel coupling system.

details, will the playback result equal the quality of the recording? It should if the pickup is equally good.

Gyro/Jewel Design Approach

The ESL Gyro/Jewel stereophonic cartridge is, first of all, *not* simply a marketable redesign of a reproducer system originally developed for monophonic recordings. Design configurations which were eminently suitable to playback of monophonic recordings, when paired and rotated 45 deg. from the vertical, were found to have become considerably less competent performers on stereo recordings than their prototypes' rendition of monophonic discs.

Although we were convinced that the d'Arsonval generating movement offered the most desirable characteristics as the transducer element(s) for stereo reproduction as well as monophonic, the designs of many other domestic and foreign laboratories were scrutininzed to determine the capabilities of their products.

Experimental models of competitive units were carefully constructed by ESL engineers and technicians and were then exhaustively tested, measured, an evaluated both by the use of laboratory test gear and in listening tests.

Not to be stampeded into preliminary freezing of production designs, the entire organization agreed that no stereo pick-up would be released until the valid approach had been determined: one which would embody all the desirable features necessary to an ideal system, and would yield a device that could be produced with consistent quality. Early experimental units were devised with two d'Arsonval movements mounted at 45 deg. from the vertical (thus forming an angle of 90 deg. with each other). Incidentally, throughout the development, the accuracy of this angle was found to be an exceedingly critical factor in maintaining satisfactory inter-channel separation and constancy of generator output. The two armatures were yoked together and fitted with a stylus. Much valuable information was derived from this approach before the scheme was discarded as furnishing a fallacious solution. *Figure* 6 shows one early model.

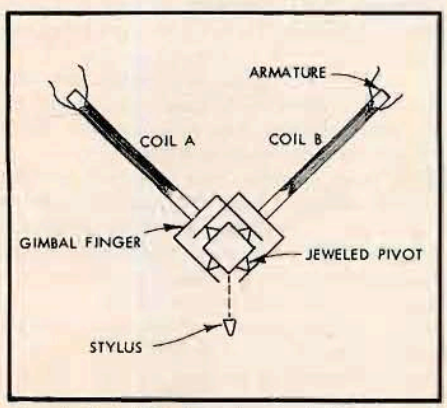

Fig. 4. Simplified mechanical diagram of coupling system.

In our opinion, every indication pointed to the d'Arsonval movement as the superior generating element for the application. The movement could be built to have an exceedingly small mass; it is inherently linear, as a characteristic of the constant location of the coil in the flux concentration between the magnet pole-pieces and its rotational motion about its own axis in the fixed magnetic field; and it could be made to generate adequate output with the necessarily small rotational movements of the coil.

In *Fig.* 2, (A) is a simplified line diagram of a typical d'Arsonval movement, while (B) shows the application of the principle to a monophonic pickup, the ESL-C60 Series cartridge. Two similar systems were devised, and mounting assemblies designed to hold the armature axes at exactly 45 deg. from the vertical and at precisely 90 deg. from each other. The functioning of the movements is shown in *Fig.* 3.

As shown in the diagram, latex mounting blocks hold the armature core so that only *rotational* motion of the coils can occur. This mounting not only exhibits mechanical stability, but further, inhibits any possible electrical non-linearities resulting from coil shift out of the maximum flux density area between the magnet pole-pieces. As the latex blocks do not slide on the armature, rotational friction is non-existent.

In order to provide generating elements which would be of sufficiently small mass and yet develop a usable output, a wire having cross section diameter of approximately 1/1000 in. was needed. Obviously, copper "magnet" wire could not be used for this application—a copper filament of this diameter would have almost no physical rigidity, and would probably disintegrate upon handling.

In order to wind coils using a wire of this diameter, a special precious-metal alloy conductor was developed. This almost microscopic conducting filament—about one-third the diameter of a human hair—could not be mounted in the pickup on a bobbin. Even the smallest of bobbins would have increased the mass and physical dimensions of the system to intolerable limits. The 60-turn coils are wound, shaped, and mounted directly on a rigid armature shaft, which is then assembled in the armature holder between the latex holding blocks.

A solid armature shaft was selected in preference to a tubular component. The difference in effective mass between the two would have been completely negligible. The probability of encountering concentricity problems in manufacturing and mounting would have been disproportionally increased, while the flux saturation of the smaller cross-sectional area of the armature material would have restricted output.

The magnet/pole-piece assembly is worthy of note, too, in that precision grinding is employed at the area of juncture. The pole-pieces are screw-clamped rather than soldered, as the possibility exists in production that during soldering, capillary flow of the solder might result in an air gap—materially reducing the effective flux density through the coil mounting area.

Coupling the stylus to the two armatures requires a reliable linkage having the ability to differentiate completely between stylus motion in the two planes of motion. The linkage design must be such that instantaneous motion in the desired direction is unrestricted. Mechanical coupling between systems must be prevented or made ineffective. A short, rigid stylus bar would be desirable to further reduce system inertia (the effective mass increases as the square of the distance from the point of applied force). The linkage should be free of any self resonance within the audible frequency range to prevent distortion in frequency linearity.

The development of a stylus arm and

coupling "shoe" along with the attaching yokes for converting the angular motion of the stylus to rotational motion for the d'Arsonval generators resulted in a straightforward, essentially frictionfree design, with inherently low mass and minimum response to any but the desired motional mode.

The final design adopted employs four jeweled pivots for attaching the stylus shoe to the armatures of the d'Arsonval generators. *Figure* 4 is a simplified mechanical diagram of the assembly.

As the stylus is influenced by the undulations of the record groove—in *Fig.* 3—angularly, to the left, the armature of generator A is caused to describe a corresponding rotary motion, while that of generator B, restricted by the armature mountings is unaffected by this excursion of the stylus.

By reason of the friction-free jewel pivots attaching the shoe to system B, no restriction is offered to the movement of the system A armature, nor is any of the angular motion of the stylus as it moves to the left transmitted to the armature of system B.

When the excursion of the stylus is to the right, the opposite effect takes place and the armature of system B is caused to rotate. In this instance, no motion is coupled to system A.

The yokes—which serve the dual purpose of coupling stylus motion to the armatures of the generators and supporting the stylus shoe assembly (the universal gimbal fingers at the jeweled pivot points)—possess the necessary qualities of rigidity to prevent deformation under stress, and the hardness to resist wear at the pivot points.

The clamping action of the gimbal fingers on the jeweled pivots—a quality of the resiliency and mechanical design of the yokes—provides a mounting which will remain secure even under conditions of unusual mechanical shock, yet retain the ability to swing freely.

Cartridge Performance

Response tests of the ESL Gyro/Jewel cartridge show that no mechanical resonances occur in the audible range. This condition, coupled with the natural linearity of the generator system, permits the over-all response of the cartridge to remain flat within ±2 db over the frequency range from 30 to 15,000 cps on presently available stereo test discs, which are restricted to this range. When playing conventional microgroove test records, the frequency response extends to well beyond 20,000 cps.

The complex motion to which the system must respond in the 45/45 system is applied at an angle of 45 deg. to the vertical. To achieve unrestricted response to this angular mode of motion, the measured vertical and lateral compliance should be essentially equal (the resultant vector angle of two equal forces acting at right angles being 45 deg). By accurate assembly methods and precision manufacture, the production cartridge has vertical and lateral compliances equal, with a value of 5×10^{-6} cm/dyne or greater.

By reason of the extreme miniaturization of the moving components of the reproducer system(s), the dynamic mass of the ESL Gyro/Jewel stereo cartridge is held to a value of 2 mg. The high compliance and low dynamic mass contribute greatly to reduced record wear.

A stylus force of six grams on the 0.7 mil stylus used for stereo playback results in record wear as great as a tracking force of twelve grams on the 1.0 mil stylus used for monophonic pickups. In an arm of proper design, a tracking force of two or three grams is

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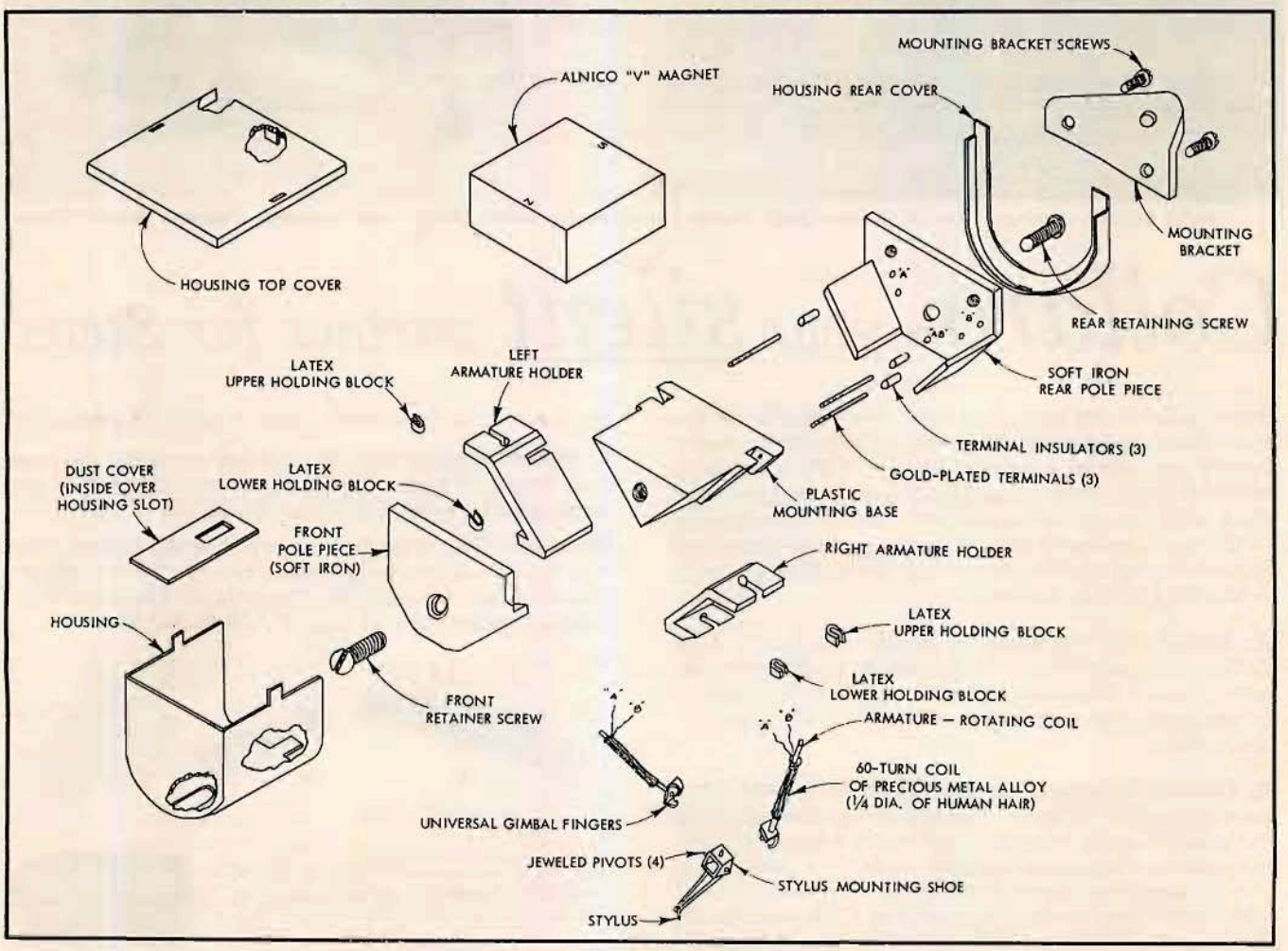

Fig. 5. Exploded view of the complete cartridge.

CARTRIDGE

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sufficient to permit the Gyro/Jewel stereo pick-up to follow all groove undulations accurately. The manufacturer recommends that tracking force should not exceed four grams, as greater vertical force not only increases record wear, but set up mechanical biasing effects leading to unbalance in the response pattern.

Channel Separation

If stereophonic reproduction is to be effective, separation of channels must be as complete as possible *throughout the entire frequency range.* In stereo reproducer systems which depend upon elastic damping of any sort to remove mechanical resonances, the danger exists that at one end of the frequency spectrum or the other (possibly both), or at indeterminate frequencies elsewhere in the spectrum, some mechanical coupling between channels may take place.

Early efforts at recording showed evidence of this undesired interchannel coupling. Where channel separation of about 20 db was measurable at frequencies from 1000 to 5000 cps, this separation had dwindled to some 5 db at 10,000 cps.

The undamped design of the ESL Gyro/Jewel stereo cartridge system precludes such variations in channel separation/frequency response ratio. Channel separation is maintained at a constant 20 to 25 db over most of the audible range. Moreover, the design is such that factory adjustment of the two d'Arsonval movements, by means of eccentric screws, permits optimum crosstalk ratios.

A mean output level of approximately two millivolts per channel is developed at a stylus velocity of ten centimeters per second. Highest quality voltage step-up transformers to the stereo preampli-

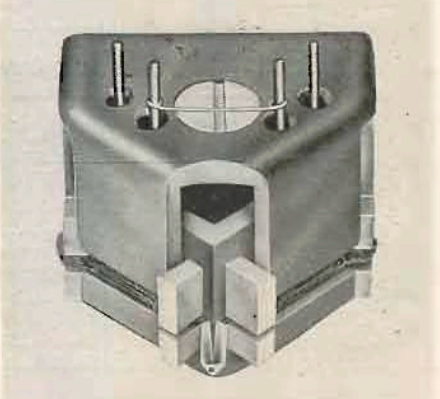

Fig. 6. An early design having direct channel separation by means of a bifurcated stylus shoe. Discarded because of inadequate separation above 8 kc.

per second. Highest quality voltage step-up transformers to the stereo preampli-

fier inputs prevent degradation of the signal quality.

Installation Factors

An adaptor plate is supplied as a part of the mounting hardware for the ESL Gyro/Jewel cartridge so that it can be mounted in any standard phono arm or record changer. For optimum results, it is recommended that the arm used be rotationally balanced as well as laterally balanced. Lateral and rotational balance can be achieved only in an arm whose stylus force adjustment is independent of the arrangement for counterbalancing the mass of the cartridge in the arm head.

A perfectly level turntable is not unattainable, and is desirable in order to reduce any tendency for one side of the stereo groove to be favored over the other. Even with a perfectly level turntable, slight warp in a disc can create similar problems on playback.

Because of the complicated series of motions described by the stylus in stereo playback, more serious reproduction faults are detectable when playing warped records than under similar conditions during monophonic playback. In stereo reproduction, interchannel separation is degraded, IM distortion rises, frequency response characteristics are likely to bounce out of specifications, and listening pleasure is markedly reduced.

A new playback arm has also been developed: one which through its design permits realization of the advantages of the Gyro/Jewel stereo cartridge. In order to reduce the need for exact leveling of turntables and to prevent degradation of the output signal quality when encountering warped discs, the tubular member of the ESL Gyro/Balance arm is displaced laterally. This configuration permits rotational balance through the point of effective mass of the head assembly, the lateral pivot, and the counterbalance weight.

Actually, with the Gyro/Balance arm, it is quite possible to play discs at any angle to the horizontal up to 90 deg. *without degrading the stereo channel separation ratio.* All vertical and horizontal pivots are precision ball bearings.

The zero-balance counterweight is used to accomplish exactly that for any cartridge used. Stylus force is then separately adjusted, by rotating a knurled knob on the side of the bearing gimbal against a spring. This arrangement allows for infinite stylus force adjustment, within the recommended range for the cartridge in use. Although developed for stereo use, this arm also works improvement on the playback of monophonic discs.

Enhanced Stereo Listening

The advent of stereo disc recording is

Turntable ideal for broadcasting station use. $59.95. Also available in kit form, without base or mounting plate,

Actually, with the Gyro/Balance arm, it is quite possible to play discs at any

perhaps as great a step forward in re-creating the effect of "presence" when listening to recorded music, as was the introduction of the full-fidelity micro-groove recording a few years ago. The listening public has become accustomed to the experience of clean full-range—both frequency and dynamic—reproduction from good monophonic discs, and is sure to demand equal quality from stereo discs. Æ