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Wide-Band Subminiature Audio Transformers

A great deal of attention must always be paid to each element that goes into the makeup of a transformer. But when miniaturization is demanded extra attention must be achieved. This article explains the manufacturing steps used by Beyer to achieve quality and small size.

TRANSFORMERS have been used for many years as coupling devices between the stages of amplifiers. Their unique properties make them amenable to a great variety of uses and some interesting designs have evolved. The increase in transformer utilization has inspired new developments in soft-magnetic material technology and refinements in the manufacture of wire. This has improved transformer performance, but the increased complexities of situations where transformers are used has led to the necessity of new designs, especially miniaturization.

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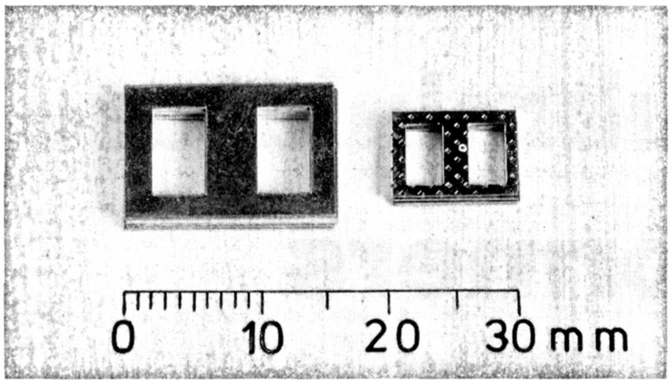


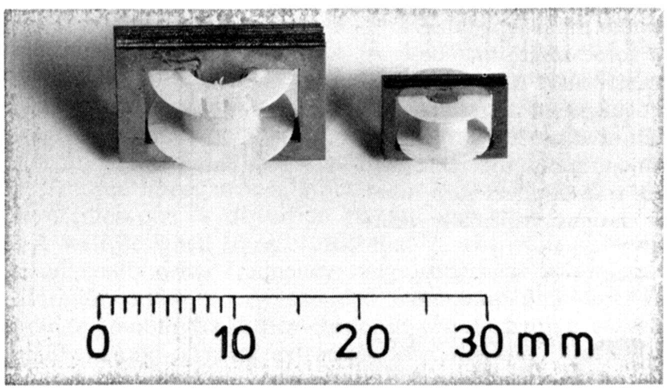
Figure 1. Two sizes of lamination stacks showing the unbroken frames.

This has required ingenuity, especially in dealing with laminated core construction, which is used in transformer production because it represents a practical and economical method of manufacture, especially if a wasteless core stamping method is used. The conventional method used for assembling the laminated core, however, results in a splitting of the magnetic circuit, which in turn makes it impossible to increase further the effective permeability of the core—the permeability converges toward a certain limit, thus determining the inductivity constant of the iron core.

There are three possible ways of overcoming this and improving the inductivity: enlarging the cross-section of the core, shortening the magnetic circuit, or increasing the cross-section of the coil. But, since these factors are inversely related to each other, the solution must be found in a compromise. Logically, the ultimate method would be to increase the number of turns combined with a decrease of the wire gauge. This, however, entails an increase in the insertion loss, which cannot be tolerated beyond a certain limit when involving input transformers between the microphone and the first transistor. In addition, the increased capacitance of the coils reduces the high frequency response, thus setting a limit for the turns ratio.

All these considerations have led to a completely new concept in the production of studio quality miniature transformers at Beyer. Permeability was the critical factor. As pointed out above, the permeability of the core cannot be increased with split cores, even if the permeability of the material itself were to be increased. The only remaining possibility would be a gapless core circuit. The use of a gapless ring in toroidal transformers is nothing new, but in view of the difficulties encountered in winding such transformers, economic reasons mitigated against their use.

Figure 2. The coil forms have been glued together on the lamination stacks.



In these miniaturized transformers, the conventional laminated core has been retained but now it consists of gapless individual laminations only. We just stamp two windows into each lamination to make space for the coil. These laminations are stacked to form a core with a square cross-piece. Around this cross-piece we glue together two halves of an injection-molded plastic bobbin, forming a complete bobbin onto which the wire is wound. The wire ends come out of the coil on one side without reinforcements and are then soldered to leads which are threaded through the space remaining betwen the circular bobbin and the square core cross-piece. A special plastic wedge prevents the leads from accidentally being pulled out. Finally, the transformer is impregnated and enclosed in two mu-metal cups.

The specifications achieved with this system are quite impressive. By using laminations 16 mm long by 11 mm wide to form a core cross-section 4 mm by 3 mm and 17,000 turns of 25 μm wire on the bobbin, an inductance of 4,000 H can be obtained. If this is divided into a primary and a secondary winding, it is most eminently suitable for use as a microphone input transformer. With a turns ratio of 1:15, it has a primary inductance of 5 H, and a frequency response from 30 to 15,000 Hz with a maximum deviation of -0.5 dB at the extremes of the curve. In production, the measured values are around -0.3 dB. The dimensions of the whole transformer, complete with mu-metal casing, are only 16 mm in diameter by 20 mm high. (0.65 inches x 0.8 inches.)

Here is a second example to further illustrate the quality achieved. A transformer was made for a 600 ohm line with a maximum input voltage of 8.8 volts (+21 dB) and a frequency range of 30 to 15,000 Hz. To keep magnetic induction low, the inductance was brought to a maximum. Thus, the input inductance was 1,500 H and the required standards of -0.5 dB at the extremes of the frequency response range were maintained. The turns ratio was 1:1 and the outside dimensions again were 16 mm diameter by 20 mm high. Additionally, these transformers were imbedded in silicone rubber within their mu-metal cases to make them shock and climate proof.

A similar design with a turns ratio of 1:1 was made to serve as an isolation transformer to be used as a d.c.-free coupling between a.c./d.c. television sets and tape recorders. In this case, a high insulation value was imperative. By means of a vacuum-impregnating process, a rating of 2,000 V was obtained.

These two are only random examples of the application of this principle; Beyer employs this unique design in the manufacture of hundreds of transformers to meet the individual requirements of original equipment manufacturers. In the course of further development, we have been successful in making a still smaller transformer than the one described above. This unit, whose laminations measure only 9.5 mm in length and 7 mm in diameter, represents, most likely, the smallest mass-produced transformer in the world.

The bobbin measures 7 mm (outside diameter) while the dimensions of the core cross-piece are 2 x 2 mm^2 (80 mil x 80 mil). With these sub-miniature transformers it is possible to attain a turns ratio of 1:20 and a fre-

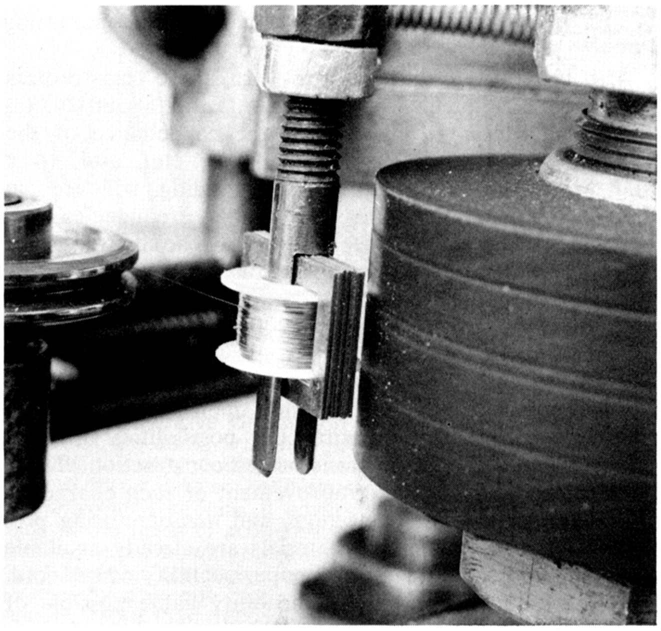


Figure 3. The winding process is shown. The laminations are held stationary while the coil form is friction driven by the rubber wheel at the bottom. The wire comes from the back of the winding machine.

quency response with a loss of three dB at 35 Hz and only one dB at 20,000 Hz. Because of its small dimensions, (its mu-metal case is 12 mm long and 10 mm in diameter) this transformer can be built into the shell of a connector. In keeping with the prevailing cost-saving technique of designing preamplifiers with high impedance inputs, it is possible to produce a dynamic microphone which has this transformer built into the end of the cable. This results in optimum frequency response combined with the absence of induced interference. The transformer is wound with lacquered copper wire with a diameter of 20 μm, or 0.0008 inch. This represents, at least for the present, the practical limit for economical production while maintaining the required specifications. Theoretically, using this winding process, it would be possible to employ 15 μm (0.0006 inch) or even 10 μm (0.0004 inch) wire.

The production methods used in making a transformer of such unique design are, naturally, unconventional. The stamping of the core laminations is done quite simply. The strips for making the laminations are supplied by the manufacturer in the desired width, under the trade mark Hyperm 900. Only two windows have to be stamped out and proper lengths cut. All this is done by means of a fully automatic stamping tool, which minimizes waste. The laminations are manufactured of either 0.35 or 0.2 mm high-alloy metal with 78 per cent nickel content. Special care is taken to assure that the sheets are even and free of burrs.

After being washed and stacked in special containers, the stamped laminations undergo a heat treatment which varies with the specific metal charge in order to obtain the maximum permeability of the material and the core. Present techniques have made possible permeability figures of about 50.000, measured at 50 Hz, in material with an initial permeability of 0.3979 A/m. Since the frequency limitation of the laminations is relatively small, higher values are achieved at 20 and 30 Hz. This is beneficial to the low frequency response of the completed transformer: because its inductance varies with frequency, a reduction in inductive reactance results in a lowering of the specific resonant frequency of the transformer. This

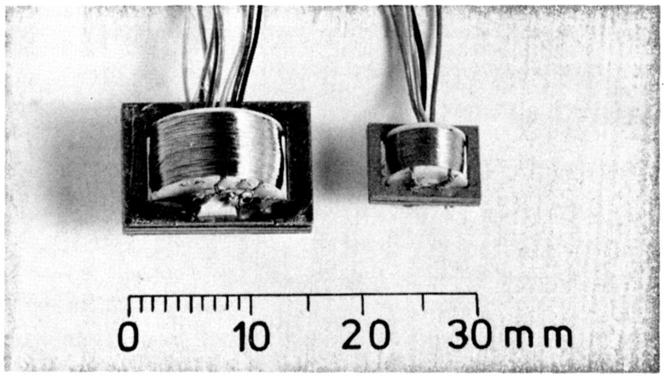


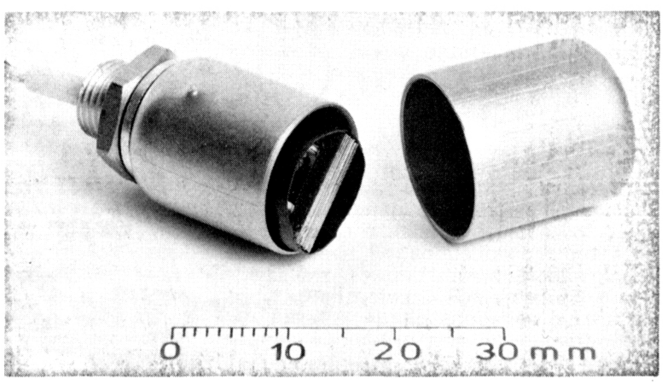
Figure 4. The fully-wound transformer showing the leads soldered to the coil ends.

is why the transformer is not evaluated by its inductance at 800 Hz.

Following the heat treatment, the laminations are sorted according to their tolerance and glued together to form core-packs consisting of eight single laminations of 0.35 mm each. Core laminations with such high permeability values need to be handled with utmost care and the laminating process must be carefully controlled to assure that no excessive tensions occur within the core material. After the two halves of the bobbin are glued together around the prepared core's cross-piece, the bobbin must be checked to see that it spins freely. The transformer is placed in a special vise on the coil winding machine and friction rollers spin the bobbin while the core remains stationary. The wires are threaded through lateral slots in the bobbin and a collar placed on the body of the bobbin to assure that the necessary distance from the corepack is maintained and to prevent the wire from being sheared off. The copper wire is fed from a supply spool located overhead, with constant wire tension within the limits prescribed for the particular wire maintained; since the supply spool need not be driven, breakage of the wire is avoided. Using this new winding process, ten to twenty thousand turns on the secondary side are not uncommon. A spot of lacquer keeps the ends from unravelling. The leads, which emerge very close together, are run out according to a specified plan to avoid any mixup. Because the leads are very short, special solder containing copper must be used to minimize alloy formation on the hair-thin copper wires.

Finally, the transformers designed for normal use are given a protective coat of lacquer, while an additional vacuum impregnation is given to those designed for higher safety requirements. The transformer is then installed in a double-walled, high quality mu-metal shell to protect it

Figure 5. The transformer is inserted into a mumetal shielding can and the leads are brought out through the threaded stud at the bottom.



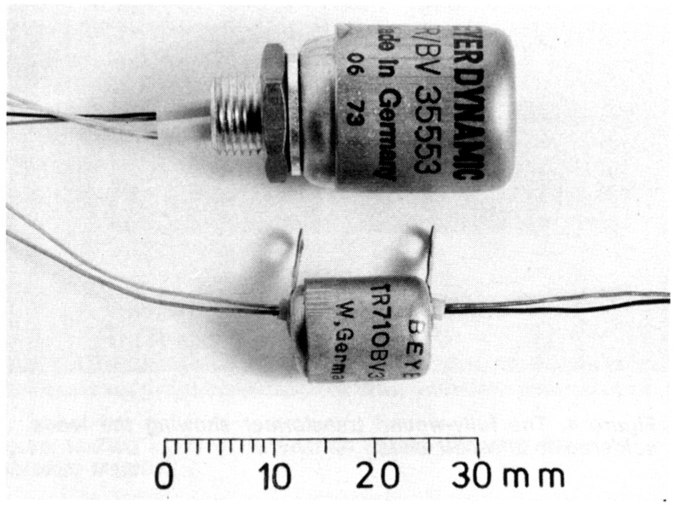


Figure 6. The models TR-145 (at the top) and the TR-710 (below) fully assembled, and showing the relative size of each.

from interference caused by stray magnetic or a.c. fields to the extent of about 70 dB. This mu-metal case may have a threaded stud at one end (type BV-35) to permit single hole mounting with the wires threaded out through its center or solder lugs may be attached to each end, allowing installation like a condenser on a terminal board. This mounting is known as the BV-35L version. The entire unit may also be encased in injection-molded plastic with a seven-pin miniature tube header (BV-36) or a standard 0.2 inch grid printed circuit header. (7-pin = BV-37; 8-pin = BV-38; 9-pin = BV-39) Most transformers sold today for o.e.m. applications are of the PC board mounting type.

With low turns ratios of up to 1:15, these transformers will cover a frequency range of 20 Hz to about 20,000 Hz. If the turns ratio is higher, the capacitance of the connecting elements—wire entry, leads, etc., and, to a small extent, the capacitance of the winding, will become effective. This is why, for the higher frequencies, the reactance of the transformer becomes capacitive. It must be borne in mind that, with a turns ratio of 1:30, the capacitance of the secondary side appears on the primary side mulitplied by a factor of 900; this may impose a considerable load on the source.

Even though all the particulars regarding sub-miniature transformers have not been touched upon here, the design engineer will readily recognize the possibilities inherent in this unique method of transformer construction. There is still much room for the improvement of such characteristics as permeability, wire gauge, and manufacturing precision. Some soft-magnetic materials are already available which may enable an even higher permeability of the core. A doubling of the present permeability value possible of 50,000 Oe will allow an increase in the number of turns and, thereby, an improvement in low frequency response. Better methods of reducing mechanical strain in the core lamination process will permit the use of thinner material. This, in turn, will allow a further increase in the frequency range of the sheet metal. The use of ceramic materials may also prove advantageous in the future. With the improvements already achieved and those contemplated, specifications, using miniature and sub-miniature transformers, will be expected in applications previously deemed impractical or impossible. ■