July 13, 1965 H. C. SMITH 3,194,894

ELECTRO-MAGNETIC HEADS

Filed May 23, 1962 3 Sheets-Sheet 1

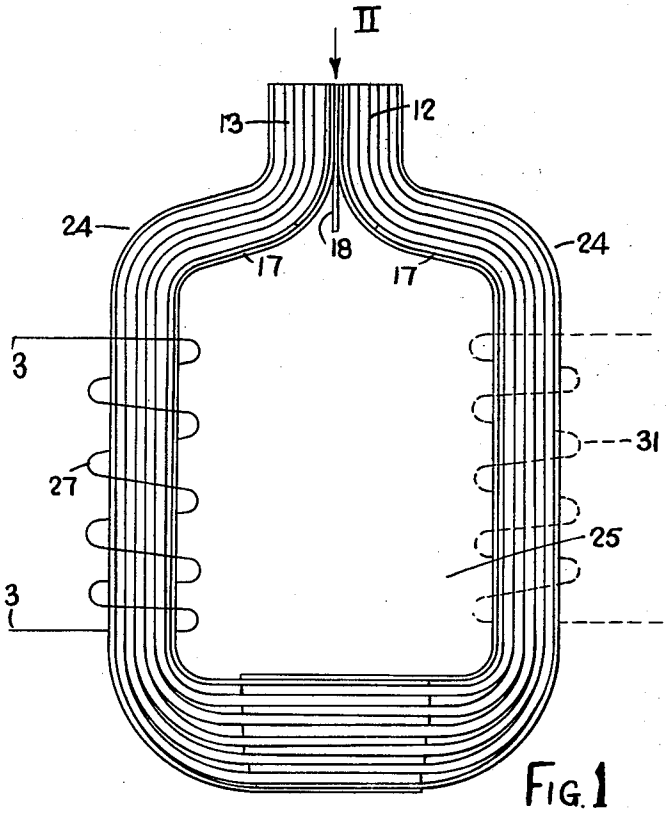


FIG. 1

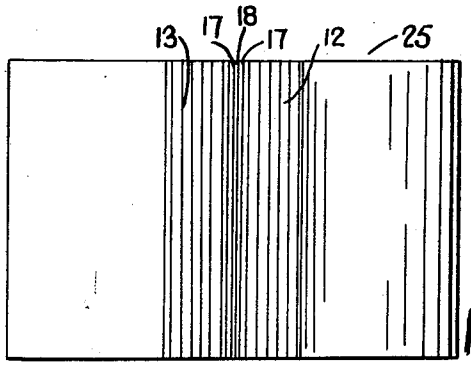


FIG. 2.

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ELECTRO-MAGNETIC HEADS

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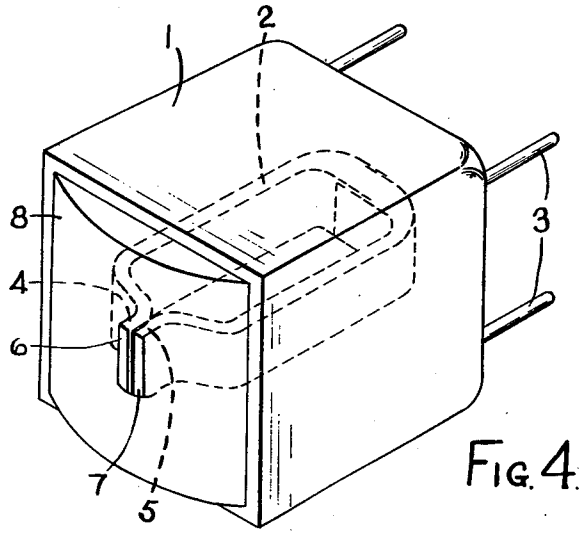


FIG. 4.

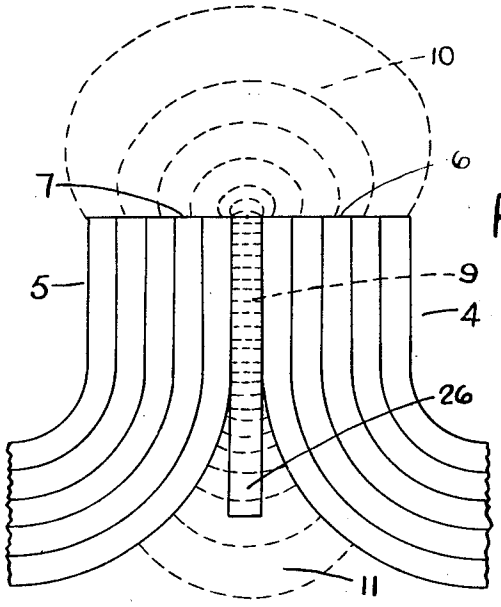


FIG. 3.

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ELECTRO-MAGNETIC HEADS

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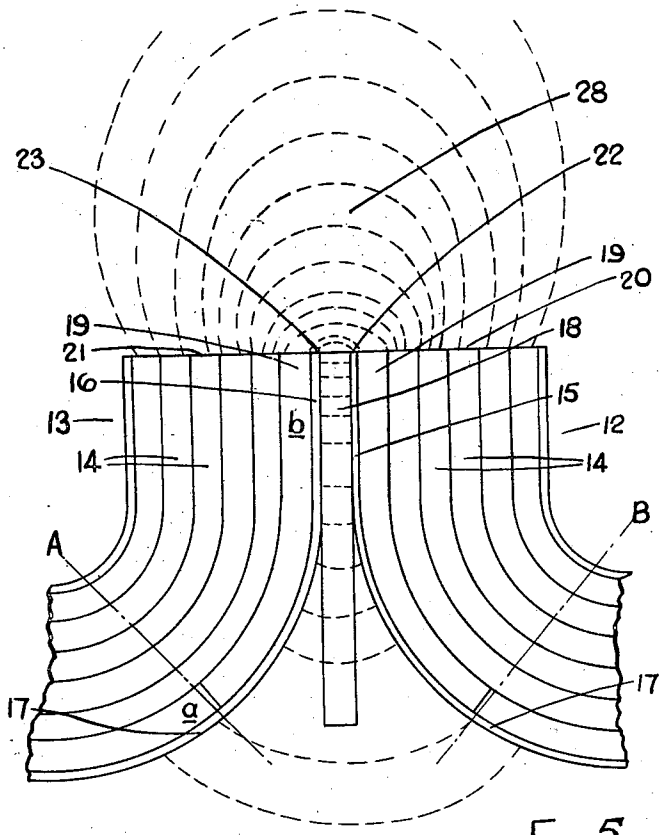


FIG. 5.

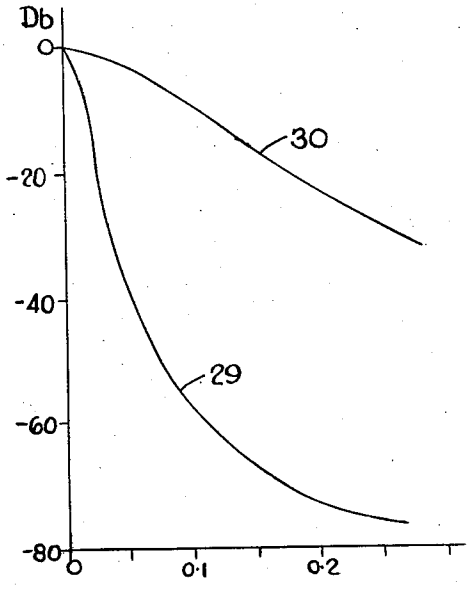


FIG. 6.

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ELECTRO-MAGNETIC HEADS

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Claims priority, application Great Britain, May 30, 1961, 19,429/61
6 Claims. (Cl. 179—100.2)

This invention relates to electro-magnetic transducer heads, that is electro-magnetic heads which are used for the transduction or production of magnetic fields in sound recording and reproducing apparatus, including erasing of magnetic records, involving wire, tape and other record carriers, in apparatus employed in the non-destructive testing of materials and like apparatus for analogous purposes. The invention is specifically concerned with such heads of the kind in which the pole pieces at the free ends of the magnetic circuit present substantially aligned pole faces to be brought into engagement with the record carrier or other member which is required to be magnetically coupled to the electro-magnetic head.

The object of the present invention is to provide a new or improved construction of electro-magnetic head which enables a greater operating efficiency to be attained.

An electro-magnetic head in accordance with the invention comprises a pair of outer pole pieces and a pair of inner pole pieces which are disposed between the outer pole pieces, a spacer of non-magnetic material between the inner pole pieces and also two other spacers of non-magnetic material arranged one between each of the inner pole pieces and the adjacent outer pole piece, which spacers provide non-magnetic gaps extending to the pole faces and the arrangement being such that the reluctance of the path presented by the inner pole pieces and the gap between them is less than the reluctance of the path external to the head from one to the other of the outer pole pieces, whereby a common magneto-motive force applied to the outer and the inner pole pieces with the like poles of the inner and outer pairs of pole pieces arranged adjacent to each other will result in a higher flux density in the gap between the inner pole pieces than in the path external to the head between the outer pole pieces.

With the improved arrangement the inner pole pieces will act to direct flux emanating from the outer pole pieces outwardly to a path external to the head, that is into the region normally occupied by the so-called leakage flux, and it is this external flux which is available for useful work.

Conveniently the three gaps thus provided may be of the same length, for instance in the order of .002 inch.

Preferably the arrangement is such that only slightly more flux passes between the inner pole pieces than that which passes between the outer pole pieces. Since the outer pole pieces are of necessity spaced apart by a greater distance than the inner pole pieces, the reluctance of the free end of the magnetic circuit constituted by each of the inner pole pieces alone is increased as compared with the reluctance of the free end of the magnetic circuit constituted by each outer pole piece, in order that the reluctance of the path presented by the free ends of the magnetic circui represented by the inner pole pieces and the gap between them shall only be slightly less than the reluctance of the path between the two outer pole pieces external to the head. This condition may be achieved by reducing the cross-sectional area of each inner pole piece as compared with that of each outer pole piece and/or by using for the inner pole pieces material having a lower permeability than the material

used for the outer pole pieces. Thus, for example, the reluctance of the path comprising the free ends of the magnetic circuit as represented by the inner pole pieces and the gap between them as compared with the reluctance between the outer pole pieces may be in the ratio 3:5 resulting in three-eighths of the total flux being projected into the region externally of the head.

In accordance with a further aspect of the invention, particularly as applied to an erasing head, there may be provided, in the pole faces, additional non-magnetic spacers between at least those laminations of the outer pole pieces which are nearest the inner pole pieces. The effect of this arrangement is to modify the flux distribution in the outer pole pieces in such a manner that there will be less tendency than otherwise for the external field to be concentrated at or close to the inner boundary edges of the outer pole faces. In other words the intensity of the external magnetic field will not fall off so quickly in the direction from the inner towards the outer boundary edge of each outer pole face, thus causing the tape or other record carrier to be subjected sooner to an intenser field as it moves across the leading pole face and longer to the intenser field as it moves across the trailing pole face.

The invention will be further described and illustrated by way of example in and with reference to the accompanying diagrammatic drawings, wherein:

FIGURE 1 represents the magnetic circuit of a head for erasing the signal in a record tape,

FIGURE 2 is a view as seen in the direction of the arrow II in FIGURE 1,

FIGURE 3 is a fragmental view of a previous arrangement of the magnetic circuit which is replaced by the arrangement shown in FIGURE 1,

FIGURE 4 is a perspective view showing a head incorporating the magnetic circuit illustrated in the previously mentioned figure.

FIGURE 5 is a view similar to FIGURE 3 of the magnetic circuit incorporating the present invention, and

FIGURE 6 is a graph illustrating the improvement which can be attained by means of the present invention.

The head represented in FIGURE 4 comprises a generally four-sided can or container **1** which serves as an enclosure for an electro-magnet consisting of a laminated core **2**, which is illustrated in broken line in the figure, and an energizing and/or other winding (not shown) connected to appropriate terminals such as the terminals **3**. The core **2** is formed of laminations bent into a substantially rectangular shape and the pole pieces **4** and **5** are constituted by the outwardly turned ends of the laminations in the central region of a shorter side of the core. The pole pieces **6** and **7** are presented close together in the centre of and flush with the convex contact surface of a closure member **8** formed of non-magnetic material over and in contact with which will be passed a record tape carrying an appropriate surface layer of magnetic material.

The diagrammatic FIGURE 3 represents the pole pieces **4** and **5** of the above mentioned arrangement, not incorporating the invention. In this construction there is a concentration of flux in the small gap **9** between the pole pieces, most of the flux being in fact concentrated in this region. Outside the pole faces **6** and **7** there appears only the stray leakage flux **10**, and it is only this leakage flux through which will pass the record tape in contact with the pole faces which will perform any useful work. A certain amount of leakage flux also appears in the region **11** beyond the inner end of the gap **9** where the laminations diverge.

The efficiency of the device would be increased if a greater proportion of the flux could be diverted into the region **10** through which the record tape will pass.

One possible way of obtaining such a modification of the magnetic field would be by reducing the cross-sectional area of the gap 9, as by reducing its depth, that is the distance from the plane of the pole faces 6 and 7 to the position at which the dimension of the gap begins to increase as the laminations diverge. This would reduce the flux 9 in the gap and increase the leakage flux, but this increase of the leakage flux would occur not only in the effective position 10 but also in the ineffective position 11 so that while this would represent some increase in efficiency there would still be the loss represented by the increased leakage flux in the ineffective position 11. Also there are practical disadvantages associated with the adoption of such a procedure in that the depth of the gap cannot be reduced to such an extent that it will not allow for a useful amount of wear at the pole faces 6 and 7 due to their contact with the moving record tape. Another method of increasing the efficiency of the magnetic system would be to pass a comparatively heavy current through a copper spacer 26, which is used to determine the gap, in the appropriate direction vertically with reference to the plane of the paper in FIGURE 3 in order to produce a counter-field in the region 11 and an aiding field in the region 10. Apart from the practical difficulties associated with such an arrangement, the increased efficiency of the magnetic system is offset by the additional power required to generate the sufficiently heavy current.

The object of this invention is to provide an improved arrangement for eliminating or substantially reducing the flux 9 in the gap and the leakage flux 11 at its inner end to cause a greater proportion of the available flux to appear in the effective position 10.

The arrangement for effecting this object in accordance with the invention will now be described with reference to FIGURES 1, 2 and 5.

The improved head comprises a pair of outer pole pieces 12 and 13 each consisting of a number of laminations 14 of magnetic material, together with a pair of inner pole pieces 15 and 16 which each consist of a single lamination 17 and which are disposed between the outer pole pieces 12 and 13. The inner pole pieces 15 and 16 are separated by a spacer 18 of non-magnetic material to provide a gap, which will be called the inner gap 18. Furthermore a spacer 19 of non-magnetic material is inserted between each of the inner pole pieces 15 and 16 and the adjacent one of the outer pole pieces 12 and 13 to provide a pair of outer gaps, which will be called the outer gaps 19. The outer pole pieces 12 and 13 present outer pole faces 20 and 21 and similarly the inner pole pieces 15 and 16 present the pole faces 22 and 23, all the pole faces being coplanar so that in the complete unit they will be presented flush with the contact surface of the unit, similarly to the faces 6 and 7 in the arrangement described with reference to FIGURE 4.

At positions remote from the pole faces 20–23 all the laminations 14 and 17 are brought together and bend round to form a magnetic circuit 25 similar to that represented by the reference 2 in FIGURE 4. An energizing winding 27 extends from the terminals 3 round all the laminations in the circuit so that on applying current to the winding 27 both pairs of pole pieces 12, 13 and 15, 16 will be energized simultaneously. The arrangement is such that each two adjacent inner and outer pole pieces, namely 13, 16 and 12, 15 will be of the same polarity and moreover the flux density in the inner gap 18 between the inner poles 15 and 16 will be greater than the flux density between the outer poles 12 and 13. This will have the effect of repelling flux which might otherwise pass directly between the two outer poles 12 and 13 into the effective region 28 beyond the pole faces.

The electro-magnetic head which is here described is specifically an erasing head adapted to generate an appropriate magnetic field for "wiping" the record from a length of tape passed over and in contact with the pole faces. Since the provision of the inner pole pieces 15 and 16 has the effect of repelling flux which might otherwise pass directly between the pole pieces 12 and 13 then a greater proportion of the generated flux will extend outwardly, as so-called leakage flux, and thereby provide a greater efficiency of operation.

The results obtainable by the use of the invention are generally indicated by the graph shown in FIGURE 7. The upper curve 30 represents the degree of erasure to a decibel scale D*b* in relation to the power consumption of the electro-magnetic head in volt-amperes VA, when using a conventional head such as has been described with reference to FIGURE 3. The lower scale 29 represents the results obtained with the improved head. It will be seen from that figure for a given expenditure of power the results obtained with the improved head are considerably better than those obtained with the old head.

The following explanation sets out the technical considerations leading to the design of the most efficient head incorporating the invention. Referring to FIGURE 5 it is desirable to provide an arrangement in which the reluctance in the gap existing between the line B and the pole pieces 20 and 22 is greater than the reluctance between the inner pole path from *a* to *b* in one inner pole piece 16 or its counter-part on the other inner pole piece 15, otherwise each inner pole piece will tend to become an effective part of the adjacent outer pole piece. Moreover it is desirable to ensure that the reluctance of the inner gap 18 shall be neither greater nor less than that of either of the outer gaps 19. If the inner gap 18 has the higher reluctance it will tend to share its flux with an outer pole across the lower reluctance outer gap 19. If on the other hand the reluctance of the inner gap 18 is the lower, the tendency will be for the leakage flux to be concentrated between the inner pole pieces, leaving less flux to be propelled in other directions to repel the main flux from the outer pole pieces. Thus the most efficient arrangement will be one in which the spacers which determine the inner and outer gaps are of equal thickness.

Attention must also be given to the governing factor represented by the reluctance of those portions of the inner pole pieces which are separate from the outer pole pieces, that is those portions generally indicated in FIGURE 3 as the parts which extend from the lines A and B respectively to the pole faces and which are isolated by the outer spacers 19 from the outer pole pieces. Also it is desirable to provide for the path length external to the assembly between the outer pole faces 20 and 21 to be as short as possible in order to provide a low reluctance path and therefore a maximum flow of flux between those pole faces. By making the gap spacers and the inner pole pieces all the same thickness and using the same magnetic material for the formation of all the poles the relation between the reluctance of the external path between the outer pole pieces and that across the inner gap would be such that five times more flux would flow across the inner gap than in the external path. It is only necessary to allow slightly more flux to pass across the inner pole pieces, between the outer pole pieces, than that which extends externally between the outer pole pieces. To obtain this the reluctance of the inner pole pieces may be increased by decreasing the cross-sectional area of the magnetic path which they represent and by using for them a material of lower permeability. For instance, by using for the outer pole pieces material having a permeability which is ten times the permeability of the material used for the inner pole pieces it can be arranged that slightly more than half the total flux generated will pass across the inner pole pieces, that is nearly half of the total flux generated will be projected outwards into the useful area.

In one typical example the three gap spacers were formed of single layers of aluminium foil of thickness 0.002 inch (0.05 mm.). The inner pole pieces were formed as single laminations of grain orientated silicon iron alloy also of thickness 0.002 inch (0.05 mm.) The outer poles each comprised five mu-metal laminations

each 0.004 inch (0.1 mm.) thickness. Using an energizing coil of 150 turns and 250 ohms impedance at 50 kilocycles per second the de-magnetization effect obtained at various current loadings was as generally indicated by the curve **29** in FIGURE 7. The decibel scale D*b* represents as negatively expressed values the degrees of de-magnetization at different values of power input represented as volt-amperes on the scale VA at the above mentioned frequency.

Particularly in an erasing head constructed in accordance with the invention, the total amount of flux which requires to be generated in order to provide a given degree of erasure is less than that required in a conventional head not provided with the inner poles. This means that the flux density in the main magnetic core of the head can be reduced, consequently reducing losses due to eddy currents and hysteresis.

Additionally the invention enables a higher permeability metal, e.g. Mu Metal, than hitherto to be used for the material of the main pole pieces. This in itself further reduces the required intensity of the energizing current and also in consequence reduces the eddy current and hysteresis losses. Such high permeability metal was not sufficiently effective in the erasure heads not incorporating the invention because it became magnetically saturated before complete erasure was obtained.

The use of the inner poles in accordance with the invention as a repellant of the main usable flux has many other applications in the field of industrial electronics, in that it is applicable in any electro-magnet sensing head where the projection of flux eminating from a coil system is required to penetrate deeply into a workpiece external to the coil system. Such applications include pick-up units used for non-destructive testing of ferrous, non-ferrous and insulating materials for defects, where changes of the magnetic field passing through the material under test produces changes in the electro-motive force in one or more secondary pick-up coils or an unbalanced relation between the electro-motive forces induced in two pick-up coils or a change of inductance in one or more pick-up coils. As these systems all rely for their efficiency on the external field produced by the originating coil system, the efficient projection of the flux by that which is usually known as the energizing coil is all important in determining the signal/noise ratio of the detecting system.

In accordance with another aspect of the invention, and in so far as it is applied to an erasing head incorporating an energizing winding on a core, the latter may also be provided with a further winding so that the structure can serve as a transformer of which the energizing winding is the primary winding and the further winding is the secondary winding which may be used to supply a high frequency input to the bias winding of a magnetic recording head. Such a coil **31** is indicated in broken line in FIGURE 1.

It has previously been proposed to connect the high frequency bias winding of a recording head in series with the energizing winding of an associated erasing head. Such a winding has necessarily consisted of only a comparatively small number of turns and to obtain the necessary intensity of biasing field the winding has been required to carry a comparatively large current.

The more usual practice is to use in the recording/reproducing head a single winding which will serve for the audio-frequency transduction and to which, during recording, will also be applied the high frequency biasing voltage. This winding must have a comparatively high impedance at audio-frequency and therefore at the higher super-sonic biasing frequency its impedance will be so high as to require a comparatively high bias voltage to be applied in order to obtain an effectively intense biasing field. The practice has been to provide an additional high voltage winding on the high frequency oscillator coil to provide the bias voltage. Neither of these systems is best suited for use in association with a battery fed transistor built oscillator.

Since the incorporation of the invention in an erasing head reduces the required power input to its energizing coil, there is a consequent reduction in the power output required of the oscillator. Moreover if the bias winding can be fed otherwise than by a high tension winding associated with the oscillator the latter is further simplified. The provision of the above mentioned further or secondary winding on the core of the erasing head will serve to provide the high voltage biasing current and thus enable the oscillator to be so simplified. Yet a further simplification of the oscillatory circuit is also possible, in that the energizing winding of the erasure head can now be directly included as at least part of that circuit.

What I claim then is:

1. An electro-magnetic transducer head comprising an electro-magnet having a two-ended magnetizable core, the two ends of said core together comprising a pair of inner pole pieces of opposite polarities and a pair of outer pole pieces also of opposite polarities, the inner pole pieces being between the outer pole pieces with each inner pole piece adjacent to an outer pole piece of the same polarity at the same end of the core, a first non-magnetizable spacer between the inner pole pieces, two second non-magnetizable spacers of which one is located between one inner pole piece and its adjacent outer pole piece and of which the other is located between the other inner and outer pole pieces, the pole pieces presenting substantially co-planar pole faces and the non-magnetizable spacers extending to the plane of the faces.

2. An electro-magnetic transducer head as claimed in claim **1**, in which the non-magnetizable spacers are of equal thicknesses.

3. An electro-magnetic transducer head as claimed in claim **1**, in which the cross-sectional area of each of the inner pole pieces is less than the cross-sectional area of each of the outer pole pieces.

4. An electro-magnetic transducer head, comprising an electro-magnet having a two-end magnetizable core, the two ends of said core together comprising a pair of outer pole pieces of opposite polarities and a pair of inner pole pieces also of opposite polarities, the inner pole pieces being between the outer pole pieces with each inner pole piece adjacent to an outer pole piece of the same polarity at the same end of said core, a first non-magnetizable spacer between the inner pole pieces, two second magnetizable spacers of which one is located between one inner pole piece and its adjacent outer pole piece and of which the other is located between the other inner and outer pole pieces, the pole pieces presenting substantially co-planar pole faces and the non-magnetizable spacers extending to the plane of the faces, and the inner pole pieces being of material having a lower permeability than the material of the outer pole pieces.

5. An electro-magnetic transducer head, comprising an electro-magnet having a two-ended magnetizable core in the form of a group of laminations of magnetizable material, the group of laminations being in the form of a loop presenting pole pieces at two ends thereof, the pole pieces consisting of a pair of outer pole pieces of opposite polarities and, between the outer pole pieces, a pair of inner pole pieces also of opposite polarities, each inner pole piece being adjacent to an outer pole of the same polarity at the same end of said core, a first non-magnetizable spacer between the inner pole pieces, two second non-magnetizable spacers of which one is located between one inner pole piece and its adjacent outer pole piece and of which the other is located between the other inner and outer pole pieces, additional non-magnetizable spacers between at least those laminations of the outer pole pieces which are nearest the inner pole pieces, the pole pieces presenting substantially co-planar pole faces

and all the non-magnetizable spacers extending to the plane of those faces.

6. An electro-magnetic transducer head comprising an electro-magnet having a two-ended magnetizable core, the two ends of said core together comprising a pair of inner pole pieces of opposite polarities and a pair of outer pole pieces also of opposite polarities, the inner pole pieces being between the outer pole pieces with each inner pole piece adjacent to an outer pole piece of the same polarity at the same end of said core, a first non-magnetizable spacer between the inner pole pieces, two second non-magnetizable spacers of which one is located between one inner pole piece and its adjacent outer pole piece and of which the other is located between the other inner and outer pole pieces, the pole pieces presenting substantially co-planar pole faces and the non-magnetizable spacers extending to the plane of those faces, and two windings carried by said core, one of said

windings being an energizing winding and the other winding being the secondary winding of the transformer which is represented by the combination of the two windings and said core.

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