

Dec. 23, 1947.

S. D. EILENBERGER

2,433,207

RECTILINEAR POLE PIECE FOR MAGNETIC SOUND HEADS

Filed May 19, 1945

2 Sheets-Sheet 1

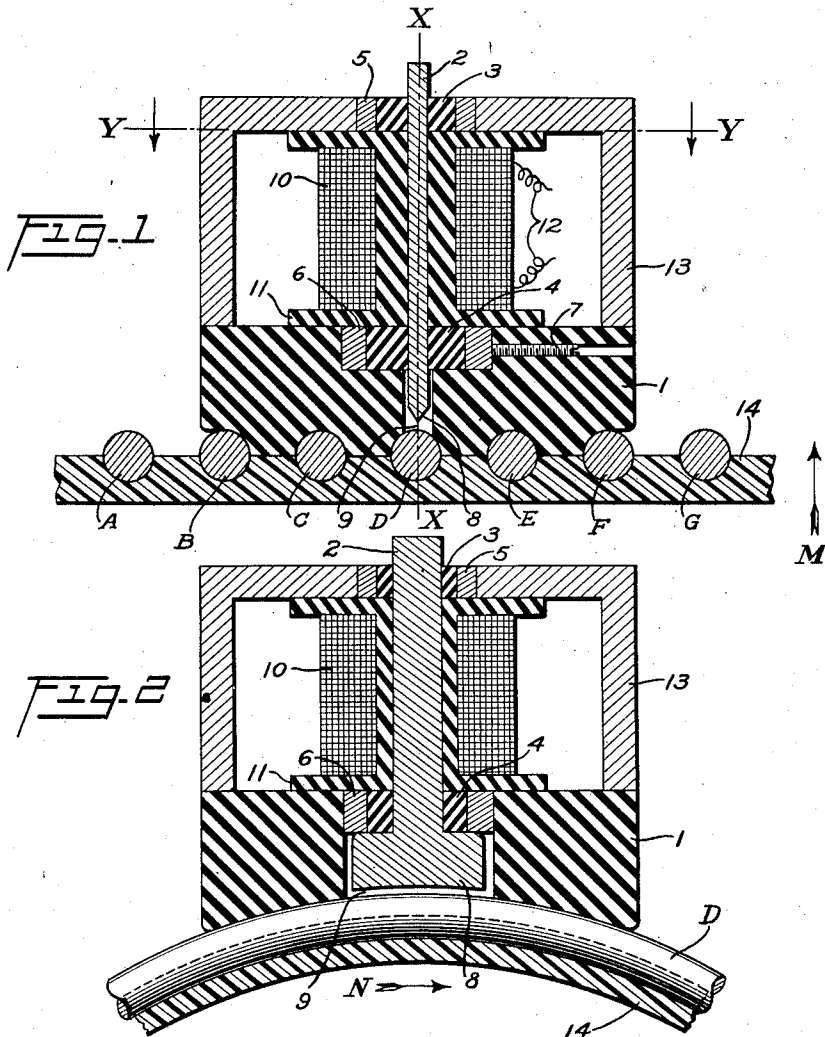
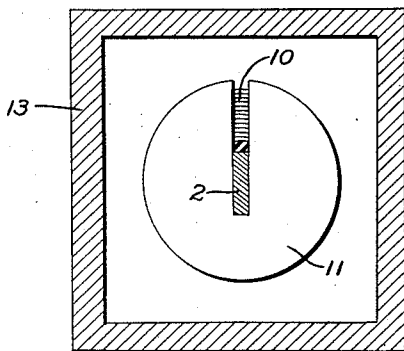


FIG. 3



Inventor,
Stanley D. Eilenberger
By Robert L. Kalin
Attorneys

Dec. 23, 1947.

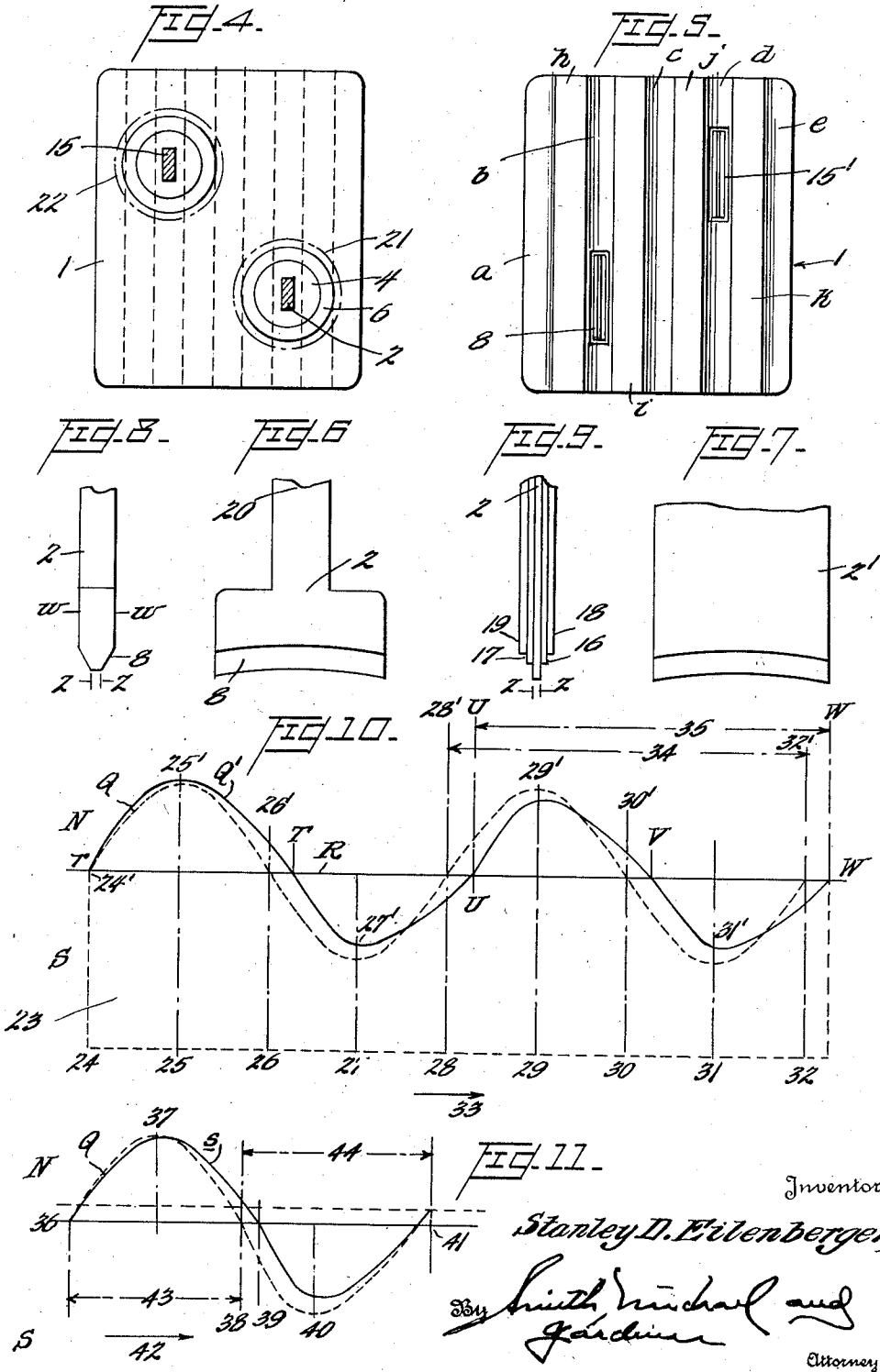
S. D. EILENBERGER

2,433,207

RECTILINEAR POLE PIECE FOR MAGNETIC SOUND HEADS

Filed May 19, 1945

2 Sheets-Sheet 2



Inventor

Stanley D. Eilenberger,

By Smith, Vinchell and
Gardner

Attorney

UNITED STATES PATENT OFFICE

2,433,207

RECTILINEAR POLE PIECE FOR MAGNETIC
SOUND HEADS

Stanley D. Eilenberger, Kenosha, Wis., assignor,
by mesne assignments, to Chicago Coin Ma-
chine Co., a corporation of Illinois

Application May 19, 1945, Serial No. 594,680

3 Claims. (Cl. 179-100.2)

1

This invention relates to improvements in mag-
netic recording, reproduction or obliteration and
particularly to magnetic head design for record-
ing, reproduction or obliteration with a magne-
tizable sound carrier in the form of a circular
drum, analogous in shape to the cylindrical rec-
ord ordinarily used on well known dictating ma-
chines. The magnetic sound carrier is of mag-
netizable material, such as steel, most of the fer-
ric alloys and certain nickel aluminum combina-
tions.

This invention more specifically relates to im-
provements in methods disclosed by my United
States patents entitled "Magnetic pole piece,"
numbered 2,361,753, and "Magnetic recording and
reproducing system," numbered 2,361,752, and
also my copending patent applications entitled
"Magnetic recording and reproducing head," filed
February 2, 1945, Serial Number 575,832, "Mag-
netic head," filed February 2, 1945, Serial Number
575,833, now Patent No. 2,428,701, issued Oct. 7,
1947, and "Magnetizable record," filed February
2, 1945, Serial Number 575,834, now abandoned.
The above cited United States patents and pat-
ent applications disclose methods and means of
confining the stray magnetic field normally as-
sociated with magnetic pole piece tips, reducing
wear on such pole piece tips, the use of a non-
magnetic shoe in magnetic head construction,
and certain improvements in magnetizable cylin-
der record construction. The present invention
discloses improvements in pole piece design, here-
in referred to as a rectilinear pole piece, and, for
a better understanding of the present invention,
reference should be made to the United States
patents and co-pending patent applications above
cited.

The magnetic recording, reproducing or oblit-
erating heads disclosed by the above cited patents
and patent applications all made use of a round
pole piece having a conical tip, reducing the pole
piece tip to a very fine dimension. This practice
is in accord with the previously established prac-
tice in magnetic recording systems, where it has
been shown and is generally accepted that for a
given finite pole piece dimension and a given
sound track speed there is a definite upper fre-
quency limit which can be recorded, and this lim-
itation also applies in the patents and patent ap-
plications cited above. A further limitation of a
conical pole piece is that flux spreading or leak-
age flux exists uniformly in all directions and,
while this is no disadvantage where adjacent
sound tracks on a spiral wound cylindrical record
are spaced sufficiently far apart so that this leak-

2

age flux does not include the nearest adjacent
sound track in its field, it precludes the use of
closely adjacent sound tracks.

Experience has shown that a conical pole piece
reduced to a very fine point may be used with
sound tracks spaced 128 to the inch, where the
sound track is composed of .004" carbon steel
wire. By careful design, such a system is oper-
able without ghost or echo recordings, when such
conical pole piece is associated with shielding
means and mounted in a guiding shoe, as dis-
closed by my previously mentioned patents and
patent applications. However, with a .004"
sound track spaced closer than 128 sound tracks
per inch, it has been found impossible to elimi-
nate the ghost recordings produced by leakage
flux, except for a condition where the pole piece
tip was in actual magnetic contact with the sound
track, thus reducing the reluctance to zero. Such
a condition is untenable in practice, as physical
contact between the pole piece tip and the sound
track produces a high noise level. As previously
mentioned, the conical pole piece tip is also sub-
ject to a definite frequency limitation, dependent
on sound track speed and effective pole piece di-
mension, where effective pole piece dimension is
defined as the finite pole piece dimension plus the
effective area recorded as a result of leakage flux
or flux spreading.

The object of the present invention is to pro-
vide a pole piece design which is not subject to
the foregoing limitations, where such pole piece
will be suitable for operation with closely adja-
cent sound tracks on a spirally wound cylinder
record, without ghost or echo recordings, and to
provide a pole piece which is substantially inde-
pendent of frequency as a function of sound track
speed.

As previously stated, it is generally accepted
that a pole piece having finite dimensions will
have a definite high frequency cut-off as a func-
tion of sound track speed, where it has been
shown that the product of effective pole piece di-
mension and sound track speed must be equiv-
alent in time to less than one full cycle of the
highest frequency that will be recorded. In prac-
tice, it is generally necessary to make this prod-
uct of pole piece dimension and sound track speed
equal to one-half cycle of the highest frequency
that will be recorded. For example, with a pole
piece dimension on the order of .0016" and a
sound track speed of 16" per second, it would be
theoretically possible to record 10,000 c. p. s., but
in actual practice these conditions would not be
effective above 5000 c. p. s. Furthermore, in ac-

tual practice it is virtually impossible to obtain an effective pole piece dimension on the order of .0016", so that in general it is necessary to use a much higher speed than, for example, the 16" per second given above, where several modern recording systems available commercially operate at speeds on the order of 65" per second to obtain a 5000 c. p. s. high frequency cut-off.

Two general methods of magnetic recording have been recognized, where one is generally referred to as vertical recording, where two pole pieces are operated directly opposite each other, as, for example, in the patent to Hickman, numbered 1,944,238, the other system being generally referred to as longitudinal recording, where the pole pieces are offset in respect to each other, an example of this method being disclosed in the patent to Begun, numbered 2,224,854. While numerous variations of these two basic methods exist, they all fall into one class or the other. For example, recent patents to Camras, such as Number 2,351,003, disclose a novel method of recording on a free wire, but this method is a variation of longitudinal recording.

The present invention deals with a method of vertical recording utilizing a new and novel pole piece design. It has been found that the limitation of pole piece dimension exists up to a certain point but that if this point is greatly exceeded the limitation disappears. For example, assuming a pole piece having a rectangular point equal to the sound track diameter and further assuming a sound track diameter of .004" and a pole piece having an effective dimension of .004" laterally and .004" in the direction of sound track travel, a definite frequency cut-off would occur in accordance with sound track speed and, if the .004" dimension in the direction of sound track travel is increased, the high frequency cut-off will decrease, assuming a constant sound track speed, and this continues to be so up through any practical combination of dimensions, frequency cut-off and sound track speed. It has been found, however, that if this dimensional restriction is greatly exceeded that it no longer applies. For example, again assuming a sound track having a diameter of .004" and a pole piece having a thickness of .004" and a width in the direction of sound track travel of $\frac{1}{2}$ ", it has been found that recording takes place entirely in disagreement with the limitations set out above. Such a pole piece having an effective width of $\frac{1}{2}$ " in magnetic relation to the sound track would correspond to a full wave length at some very low frequency, on the order of 15 or 20 c. p. s., dependent upon sound track speed, and, theoretically, the pole piece should not record higher frequencies. Experimentally, it has been determined that such a pole piece will record higher frequencies and that, initially, recording takes place at both the leading edge and the trailing edge, where the initial recording made at the leading edge is subsequently obliterated, and the final recording impressed on the sound track always occurs at the trailing edge. Apparently, this trailing edge acts as an infinitely fine point, in spite of the fact that a full half inch of the sound track is instantaneously in magnetic relation to the pole piece.

Experimentally, it has been found that with such a pole piece having a finite dimension of $\frac{1}{2}$ " in the direction of sound track travel, frequencies up to and beyond 10,000 c. p. s. may be recorded and reproduced without appreciable loss at a constant sound track speed on the order

of 40" per second. At the same speed, with a conical pole piece sharpened to an infinitely fine point, the highest frequency that can be recorded is on the order of 3500 c. p. s. A further important advantage of this type of pole piece structure is that there is essentially no leakage flux to closely adjacent sound tracks, and it has been found practical to make such a pole piece with a thickness corresponding to the sound track diameter, a length in the direction of sound track travel on the order of $\frac{1}{2}$ " and a length at right angles to the sound track as determined by coil design. Assuming a sound track diameter of .004" and a pole piece thickness of like dimension, it has been found practical to record on 250 sound tracks per inch, which is the maximum number possible when the sound track is formed of .004" wire. Carrying this still further, it has been found practical to record on .0025" wire at 400 sound tracks per inch without flux spreading to the next adjacent sound track, utilizing a pole piece having a thickness of .0025" and a width on the order of $\frac{1}{2}$ " in the direction of sound track travel.

The foregoing general description covers the principal novel features of this new pole piece design, the details of which will be better understood by reference to the drawings.

In the drawings:

Figure 1 represents a cross section view of a complete recording and reproducing head, using the rectilinear pole piece described.

Figure 2 represents an end cross section view of Figure 1, through the line XX.

Figure 3 represents a top cross section view of Figure 1, through the line YY.

Figure 4 represents a top plan view of shoe 1 from Figure 1, showing in cross section both the recording/reproducing pole piece and, separately, an obliteration pole piece.

Figure 5 represents a bottom plan view of the shoe 1 in Figure 1, again showing both the recording/reproducing pole piece tip and, separately, the obliteration pole piece tip.

Figure 6 represents a preferred form of this rectilinear pole piece in outline.

Figure 7 represents an optional form of rectilinear pole piece in outline.

Figure 8 represents an end plan view of the pole piece shown by either Figure 6 or 7.

Figure 9 represents a laminated pole piece structure, which may be utilized with the basic pole piece shown by Figure 6 or 7.

Figure 10 represents the theoretical magnetic induction process when recording with a rectilinear pole piece.

Figure 11 represents the relationship between the recording wave form and the reproduced wave form.

Referring now particularly to Figure 1, non-metallic shoe 1 supports and partly encloses rectilinear pole piece 2, which is mounted in rubber sections 3 and 4, said rubber sections being in turn mounted within collars 5 and 6, collar 6 being held in place by set screw 7. This overall mounting arrangement is designed to provide a form of shock mounting for pole piece 2, so that mechanical vibrations resulting from the traverse movement of shoe 1 will have a minimum effect on pole piece 2, the effect of the shock mounting being to reduce the noise level during the reproduction process. Tip 8 of pole piece 2 is reduced to a dimension equal to or less than the diameter of the sound tracks A, B, C, D, E, F or G. A small air gap 9 is interposed between pole piece tip 8

5

and sound track D, these two members being shown in instantaneous magnetic relation. The physical dimension of the air gap is non-critical, the main requirement being that pole piece tip 8 does not actually touch sound track D. In actual practice, an air gap on the order of .001" has been found satisfactory. Pole piece 2 is mounted within coil 10, which is wound on coil form 11, and leads 12 from coil 10 are connected to a suitable recording or reproducing amplifier. The overall pole piece and coil assembly are mounted within magnetic shield 13, which is preferably made from cast iron or one of the magnetizable alloys, where shield 13 provides not only additional mechanical mounting for pole piece 2 and inductive shielding for coil 10 but also aids in providing a return magnetic path between record 14 and end P of pole piece 2. Figure 1 is a cross section view of the complete magnetic head assembly and a partial cross section view of cylinder record 14, which has spirally arranged sound tracks A, B, C, D, E, F, G, etc., the direction of motion of cylinder record 14 being indicated by arrow M.

Referring now more particularly to Figure 2, this is an end cross section view of Figure 1 through the line XX, all reference numerals being the same as used in Figure 1, with the direction of motion of record 14 being as indicated by arrow N. Figure 2 clearly sets out the magnetic relationship between pole piece 2 and sound track D.

Referring now more particularly to Figure 3, this is a top cross section view of Figure 1 through the line YY, all reference numerals being the same as used in Figures 1 and 2. It is believed that Figure 3 is self-explanatory, this figure being included only for additional clarity in the drawings.

Referring now to Figure 4, which represents a top outline view of non-metallic shoe 1, pole piece 2 is shown in cross section, and additional pole piece 15, representing an obliteration pole piece similar in design to recording/reproducing pole piece 2, is shown in cross section. The area within broken circle 21 represents the area occupied by recording/reproducing coil 10, and the shock mounting means associated with pole piece 2 is represented by areas 4 and 6. The area within broken circle 22 represents the area occupied by the obliteration coil, not otherwise shown in the drawings. While it is not essential that obliteration pole piece 15 be mounted common to recording/reproducing pole piece 2, it is usual practice to do so as a matter of mechanical convenience. While obliteration pole piece 15 is shown off-set one sound track from recording/reproducing pole piece 2, it is understood that this is shown merely for purposes of example and that such obliteration pole piece may be operated on the same sound track or separated by any desired number of sound tracks, it being further understood that obliteration may be carried out by any desired means, without departing from the operational methods disclosed by this invention.

In further reference to obliteration methods, it has been found satisfactory to obliterate with a circular pole piece having a conical point, with the limitation that such circular pole piece must be off-set a relatively large number of sound tracks from the sound track in instantaneous magnetic relation to the recording pole piece, to prevent partial obliteration of the recorded signal. A rectilinear pole piece similar in design to recording/reproducing pole piece 2 has been

6

found fully satisfactory for obliteration purposes, and when such pole piece design is used obliteration may be carried out on the same sound track or on the next adjacent sound track to the sound track in instantaneous magnetic relation to the recording pole piece.

In Figure 5 a bottom view of non-metallic shoe 1 is shown, the sound track areas being represented by the shaded area a, b, c and d, and the guiding ribs by areas h, i, j, k and l. Pole piece tip 8 of the pole piece 2 is represented as an end view, and pole piece tip 15¹ of pole piece 15 is also represented in end view.

Referring now to Figure 6, an outline view of pole piece 2 is shown, the design of pole piece tip 8 being clearly illustrated, where T section 20 is designed to receive the recording, reproducing or obliteration coil.

In Figure 7 an alternate design of pole piece is designated as 2¹, where the T section 20 of pole piece 2 has been omitted, and the entire pole piece is carried through as a straight section. While this design is operable, pole piece 2 as represented by Figure 6 is the preferred form.

In Figure 8 an end view of pole piece 2 from Figure 6 is shown. In this view it is assumed that the main thickness dimension WW of pole piece 2 is greater than the sound track diameter, and this main dimension is reduced at pole piece tip 8 to a dimension ZZ equal to or less than the sound track diameter.

In Figure 9 an alternate method of pole piece assembly is shown. In this case, pole piece 2 has a basic thickness dimension ZZ equal to or less than the sound track diameter, and the laminated sections 16, 17 and 18, 19 are added for reasons of mechanical strength and to provide better magnetic coupling between pole piece 2 and its associated recording, reproducing or obliteration coil.

It is understood that the straight section pole piece shown by Figure 7 may be incorporated into a pole piece assembly essentially as shown by Figure 9 or may have a tapered tip section as shown by Figure 8.

Referring now to Figure 10, Q represents the recording wave form at the output of the amplifier, where Q is assumed to represent a conventional sine wave having arbitrary frequency in the audio range, and R represents the zero base line.

The pole piece is represented by 23, and it is assumed that the pole piece has a length 24'/32' and, that the pole piece is moving in the direction indicated by arrow 33. At the start of the magnetic induction process, the pole piece is in the position indicated by 24, and the induced magnetism in the sound track, for the quarter cycle 24'/25', will be essentially a sine wave quarter cycle, closely the same as the first quarter cycle of the recording wave Q, assuming that recording takes place on an essentially flat portion of the ascending hysteresis loop. The next quarter cycle of recorded wave Q' will depart from the sine wave form of Q, due to the curvature of the descending loop, it being well known that in any magnetic induction process the ascending loop and the descending loop do not lie in the same path and are not necessarily parallel. For this reason, the recorded quarter cycle 25'/26' will not return to the zero base line R at the same instant that pole piece 23 is in position 26, but as the magnemotive force changes polarity, the recorded wave will continue along the descending loop and intersect the zero

base line at point T. The distance from point 26' to point T is a function of the hysteresis loop for any particular material composing the sound track. For medium carbon steel, for example, on the order of .75 carbon, the displacement 26'/T is not great. The third quarter of recorded wave Q' will essentially follow the path of recording wave Q but will be displaced in amplitude, although the south pole point 27' will coincide with the south pole point 27 for recording wave Q. The final quarter of recorded wave Q' will again lag in time behind recording wave Q and at the instant in time that pole piece 23 is at position 28, the final quarter cycle of recorded wave Q' will not have intersected zero base line R, but as the magnetic induction process continues on the next north quarter cycle, the final quarter cycle of wave Q' will intersect zero base line R at point U, the distance 28'/U being equal to the distance 26'/T.

The next cycle of the recorded wave Q' will closely follow the pattern of the first cycle where again points 29' and 29 will coincide in time as will points 31' and 31 and the offset in time 30'/V will be equivalent to the offset in time 26'/T and the offset in time 32'/W will be equal to the offset in time 28'/U.

From Figure 10 it may be seen that the distance 35 between points U and W is exactly the same as the distance 34 between the points 28' and 32' and therefore there will be no frequency distortion, although a displacement in time equivalent to phase distortion will exist.

Referring now to Figure 11, Q again represents the wave form for a single cycle of the recording wave of arbitrary frequency having base line R, and S represents the reproduced wave form, as determined from the magnetic induction process explained in connection with Figure 10, where it is assumed that magnetic induction takes place in the direction indicated by arrow 42. Some correction has been applied to reproduced wave S so that the zero base line R has the same length for a single cycle of recording wave Q as for reproduced wave S, where both waves coincide in time at starting point 36, quarter cycle point 37, three-quarter cycle point 40, and ending point 41. However, these 2 waves will still be displaced in amplitude at three-quarter cycle point 40 and in time at the half cycle point 38/39. By shifting zero base line R to theoretical base line R' so that the distance 43 is exactly equal to the distance 44, which is what actually occurs in practice, reproduction is obtained which for all practical purposes is high fidelity. While further correction may be employed to force points 38 and 39 to coincide, it is not believed that this is essential. It has been determined experimentally that any departure from the recording sine wave form is not noticeable as distortion to the ear upon reproduction. However, for certain high fidelity purposes, it may be desirable to correct this wave form by equalizing in the reproduction amplifier.

A method of magnetic recording, reproduction or obliteration has been described in detail, using a rectilinear pole piece as herein disclosed. There are no rigid requirements regarding the optimum width of such pole piece in the direction of sound track travel, but it has been determined that the minimum width for such a rectilinear pole piece in the direction of sound track travel should not be less than one full wave length of the lowest frequency it is desired to record and, preferably, the width of this rectilinear pole piece should be

on the order of twice the width of the lowest frequency it is desired to record, where frequency is considered in terms of time as determined by sound track speed. Using a pole piece having a width in the direction of sound track travel less than one full wave length of the lowest frequency it is desired to record, it has been found that the pole piece tends to follow the rigid requirements imposed on pole pieces having a small dimension in the direction of sound track travel. Exceeding the requirements of a width in the direction of sound track travel of twice the lowest frequency it is desired to record apparently produces no improvement; although the reluctance would be slightly lower, the greater mass counteracts this, and no improvement is noted.

By way of example, assuming a sound track speed of 50'' per second and that it is desired to record a frequency of 100 c. p. s. as the lower limit, the sound track will travel $\frac{1}{2}$ '' in .01 second, and .01 second in time is equivalent to one full wave length at 100 c. p. s., and, therefore, it may be anticipated that 100 cycles will be recorded with a rectilinear pole piece having a thickness equal to or less than the sound track and a width in the direction of sound track travel on the order of $\frac{1}{2}$ ''.

Increasing this $\frac{1}{2}$ '' dimension to 1'' will produce somewhat better results at the low frequency limit of 100 cycles. In terms of medium or high frequency response, there is little gain in increasing the basic $\frac{1}{2}$ '' dimension, and high frequency cut-off is not a rigid function of this pole piece dimension in the direction of sound track travel, where it may be anticipated that in the example given above 10,000 cycles may be recorded and reproduced without serious high frequency loss when the rectilinear pole piece described is used in connection with a well designed recording/reproducing coil, which is in turn connected to a well designed and properly equalized amplifier.

By way of further example, if the rectilinear pole piece cited in the example above was confined to the rigid limits previously assumed for pole pieces utilized in magnetic recording, then it would be anticipated that such a pole piece would not record a frequency greater than 100 cycles and would not record well at a frequency greater than 50 cycles. From the foregoing description, it is obvious that this is not so with the rectilinear pole pieces herein described, it having been discovered that if the finite dimension of a pole piece is greatly exceeded in the direction of sound track travel the limitation on finite width no longer applies.

Reducing the dimension in the direction of sound track travel below the optimum conditions given above results in serious impairment of high frequency response, lowers the overall efficiency of the recording/reproduction process and results in serious flux spreading to adjacent sound tracks. In the example given for a $\frac{1}{2}$ '' rectilinear pole piece and a sound track speed of 50'' per second, under which condition excellent results are obtained, reducing the pole piece dimension to $\frac{1}{4}$ '' in the direction of sound track travel results in a lowered high frequency cut-off, lower overall efficiency and moderate flux spreading to adjacent sound tracks, while reducing the dimension in the direction of sound track travel to $\frac{1}{8}$ '' precludes satisfactory operation at any frequency. Leakage flux is so high with a rectilinear pole piece having a dimension of $\frac{1}{8}$ '' in the direction of sound track travel that a clean recording cannot be made,

the upper frequency is too low for even good voice reproduction, and the overall efficiency is very poor. It is believed that in rectilinear pole piece design for any condition there is an optimum width in the direction of sound track travel, which is roughly on the order of twice the lowest frequency it is desired to record, but, as previously stated, this is not a rigid limitation and is in part determined by the thickness of the pole piece, the type of coil associated with the pole piece, the type of sound track, the sound track material and the pole piece material. In general it may be stated that for all practical purposes the face of the pole piece shall have a linear dimension in the direction of sound track travel greater than the distance through which the sound track travels in an interval of time corresponding to one quarter cycle of the lowest frequency to be recorded. High permeability alloys have been found satisfactory as pole piece material, the other factors being a function of good engineering design for any particular purpose.

The present invention is designed particularly for use in translating complex sound waves, that is, sound waves comprising several frequencies with their associated harmonics, such as characterizes speech, music, and the like, and in the appended claims, the term "complex sound waves" is used accordingly.

The above examples are for the purpose of illustrating some of the methods and means by which the broad purposes of this invention may be carried out and are not to be deemed as restrictive in any manner. Other modifications and alternatives will occur to those skilled in the art without departing from the scope of this invention as defined by the following claims.

Reference is made to my copending application entitled "Rectilinear pole piece for wire recording," Serial No. 592,811, filed May 9, 1945, in which the principles underlying the invention herein disclosed are applied to free wire recording.

Having thus described my invention, what I claim as new is:

1. In a system for magnetically translating intelligence in the form of complex sound waves, including a cylindrical record having a plurality of magnetizable sound tracks thereon and means for moving said record tangentially with respect to the polar extremity of a recording or reproducing head including a bi-polar electromagnet hav-

ing a pole piece provided with a single undivided polar face disposed in magnetic relation to one of said sound tracks, said pole face having a dimension in the direction of sound track travel at least equal to the wave length of the lowest frequency to be recorded, said pole piece having the ability to translate the complex sound waves constituting said intelligence.

2. In a system for magnetically translating intelligence in the form of complex sound waves, including a cylindrical record having a plurality of magnetizable sound tracks thereon and means for moving said record tangentially with respect to the polar extremity of a recording or reproducing head including a bi-polar electromagnet having an inverted T-shaped pole piece provided with a single undivided polar face disposed in magnetic relation to one of said sound tracks, said pole face having a dimension in the direction of sound track travel at least equal to the wave length of the lowest frequency to be recorded, said pole piece having the ability to translate the complex sound waves constituting said intelligence.

3. In a system for magnetically translating intelligence in the form of complex sound waves, including a cylindrical record having a plurality of magnetizable sound tracks thereon and means for moving said record tangentially with respect to the polar extremity of a recording or reproducing head including a bi-polar electromagnet having a pole piece provided with a single undivided polar face disposed in magnetic relation to one of said sound tracks, said pole face having a dimension in the direction of sound track travel substantially equal to twice the wave length of the lowest frequency to be recorded, said pole piece having the ability to translate the complex sound waves constituting said intelligence.

STANLEY D. EILENBERGER.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
788,790	Pedersen	May 2, 1905
889,317	Lieb	June 2, 1908
2,092,024	Rowe	Sept. 7, 1937
2,300,320	Swartzel	Oct. 27, 1942