June 13, 1944. M. CAMRAS 2,351,004

METHOD AND MEANS OF MAGNETIC RECORDING

Filed Dec. 22, 1941 2 Sheets-Sheet 1

Fig. 1.

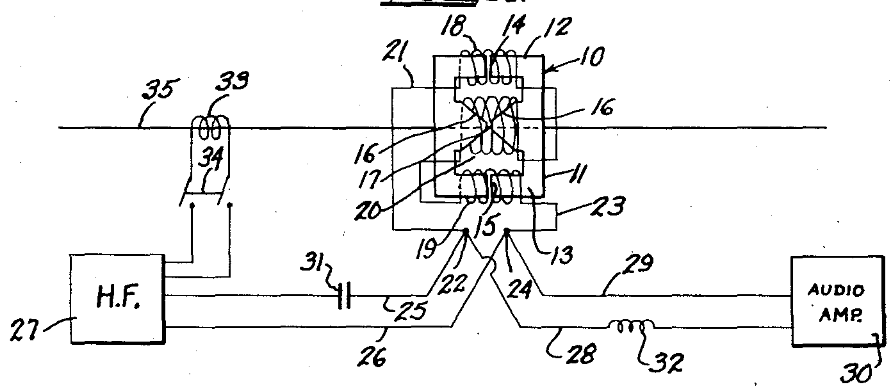

Fig. 2.

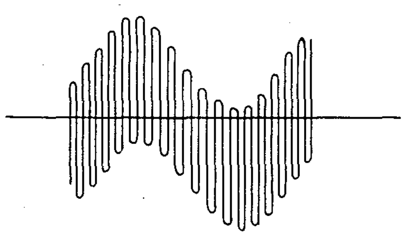

Fig. 3.

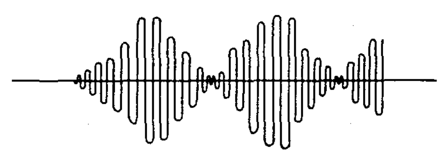

Fig. 4.

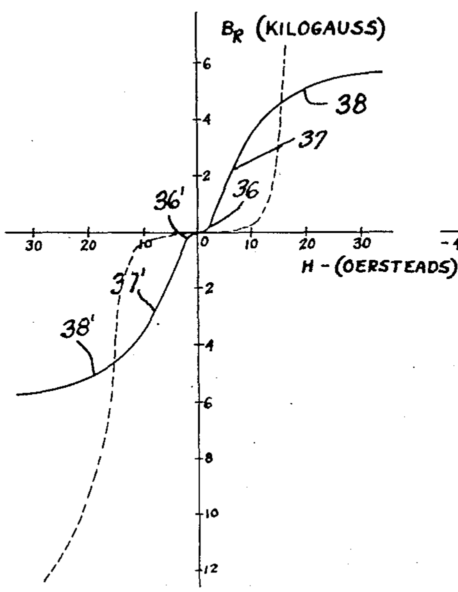

Fig. 5.

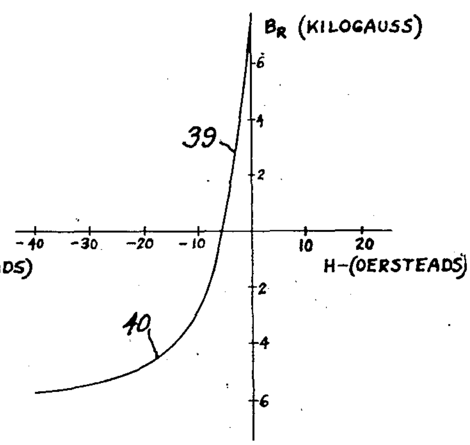

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Fig-6.

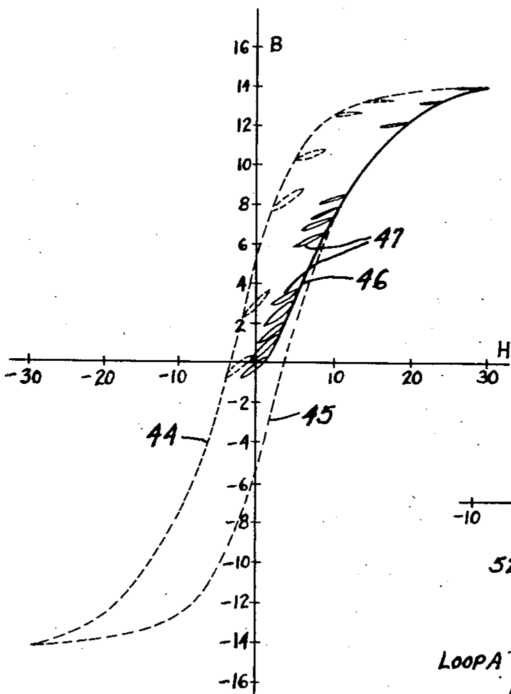


Fig-7.

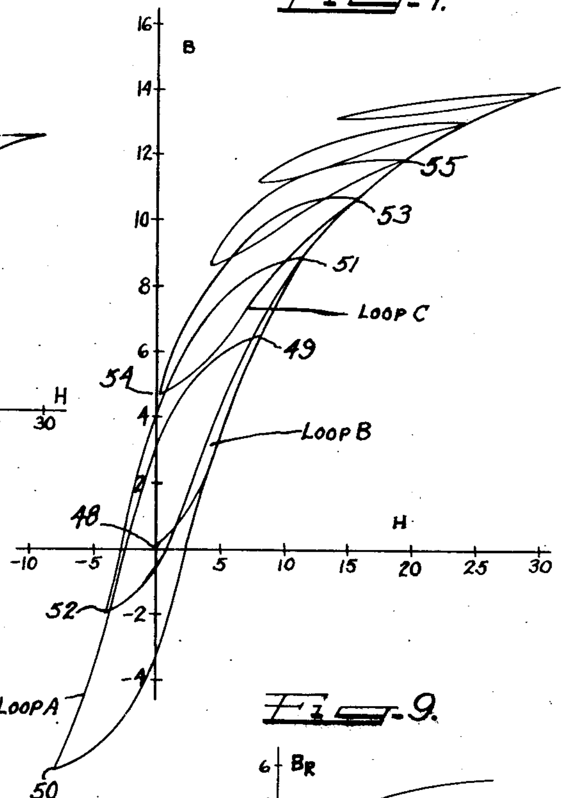


Fig-8.

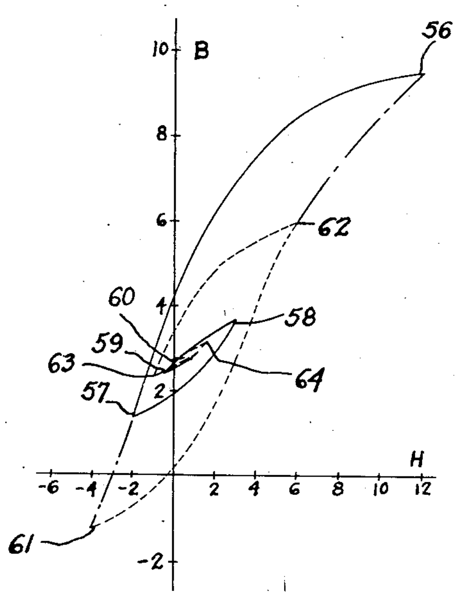
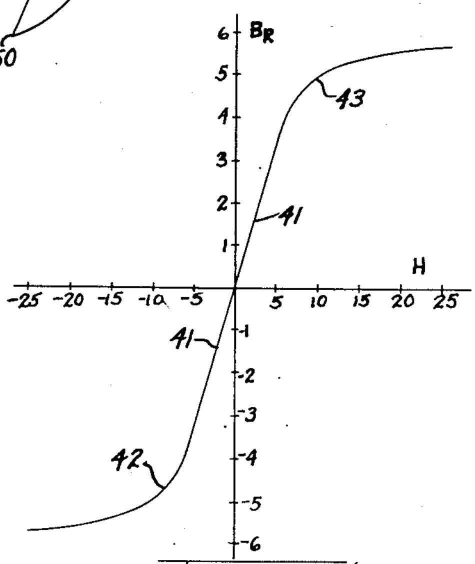


Fig-9.



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METHOD AND MEANS OF MAGNETIC RECORDING

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Application December 22, 1941, Serial No. 423,928

11 Claims. (Cl. 179—100.2)

This invention relates to a method and means of magnetic recording, and more particularly, to a system for linearly impressing magnetic variations or recordings on a completely demagnetized steel wire.

A system for magnetically recording audible sounds on a steel wire was developed in 1898 by Valdemar Poulsen. The Poulsen system, as well as other systems developed and experimented with for some years thereafter, included the fundamental concept that a demagnetized paramagnetic body, such as a steel wire or tape, should be passed through a magnetic field whose intensity varied as a function of the fluctuating sound waves to be recorded. These systems, due to the fact that the steel wire was initially demagnetized, operated over and around the lower bend near the zero axis of the characteristic residual magnetization curve of the wire. Because the system operated on a non-linear portion of the residual magnetization curve, faithful recording and reproduction of the sound waves was impossible.

A radical change in the underlying principle of magnetic recording and reproduction was made at a much later date by causing the steel wire or tape to be magnetically saturated and then passing it through an opposite weaker magnetic field modulated by the wave to be recorded. This basic type of system was a tremendous improvement over the earlier system, although the fundamental nature of the system still made it inherently impossible to obtain completely distortionless recording and reproduction. A body which is magnetically saturated without aging or other treatment, such as was necessary in the use of such wire or tape is very sensitive to extraneous demagnetizing effect. It is a well known fact that all permanent magnets immediately after magnetization lose some of their magnetism, and for that reason, most permanent magnets have to be aged. This made the above system very susceptible to noise due to mechanical handling, etc., of the wire or tape. A further cause for distortion occurring in this latter system is due to the fact that the system operates on a curved portion of the demagnetization curve, and although this curved portion is nearly straight, and nothing like the abrupt knee portion of the curve over which the earliest system operated, it nevertheless did cause some distortion to occur.

A modification of this system involved employing a modulated high frequency wave of the exciting current for producing a field to partially demagnetize the saturated record medium. This system retains the same characteristic features as those last discussed above.

An important feature and object of the present invention is to provide a system in which recording is made on a demagnetized paramagnetic body and in which the residual magnetization curve is linear where it passes through the zero position of the residual magnetization curve and continues to remain linear throughout the maximum range of operation.

Another object of the present invention is to provide a new method and means for magnetic recording on a paramagnetic body.

A further object of the present invention is to provide a novel method and means for recording on a demagnetized paramagnetic body while operating on a substantially linear residual magnetization curve.

A still further object of the present invention is to provide a novel method and means of magnetically recording on a magnetizable body which includes simultaneously impressing a high frequency alternating current and the wave to be recorded thereon.

Still another object of the present invention is to provide a novel method and means for straightening out the lower knee in the residual magnetization curve of the magnetizable body.

Another and still further object of the present invention is to provide a novel recording and reproducing head in a system where voice or other sound waves are magnetically recorded on a steel wire and reproduced therefrom.

Still another and further object of the present invention is to provide a novel magnetic recording system in which the recording head is energized by a high frequency alternating current connected in parallel with the fluctuating electric current produced by the sound to be recorded.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization, manner of construction, and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in connection with the accompanying drawings, in which:

Figure 1 is a diagrammatic view of a recording head and the associated system for magnetic recording and reproduction;

Figure 2 is a diagrammatic illustration of the magnetizing current in the recording head which results from the superimposing of the high frequency wave on the voice wave;

Figure 3 is a diagrammatic illustration of a high frequency wave which is modulated by a low frequency wave and illustrates the contrast between what takes place in the recording head as shown in Figure 2 and a conventional modulated high frequency carrier wave as shown in Figure 3;

Figure 4 is a residual magnetization curve of a demagnetized paramagnetic body and is a typical residual induction curve;

Figure 5 is a residual induction-demagnetization force curve of a saturated paramagnetic body and illustrates the effect of demagnetizing forces on such a saturated body;

Figure 6 illustrates the major hysteresis loop, the initial magnetization curve, and a few of the minor hysteresis loops of a paramagnetic body subjected to a magnetic field which is excited by a high frequency electric current connected in parallel with the fluctuating current resulting from the sound wave to be recorded;

Figure 7 is an enlarged view of the minor hysteresis loops on the initial magnetization curve of a paramagnetic body subjected to the influence of a magnetic field produced in accordance with the teachings of the present invention;

Figure 8 is a magnetization curve and illustrates how a paramagnetic body subjected to the magnetizing effect of the recording head and then withdrawn from the head always causes the same amount of residual magnetism irrespective of what point on the major hysteresis loop you start on and irrespective of the divergence of paths followed prior to arriving at the ultimate residual magnetization point;

Figure 9 illustrates the effective magnetization curve of a paramagnetic body subjected to the influence of the recording head of the present invention and which is plotted through the ultimate residual magnetization point of the minor hysteresis loops caused by the presence of the high frequency current.

Referring now to Figure 1 of the drawings, I have illustrated diagrammatically therein a recording head 10 which includes a laminated iron core 11 having end legs 12 and 13 provided with air gaps 14 and 15, respectively, and a pair of confronting tapered head portions 16 which are also provided with a suitable air gap 17 therebetween. Coils 18 and 19 are mounted on the legs 12 and 13, respectively, and completely cover the air gaps 14 and 15. A coil 20 is mounted on the tapered head portions 16 and also covers and completely surrounds the air gap 17. The coils 18, 19 and 20 are preferably connected in series as shown. This type of recording head construction is described and claimed in the copending application for "Recording and reproducing of vibrations," U. S. Serial No. 356,324, of which I am a joint applicant, and which is assigned to the same assignee as the present invention.

One end of the group of coils 18, 19 and 20 is connected by a conductor 21 to a junction point 22 and the other end of the group of coils is connected by a conductor 23 to the junction point 24. Junction points 22 and 24 are connected by conductors 25 and 26 to a source of high frequency current 27. It has been found in practice that a convenient value for the high frequency component is 16 kilocycles. Junction points 22 and 24 are also connected by conductors 28 and 29 to the amplified output of the pickup means which receive the sounds to be recorded, diagrammatically illustrated as at 30. A by-pass condenser 31 which freely passes the high frequency wave from the high frequency source 27 is provided in the circuit of the conductor 25 to prevent any low frequency component from the voice source 30 from passing to the high frequency source 27. An inductance coil or filter 32 is inserted in the circuit of the conductor 28 which freely passes the low frequency or audio wave but which prevents passage of any high frequency component to that portion of the circuit diagrammatically illustrated as at 30.

An erasing coil 33 may, if desired, be connected to the high frequency source 27 through a switch 34, although it has been found in practice that this is not necessary.

It is to be clearly understood that the connection of the high frequency source 27 in parallel with the voice source 30 for energizing the magnetizing coils 18, 19 and 20 of the recording head produces an exciting current of the type shown in Figure 2 in contrast to the typical high frequency modulated carrier wave, as shown in Figure 3.

A paramagnetic body, which in this case is illustrated as a steel wire 35, passes through the erasing coil 35 (if one is used) and then directly through the recording head 10. A suitable aperture being provided through the recording head for this purpose.

Figure 4 is a graph showing residual induction in kilogauss plotted against the magnetization force of the field in oersteds. The curve shown in full line is the characteristic initial magnetization curve of a soft steel wire, while the dotted line curve is the central portion of the initial magnetization curve of a high carbon steel wire having a diameter of .005 of an inch, such as may conveniently be employed with the record medium 35 which passes through the recording head 10. These curves were obtained by plotting residual flux density (B_R) left in the originally demagnetized wire after the wire has been subjected temporarily to the influence of a magnetic field (H) of the values indicated.

It will be observed that the magnetization curve of Figure 4 passes through the zero position of the graph and that close to the zero position there is a sharp knee or bend for both positive and negative applications of the magnetization force H. That is to say, starting with the zero position on the graph and considering positive values of H, the slope of the curve is initially very small and then suddenly passes a sharp knee 36 in the curve and then rises with a steep slope as at 37 and finally moves into another gradually rounded curve portion 38. The curve has a similar shape for negative values of H and includes a sharp knee portion 36′, a steeply sloping and slightly curved portion 37′, and a gradually rounded curved portion 38′.

Should the high frequency source 27 of Figure 1 be disconnected from the recording head and the demagnetized wire 35 thereafter passed through the head 10, the portion of the magnetization curve shown in Figure 4 which would be operated on, would be within the range of the portions 37, 36, 36′ and 37′ of the curve. Since this portion of the curve is badly non-linear near its central portion, it is obvious that great distortion would result.

Should the wire 35 be saturated and then passed through the magnetic recording head 10, with the high frequency source 27 still disconnected, the characteristic residual magnetization curve would assume a shape similar to Figure 5. Figure 5 represents the plot of a curve of residual magnetism where a paramagnetic body was originally saturated to 10 kilogauss and then an oppositely directed weaker magnetic field of the amount indicated by H applied thereto. As is clearly shown in Figure 5, the curve starts down from this saturated point in a steeply sloping slightly curved portion 39 and then merges into a broad knee 40. This curve illustrates the characteristic underlying operation of the prior art system which record on a magnetically saturated paramagnetic body by applying a weaker oppositely directed magnetic field thereto.

When a system such as that diagrammatically shown in Figure 1 is employed, the characteristic residual magnetization curve is like that shown in Figure 9. Figure 9 is a curve resulting from a plot made when a high frequency exciting current is superimposed on the voice wave or audio exciting current. As is clearly seen from an inspection of Figure 9, the curve does not have the characteristic knee such as that shown in Figure 4. The curve in Figure 9 is substantially a true straight line that passes through the zero position of the graph, as at 41, until it reaches the broad knees 42 and 43, thereby operating on the linear portion of the curve. In other words, operating within a field intensity range of plus or minus 5 oersteds, substantially distortionless recording on the iron wire 35 which passes through the recording head 10.

The high frequency component of the exciting current, if sufficient magnitude is applied, automatically removes all previous magnetization from the wire at the same time that it records the new one. This eliminates the need of a separate erasing coil 33 (i. e., a coil for demagnetizing the wire). This has many important advantages in certain applications, one of which being that it allows recording in either direction and makes it unnecessary to re-reel the wire before recording again.

If the intensity of the high frequency component is relatively low, it has been found desirable, under certain circumstances, to employ a separate erasing head 33, which is connected to the high frequency source through a switch 34. When the erasing head 33 is employed the switch 34 is closed and the wire is then passed through the erasing head 33 first, before it passes through the recording head 10.

While the method and means of carrying out my invention are clear from the above description, an explanation will now be made of why a residual magnetism characteristic curve is obtained, having a truly linear central portion.

Referring first to Figure 6 of the drawings, the dotted line 44, 45 indicates a hysteresis loop of the same paramagnetic body as that employed for deriving the full line curve of Figure 4 or the curve of Figure 5. What would normally be the initial magnetization curve of this hysteresis loop 44, 45 is indicated by the full line 46. When the paramagnetic body is placed in a magnetic field produced by a coil excited with a high frequency current connected in parallel with the fluctuating audio current, the field varies between maximum and minimum limits and, accordingly, will produce minor hysteresis loops 47 and these minor hysteresis loops 47 will extend between the maximum and minimum values of H. The minor loops will be substantially within the boundaries of the major loops. The location of one or the minor hysteresis loops 47 will depend upon the location of the average value of H, and the upper apex of each minor hysteresis loop 47 will fall substantially on the initial magnetization curve 46, as shown in Figure 6. Due to the fact that the average value of H is constantly changing due to the fact that the fluctuating voice current is connected in parallel with the high frequency exciting current, there will be substantially an infinite number of possible minor hysteresis loops 47.

Figure 7 is an enlarged chart indicating a representative group of minor hysteresis loops 47 resulting from a high frequency field which is adjusted in this instance to cause the audio field to be rapidly varied plus and minus 8 oersteds from its mean value. The series of minor hysteresis loops 47 are traced by a curve which may be traced through the points 48, 49, 50, 51, 52, 53, 54, 55 and etc. For the purpose of readily identifying these loops I shall refer to the first minor hysteresis loop traced by the curve 48, 49, 50, 49, as loop A. The second loop I shall refer to as loop B, and the third loop I shall refer to as loop C.

The residual magnetism left in the paramagnetic body after the body is removed from the magnetic field may readily be determined, for all minor hysteresis loops whose minimum values of H are positive (such as loop C and all loops thereabove). More specifically, the residual magnetism left in the paramagnetic body will depend upon the maximum excited field force and this may be traced in the usual manner by plotting a major hysteresis loop beginning at the apex of the minor hysteresis loop and determining where the major hysteresis loop crosses the zero field axis.

For minor hysteresis loops which are established by an exciting magnetic field which varies between plus and minus values, it is important to note that the residual magnetism remaining in the paramagnetic body after the body is removed from the influence of the rapidly reversing magnetic field is always the same for any particular minor hysteresis loop, irrespective of what value of H is present, between its plus and minus limits at the moment that the paramagnetic body is withdrawn from the magnetic field. It must, of course, be remembered that the body never can be removed from the field instantaneously, but requires a finite period of time. In this connection, it should be noted that the field will fluctuate between a range of limits several at least, during the finite period of time that it takes to remove the body from the influence of the field.

Figure 8 shows the minor hysteresis loop B of Figure 7 on an enlarged scale, and in addition, shows, substantially the path followed when the paramagnetic body starts to leave the magnetic field when the magnetic field has its maximum relative positive value of H (the full line curve) and the path followed if the paramagnetic body starts to leave the magnetic field when the field is at its minimum relative value (as shown by the dotted line). More specifically, the flux density follows the full line curve 56, 57, 58, 59, and terminates on the zero field axis at the point 60. In other words, 60 represents the residual flux density, or amount of residual magnetization in the paramagnetic body when the exciting magnetic field has been removed.

Now, if the paramagnetic body has been suddenly removed from the field when the field was at its maximum negative value, the flux density would change from 61 to 62 to 63 to 64, and terminate at the point 60, which is substantially the same point as was previously found when the paramagnetic body was withdrawn from the field when the field was at its maximum positive value. It has been further found that the amount of residual magnetism is substantially the same for any given minor hysteresis loop, irrespective of what the value of H is between its maximum and minimum limits at the moment when the body is withdrawn from the field. Since it is the residual magnetization of the paramagnetic body which we are interested in for recording, we find that the presence of the high frequency exciting current has not given rise to any uncertainty as to what the value of the residual magnetism will be depending upon what moment the paramagnetic body is withdrawn from the magnetic field.

Since it is the residual flux density, or residual magnetism, of the paramagnetic body which is the sole criterion for determining faithful recording, there is shown in Figure 9 a curve of residual flux density plotted against average values of the magnetic field force. The great difference between the curves of Figure 9 and either the curves of Figures 4 and 5, lies in the fact that the curve is substantially a straight line through the zero axis of the magnetic field, and completely eliminates the lower abrupt knee in the curve of Figure 4 and overcomes the lack of symmetry in Figure 5 which produces second harmonic distortions. Since the operating characteristics of the system herein described involves operation on a strictly linear portion of the residual magnetization curve, it is apparent that faithful recording of sound vibrations is obtained.

The above described system contains all of the advantages of working on a demagnetized paramagnetic body and at the same time eliminates the heretofore great disadvantage of operating on a non-linear portion of the residual magnetization curve. The system, as described in the present application, has been found in practice to be substantially free from noise and distortion such as that caused by flutter of the wire in the recording head, or that caused by foreign particles which might become lodged therein. Another advantage is that the wire is always in a demagnetized state except when signals are recorded.

Due to the fact that the recording head is periodically energized by a strong high frequency field, it is kept in a demagnetized condition, and trouble caused by accidental magnetization is eliminated. It will furthermore be apparent to those skilled in the art that it need not be made of low retentivity iron, and materials of better saturation and mechanical properties may be employed.

The high frequency recording flux tends to "age" the retained magnetism in the wire, so that the record does not deteriorate with time or rough handling. It has still further been found in practice that the present system increases the dynamic range of recording on the wire beyond the amount possible without distortion by the earlier systems heretofore referred to.

While I have shown a particular embodiment of my invention and described a particular method of operation, it will, of course, be understood that I do not wish to be limited thereto, since many modifications may be made and I, therefore, contemplate by the appended claims to cover all such modifications as fall within the true spirit and scope of my invention.

I claim as my invention:

1. The method of magnetically recording sound on a paramagnetic body which includes longitudinally magnetizing the body by a rapidly fluctuating magnetic field, the range of fluctuation of the magnetic field being substantially constant but the average values of the field force being varied as a function of the sound vibrations to be recorded.

2. The method of magnetically recording fluctuating electrical energy on a paramagnetic body which includes passing the paramagnetic body through a high frequency magnetic field produced by the joint action of a high frequency exciting current and the fluctuating electrical energy, the direction of motion of the body through the field being parallel to the direction of the lines of force of the magnetic field.

3. A magnetic recorder for recording fluctuating electrical energy on an elongated paramagnetic body which comprises a pair of magnetic pole members through each of which the paramagnetic body is arranged to pass, a magnetizing coil associated with said pole members, means for energizing said coil with high frequency electric current, and additional means for also energizing said coil with the fluctuating electrical energy.

4. A magnetic recorder for recording sound vibrations on an elongated paramagnetic body which includes a pair of magnetizing pole members through which said body is arranged to pass and for longitudinally magnetizing the paramagnetic body, said members closely surrounding at lease a part of said body as said body passes therethrough, a magnetizing coil associated with said pole members, and means for connecting said coil directly to both a source of high frequency current and to a source of audio current produced by the sound vibrations to be recorded.

5. A magnetic recorder for recording sound vibrations on an elongated demagnetized paramagnetic body comprising a recording head which includes a core member of paramagnetic material, said core member including a pair of pole portions spaced from each other to provide a non-magnetic gap therebetween, an electric coil surrounding said tapered pole portions, said elongated paramagnetic body being arranged to pass through said pole portions and said gap, said coil being arranged to be energized jointly by a high frequency source and by a source of audio current whose signal strength is a function of the sound vibrations to be recorded.

6. The method of magnetically recording sound on a paramagnetic body which includes magnetizing the body by a rapidly fluctuating magnetizing field whose mean value is varied as a function of the sound vibrations to be recorded, and whose range of fluctuation from said mean value is in the neighborhood of twice the coercive force of the paramagnetic body.

7. The method of magnetically recording sound on a paramagnetic body which includes magnetizing the body by a rapidly fluctuating magnetizing field whose mean value is varied as a function of the sound vibrations to be recorded, and whose range of fluctuations from said mean value is approximately two and one-half times the coercive force of the paramagnetic body.

8. The method of magnetically recording sound on a paramagnetic body which includes magnetizing the body by a rapidly fluctuating magnetiz-

ing field whose mean value is varied as a function of the sound vibrations to be recorded, and whose range of fluctuations from said mean value is approximately two-thirds of the coercive force of the paramagnetic body.

9. The method of magnetically recording sound on a paramagnetic body which already has a previous magnetic recording thereon which includes passing said body directly through a high frequency magnetic field whose mean value is varied as a function of the sound vibrations to be recorded, whereby the previous recording on said body is erased simultaneously with the application of the new recording thereon.

10. The method of magnetically recording fluctuating electrical energy on a paramagnetic body which already has a previous recording thereon which includes superimposing a new recording directly on the old recording, said new recording being effected by passing the body directly through a high frequency magnetic field produced by the joint action of a high frequency exciting current and the fluctuating electrical energy.

11. A magnetic recorder for recording fluctuating electrical energy on an elongated demagnetized paramagnetic body comprising a recording head which includes a core member of paramagnetic material, said core member including a pair of pole portions spaced from each other to provide an air gap therebetween, an electric coil on said core member, said elongated paramagnetic body being arranged to pass through said pole portions and said non-magnetic gap, said coil being arranged to be energized jointly by a high frequency source and a source of audio current whose signal strength is a function of the energy fluctuations to be recorded.

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