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J. NEUFELD
TRANSDUCING SYSTEM TO COMPENSATE FOR
TORSION IN A MAGNETIC RECORD WIRE
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2,476,110

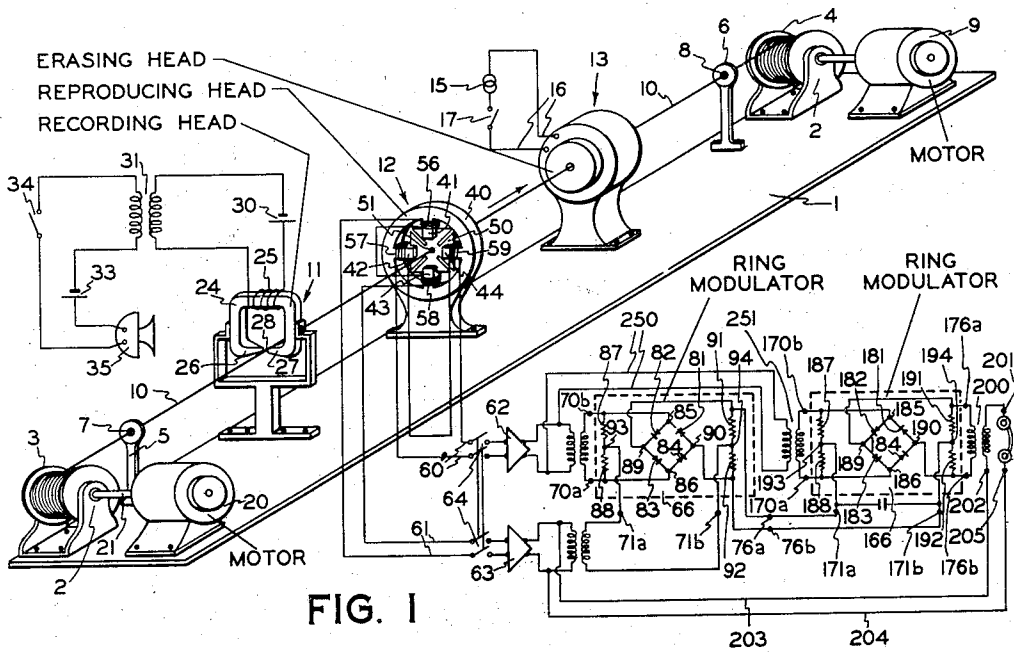


FIG. 1

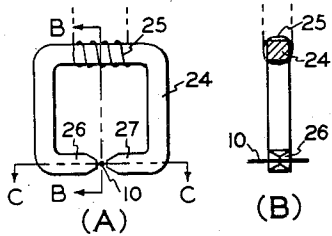
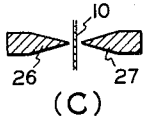
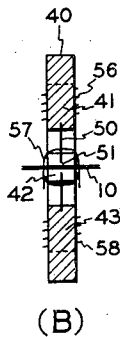


FIG. 2



(A)



(B)

FIG. 3

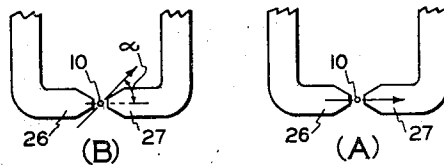


FIG. 4

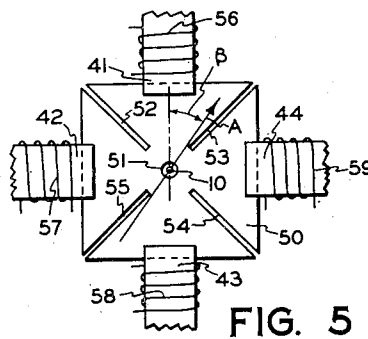


FIG. 5

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TRANSDUCING SYSTEM TO COMPENSATE
FOR TORSION IN A MAGNETIC RECORD
WIRE

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Application September 8, 1944, Serial No. 553,188

2 Claims. (Cl. 179—100.2)

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This invention relates to sound recording and reproducing apparatus of the magnetic type commonly referred to as the telegraphones, that is, apparatus in which the record is made on magnetic wire as variations in the magnetization thereof, the wire being unwound from one reel, drawn past recording or reproducing magnets and taken up upon another reel. The wire may be rewound by reversing the drive of the apparatus.

The art of magnetic recording upon movable wire or tape is very old and numerous arrangements for recording speech and music of highest possible quality have been attempted. In general, it is possible to distinguish two fundamental methods of magnetic recording: one involving "longitudinal magnetization" in which the direction of magnetization is substantially parallel to the axis of the movable magnetizable member and the other involving "perpendicular or transverse" magnetization in which the direction of magnetization is substantially perpendicular to the axis of the movable magnetizable member. (See for instance: "Sound recording on magnetic tape," by C. N. Hickman, Bell System Technical Journal, vol. XVI, No. 2, April, 1937, pp. 165-177.)

The earliest attempts of magnetic recording were of the longitudinal recording type in which a magnetizable member of round cross section, namely, a wire was magnetized longitudinally to a varying degree in accordance with the currents of the signal that it was desired to record. Although this method was workable and produced useful results, it was discovered by a number of workers that in order to achieve high quality, it was necessary to run the wire at relatively high speed, as high as 5 to 10 feet per second. Numerous efforts were made to produce an instrument that would involve lower speeds of wire, and in that connection it became apparent that it was necessary to design a recording apparatus capable of magnetizing extremely short section of wire, of the order of only a few thousandths of an inch. During this research work it was discovered, that even though only a very short section of the wire was exposed to a magnetic field, a somewhat longer section tended to become magnetized, because the magnetism would spread longitudinally along the wire. Thus, if a magnetic recording head was provided that would record so, that only an extremely small portion of length of wire were exposed to the magnetic field, three or four times that length would become magnetized. This phenomenon was identified as "magnetic spreading."

In order to overcome the effects of magnetic spreading, a method of recording transversely was developed. Transversal recording has been heretofore accomplished on a steel ribbon or tape about .001 inch thick and .125 inch wide having

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its ends secured to suitable winding reels and passing between a pair of recording magnets (see for instance British Patent 389,117 or the aforementioned paper by C. N. Hickman). The pole pieces of the recording magnets were placed directly opposite each other, so that the magnetic pattern consisted of variations in the intensity of magnetization, the direction of the magnetization being substantially perpendicular to the surface of the tape, thus producing a transverse magnetization of the tape. In transverse magnetization the flux in the tape is in the direction of its thickness, i. e. it is perpendicular to the axis of the movable tape. In other words, a tape so magnetized may be thought of as a series of elemental magnets .125 inch wide and .001 inch long, as contrasted with a tape longitudinally magnetized by poles spaced along the tape. In case of longitudinal magnetization, the flux in tape is in the direction parallel to the axis of the tape, i. e. the elemental magnets will have a length equal to the distance apart of the spaced magnet poles measured along the longitudinal axis of the tape.

Because of the geometry of the arrangement, the phenomenon of "magnetic spreading" has been substantially eliminated in the transversal magnetic recording upon tape. The method of transversal recording on tape has also gone through a very thorough development, and at the present stage the transversal recording on tape is very much superior in the quality of reproduction to the longitudinal recording on a thin wire.

When comparing the quality that can be achieved with any recording method, it is important to compare the performance for a given speed of the medium on which the record is being made. Obviously, it is possible to record higher frequencies by running the apparatus faster, but at a given speed different methods would be capable of recording a different range of frequencies, and for purposes of comparing one method to another it is important to keep this in mind. The best apparatus developed for recording transversely on steel tape is capable of recording frequencies up to 8000 cycles per second for a tape speed of 16 inches per second, (see the above referred to article by C. N. Hickman). Whereas, the most highly developed longitudinal recorder requires a wire speed of 75 inches per second in order to reproduce frequencies up to 8000 cycles per sec. This represents a very substantial difference, and this difference is mainly due to the fact that, in the one case there was no magnetic spreading longitudinally, while in the other case there was.

Despite this large difference in performance, the magnetic recording apparatus utilizing a thin wire is receiving a wide recognition and is ex-

tremely useful, because the mechanical problems in handling wire are very much easier to solve than the mechanical problems in handling a steel tape. Wire can be wound upon a spool comparatively easily with little danger of kinking; whereas, tape requires special guiding mechanism and has to be very carefully layer wound; otherwise, kinking and tangling occurs. Because of these difficulties, the storage reels on which a steel tape is wound usually are considerably larger than the storage reels on which the same length of wire has been wound. This very much greater mechanical convenience for handling wire as compared to tape or ribbon accounts for the fact that wire recorders are in use today despite the fact that the performance that can be achieved with wire recorders for a given speed of wire is very much inferior to that that can be achieved with tape recorders for the same speed of tape. As pointed out above, for a given speed, the wire recorders are about one-fourth as good as the tape recorders. However, the handling of the wire is so much easier and, therefore, this compensates for this factor of four and makes the wire recorder still competitive.

It is apparent, therefore, that great advantage could be derived from an instrument that would combine the merits of wire recording with the merits of tape recording, or transversal recording. In this case the mechanical convenience of handling a member having round cross section would be retained, and at the same time, the advantages of slow speed for a given quality would be retained.

Whereas, it is perfectly feasible to record transversely on wire with the same faithfulness that it is possible to record transversely on ribbon, the reproducing problem is very much complicated by the fact, that the wire twists, and that at certain times during the reproducing process the magnetism on the wire is directed in a direction such, that the pickup device responds very unfavorably. In fact, under certain conditions, the magnetism in the wire can be oriented accidentally exactly at right angle to the direction for which the reproducing device is set, in which case the reproduction will be completely absent, i. e., the pickup device will not respond to the magnetization of the wire and will produce zero voltage. One of the reasons, in fact, for employing steel tape instead of wire is to prevent the twisting, the steel tape being held mechanically between proper supports which present it to the reproducing head always in a given orientation. Because of the round cross section of the wire it is not possible to hold the wire always in one position and twisting is absolutely unavoidable. Numerous efforts have been made to get around this difficulty, but without success, because it is impossible to design a reproducing head that will uniformly respond to the transverse magnetism in the wire, irrespective as to whether the twisting of the wire takes place or not. No matter what kind of a magnetic circuit is employed, there always appears to be an angle in the orientation of the magnetism of the wire at which the reproducing device will give zero response. When the wire twists through the range that comprises this orientation, the reproduction is totally absent and only the noise due to the magnetic irregularities of the wire remains.

This invention describes a means for picking up transverse magnetism in the wire irrespective of orientation. The principle consists in providing a pair of pickup magnetic circuits or coils set

at right angles one to another, so that when the voltage picked up by one coil is zero, the voltage picked up by the other is maximum. Consequently, one of the pickup coils will at all times be responsive to the transverse magnetism of the wire, irrespective of the orientation of the wire cross section with respect to the pole pieces of the reproducer. Another feature of this invention consists in the provision of special electronic circuit that will always connect the two pick-up coils in such a manner as to always produce an arithmetical (not an algebraical) summation of their respective outputs. Thus, the signal from one pick-up is automatically added, so as to aid the signal picked up by the other pickup. This action is entirely automatic and, consequently, the wire can twist quite rapidly and a good reproduction is continuously obtained, because at all times both pickup devices are made to act together in the most favorable manner. By providing this arrangement, it is possible to combine all the advantages of recording upon a thin wire, such as ease of handling, cheapness, the general availability of the very long stretches of wire, etc. with all the advantages of recording upon a tape, such as high quality per unit of speed. Consequently, the present invention represents considerable advantage over the art, because it makes it possible to employ now wire recording and run the wire at a speed of only one-fourth the speed that was necessary previously for the same results.

In accordance with a specific feature of this invention, the record is made on a very thin slowly moving magnetic wire having high magnetic retentivity by employment of transverse magnetization. The transverse magnetization is induced by means of pole pieces contacting or nearly contacting either side of the wire, the pole pieces being made of laminations of magnetic material of high magnetic permeability, high resistivity and very low retentivity, and being tapered on one end so that the portion adjacent the wire is in the form of a very thin lamination perpendicular to the axis of the wire.

A shortcoming of magnetic sound recording methods and apparatus as known heretofore has been that, in order to secure recordation of all of the desired frequencies, the magnetic recording wire had to be driven at such a high speed that it was not possible to make a continuous recording of a desirable duration on a convenient length of the recording wire or tape.

It is accordingly a primary general object of the present invention to provide a magnetic recording machine and method, in accordance with which a recording of comparatively long duration may be made on a recording element of a normal or convenient length.

Other objects and advantages of the invention, will be apparent from the following specification when taken with the accompanying drawings in which:

Fig. 1 is a diagrammatic view of a recording and reproducing apparatus showing means for making a record upon a movable wire, means for erasing the record from the wire, and means for effecting the reproduction of speech from the record.

Fig. 2 shows diagrammatically the front and cross sectional views of an element of the apparatus that is used for effecting recording only.

Fig. 3 shows diagrammatically the front and a cross sectional view of an element of the apparatus that is used for effecting reproduction only.

Fig. 4 shows certain geometrical relationship

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between the wire and the pole pieces of the recording electromagnet during the process of recording.

Fig. 5 shows certain geometrical relationship between the wire and the pole pieces of the reproducing electromagnet during the process of reproducing.

The apparatus shown in Fig. 1 is provided with a supporting base 1, bearing members 2, and spools 3, 4 which are journaled in these bearing members. Upright guide members 5 and 6 are provided and these guide members are provided respectively with slots 7, 8 for the passage of the recording wire. At the commencement of a recording operation a spool of wire 3 is provided; the spools 3 are kept in stock and are ready for operation. The wire 10 is drawn off of the spool 3 and wound upon the spool 4 by any suitable motive power such as the motor 9. When the wire is passing from the spool 3 to be wound on spool 4, it is drawn through slot 7 in upright member 5 and it passes a series of electromagnetic devices. The first electromagnet 11 is provided for recording magnetically sound upon the wire and is designated as "recording head." The second electromagnet 12 is provided for reproducing sound from the magnetic recordings on the wire, and is designated as "reproducing head." The third electromagnet 13 is provided for the purpose of erasing the magnetic recordings from the wire, and is therefore designated as "erasing head."

In order that a record may be erased from the wire, the electromagnet 13 is supplied with current from a source 15 by means of conductors 16. A switch 17 is also provided to complete the circuit at will. When current is supplied to the electromagnet 13, the wire passing between the poles is left in a uniform and demagnetized condition.

The wire 10 is moved in the direction indicated by the arrow, regardless whether a record is to be made or if a record is to be reproduced. For instance, in cases that almost the entire recorded wire has been wound on the spool 4, a back winding thereof to the spool 3 is necessarily required before the reproduction of this record or records can be commenced. This backwinding is accomplished by means of a motor 20 adapted to drive the spool 3 through the shaft 21.

The recording head 11 consists of an electromagnet having an iron core 24 and a winding 25 wound around the core 24. The core 24 is provided with two pole pieces 26 and 27, immediately adjacent one to another. The pole pieces are provided with sharp edges in form of knife blades in order to localize within a narrow zone of exploration the flux that passes between them. The narrow air gap between the pole pieces 26, 27 is designated by 28. The wire 10 is made to pass through the air gap 28 in such a manner, that the axis of the wire is perpendicular to the line joining the pole pieces 26 and 27. The winding 25 is connected through the battery 30 to the secondary winding of the transformer 31, the primary winding of which is connected through the battery 33 and the switch 34 to the microphone 35.

Fig. 2 shows diagrammatically the front view and two cross sectional views of the recording head 11. In particular, Fig. 2A shows the front view, Fig. 2B shows the cross section through a plane passing through the axis of the wire and perpendicular to the line joining the pole pieces 26, 27 and Fig. 2C shows the cross section through

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a plane passing through the axis of the wire and the line joining the pole pieces 26, 27.

It is apparent, that, as the wire 10 is moved in the direction of the arrow, as described above, it is brought to a very high transverse magnetization by the flux set up between the pole pieces 26, 27. By "transverse magnetization" it is meant that the flux in the wire is in the direction of its thickness, i. e. it is perpendicular to the axis of the wire. In other words, a wire so magnetized may be thought of as a series of elemental magnets directed transversely to the axis of the wire, as contrasted with a wire longitudinally magnetized by poles spaced along the axis of the wire.

In the arrangement disclosed, the pole tips 26, 27 are very close, but not actually in contact with the wire, although in some instances an actual contact can be realized. An appreciable separation of the pole tips will, of course, materially reduce the efficiency of the system.

The reproducing head 12 is shown diagrammatically in Fig. 3. In particular, Fig. 3A shows the front view of the reproducing head and Fig. 3B shows the cross section through a plane passing through the wire 10 and through a line joining the pole pieces. The reproducing head 12 consists essentially of a ferromagnetic ring 40 with four protruding pole pieces 41, 42, 43, 44 directed towards inside of the ring, and of a thin ferromagnetic diaphragm 50 located in the central portion of the ring 40 and rigidly set into the pole pieces 41, 42, 43, 44. The diaphragm, pole pieces, and ring are all designed to be an integral unit. The diaphragm 50 is provided with a hole 51 just barely large enough to pass the wire 10 through the diaphragm, and is provided with diagonal cuts 52, 53, 54, 55. The purpose of the diagonal cuts is to produce a high reluctance path from one section of the diaphragm to another, and to help guide the magnetic lines through the pole pieces, and prevent it from short circuiting by the presence of a continuous ferromagnetic path. The pole pieces 41, 42, 43, 44 are provided with coils 56, 57, 58, 59, respectively. Coils 56, 58 are connected in series and coils 57, 59 are connected in series. These two pairs of coils are brought up to the lead wires designated as 60 and 61, respectively.

The outputs derived from the lead wires 60, 61 are respectively fed into conventional amplifiers 62, 63 through switch mechanism 64 and are applied to the input terminals of a ring modulator contained within the rectangle 66.

The ring modulator is well known in the art and has been described in the U. S. Patent No. 2,025,158, issued on December 24, 1935, to F. A. Cowan, and in an article by R. S. Carruthers on "Copper oxide modulators in carrier telephone systems," the Bell System Technical Journal, vol. XVIII, 1939, pp. 315-337. The type of the circuit contained in the dotted rectangle 66 is illustrated in Fig. 2c, page 318, of the said article. The ring modulator is essentially a double balanced modulator. By double balanced is meant a modulator in which each input is balanced out from the output, and the output contains therefore only the modulation products. The operation of a double balanced modulator shall be described hereafter.

In the ring modulator 66 two currents arrive from the leads 60, 61 and are respectively applied to the input terminals 70a, 70b and 71a, 71b, respectively.

It shall appear obvious in the subsequent description of my invention that when the magnetized wire 10 during its motion in the direction

of the arrow, passes through the opening 51, the coils 56, 58 and 57, 59 will respond to the varying magnetic field derived from the motion of the magnetized wire 10 and will produce two voltages across the windings of these coils, that are substantially proportional to the rate of change of the magnetic flux. These two voltages will be derived from each of the pairs of coils 56, 58 and 57, 59 and will be applied across the leads 60 and 61, respectively. It is apparent, that the magnitude of each of these two voltages will depend upon the orientation of the magnetism of the wire with respect to the pole pieces of the reproducing head 12, and since the wire twists, the magnetism of the wire may be directed in such a manner that one of the two pairs of coils 56, 58 and 57, 59 may respond very unfavorably. In fact, under certain conditions, the magnetism in the wire can be directed accidentally exactly at right angles to the axis of one of the pairs of coils, say to the pair of coils 56, 58. In this case the voltage generated by the coils 56, 58 will be zero because there are no flux linkages between the magnetic flux produced by the wire 10 and the coils 56, 58. However, at the same instant, the flux linkages between the magnetic flux produced by the wire 10 and the coils 57, 59 is at maximum, because the magnetism of the wire will have the same direction as the axis of the coils 57, 59. Consequently, the voltage generated by the coils 57, 59 will be maximum. It is therefore apparent, that, because of the twisting of the wire, the magnitude of the response of the coils 56, 58 and 57, 59 will continually vary and at any instant will be dependent upon the orientation of the magnetism of the wire with respect to the axis of the coils 56, 58 and 57, 59. Consequently, the two voltages derived from the coils 56, 58 and 57, 59 will be applied across the leads 60 and 61, respectively, and will have magnitudes depending upon the orientation of the magnetization of the wire (representing the speech signals) with respect to the axis of the coils 56, 58 and 57, 59, respectively. More particularly, each of these two voltages will have a magnitude representing the directional component of the speech signals impressed magnetically upon the wire 10, the said directional component being referred to the axial direction of the coils 56, 58 and 57, 59 respectively.

Consequently, we obtain across the leads 60 and 61, respectively, two voltages, each of said voltages representing the response of the corresponding pair of coils (56, 58 or 57, 59) to the varying magnetic field derived from the motion of the magnetized wire 10. It is apparent, that each of these two voltages will represent the facsimile of the speech signals impressed magnetically upon the wire and, consequently, these two voltages will vary with respect to time in a substantially similar manner. The only difference between the voltages across the leads 60 and 61, is the difference in intensity, since the intensity depends upon the orientation of the magnetism of the wire with respect to the axis of the coils 56, 58 and 57, 59, and because of the twisting of the wire, this orientation varies.

If, for instance, the orientation of the magnetism of the wire 10 is such as to make an angle of 45 degrees with the axis of the coils 56, 58, and 45 degrees with the axis of the coils 57, 59, then the signals derived from the leads 60 and 61 are equal in intensity. If, however, the orientation of the magnetism of the wire 10 is such as to make a smaller angle with the axis of the coils 56, 58, than with the axis of the coils 57, 58, the signal

derived from the leads 60 is weaker in intensity than the signal derived from the leads 61. Since, because of the twisting effect, the orientation of the magnetism continually varies, the relative intensities of the signals derived from the leads 60 and 61 vary in relationship to the twisting motion of the wire.

Consider now the effect of the voltages derived from the leads 60, 61 upon the modulator 66. As shown in the figure, the voltage derived from the leads 60 is applied across the input terminals 70a, 70b of the modulator, and the voltage derived from the leads 61 is applied across the input terminals 71a, 71b of the modulator. It is apparent, that the two input voltages applied across the terminals 70a, 70b and 71a, 71b represent the facsimile of the same speech signal and may differ one from another in intensity. It is also apparent that these two voltages may be applied to said terminals either in phase coincidence or in phase opposition, depending upon the orientation of the magnetism of the wire 10 with respect to the pole pieces of the reproducing head 12. Because of the twisting motion of the wire 10, the orientation of the magnetism continually changes, and consequently, as the reproducing process proceeds, the two input voltages applied to the modulator 66 are either in phase or in opposition. In the further description of my invention, I shall explain more in detail the geometrical relationships involved between the direction of magnetization of the signal impressed upon the wire and the orientation of the pole pieces of the reproducing head 12, and will show the particular orientations occurring during the twisting of the wire that shall correspond to the phase reversal of the input voltages of the modulator 66. These geometrical relationships shall be explained in connection with Fig. 5.

As is well known, one of the modulation products produced in the modulator 66 is the difference between the frequencies of the two applied input signals. In this case, however, the two signals have the same frequency, and consequently, the modulation product is a component having zero frequency and is therefore represented by a direct current. The polarity of this direct current depends upon the phase between the two signals supplied to the modulator 66 from the leads 60 and the leads 61. Assume that in the circuit shown the outputs of leads 60 and 61 are in phase. Then the output of the ring modulator circuit 66 will have a D. C. component such, that the polarity is so as to make the output terminal 76a positive and the terminal 76b negative. It is apparent, that when the phase between the voltages applied across input terminals 70a, 70b and 71a, 71b is reversed, the polarity of the voltage appearing between the terminals 76a and 76b will be reversed, i. e., 76a will be negative and 76b will be positive.

Consequently, we shall obtain across the output terminals 76a, 76b of the ring modulator 66 a D. C. voltage the polarity of which will depend upon the orientation of the magnetism of the wire with respect to the pole pieces of the reproducing head 12. Furthermore, during the reproducing process the twisting of the wire will cause a change in the orientation, and consequently, the polarity of the voltage across the output terminals of the modulator 66 will be subject to reversal in a definite relationship to the twisting motion of the wire.

The output terminals 76a, 76b of the ring modulator 66 are applied across the input terminals

171a, 171b of another ring modulator 166 in conventional fashion. The ring modulator 166 is structurally similar to the ring modulator 66, and the numerals designating various elements of the modulator 166 differ from the numerals designating the elements that are analogous in their functional performance in the modulator 66 by the numeral 100. Thus, for instance, in the modulator 166 the input terminals 170a, 170b correspond to the input terminals 70a, 70b in the modulator 66. Or, the rectifier bridge in the modulator 166 consists of rectifiers 181, 182, 183, 184, whereas the corresponding rectifiers in the modulator 66 are designated by numerals 81, 82, 83, and 84.

It is apparent, that voltage appearing across the output terminals 176a, 176b of the modulator 166 represents the modulation product of the respective input voltages applied across the terminals 170a, 170b and 171a, 171b, respectively. It is noted, that the voltage derived from the leads 60 is applied after amplification in the amplifier 62 through the leads 250 and the transformer 251 to the input terminals 170a, 170b, and the D. C. voltage derived from the output of the modulator 66 is applied to the input terminals 171a, 171b. Consequently, the output voltage derived from the terminals 176a, 176b represents substantially the product of the two input voltages.

It is of particular interest to note in this connection, that one of the input voltages applied to the modulator 166, namely the one applied across the terminals 171a, 171b, is always a D. C. voltage, the polarity of which varies in response to the twisting motion of wire 10. The other input voltage applied across the terminals 170a, 170b represents the signal induced by the moving wire in coils 57, 59 and is derived from the leads 60. It is apparent, that the output voltage derived from the terminals 176a, 176b represents the product of the two input voltages. Since in this case one of the inputs is represented by a D. C. voltage, the output will be substantially similar to the input voltage derived from the leads 60; however, the polarity of this output voltage will vary in direct relationship to the polarity of the input voltage applied across the terminals 171a, 171b. Consequently, the output voltage derived from the terminals 176a, 176b of the modulator 166 represents at any instant the signal induced by the moving wire in coils 57, 59 and the phase of this voltage will vary in response to the twisting motion of the wire 10. In particular, there will be a reversal in phase of the output voltage at any instant at which the twisting motion of the wire causes the reversal of polarity of the D. C. voltage applied across the input terminals 171a, 171b.

Consequently, for direct current applied across the terminals 171a, 171b the ring modulator 166 acts as a reversing switch, the reversals of which are determined by the changes in polarity of the voltage applied across the terminals 171a, 171b.

Therefore, when the terminal 171a is positive with respect to the terminal 171b, the ring modulator 166 makes a straight through connection between the input terminals 170a, 170b and the output terminals 176a, 176b. On the other hand, when the polarity of the terminal 171a is negative with respect to the terminal 171b, the ring modulator 166 provides a reverse connection between the input terminals 170a, 170b and the output terminals 176a, 176b.

The object of my invention consists in deriv-

ing the two voltages from the leads 60, 61 and adding them in such a manner that the resultant voltage is larger than any of the two component voltages derived from leads 60 and 61, respectively. Consequently, both component voltages should be arranged in series one with respect to another and have their polarities arranged in such a manner as to be in phase one with respect to the other. It is, however, apparent that the phase relationship between the voltages derived from leads 60 and 61, respectively, depends upon the twisting motion of the wire 10, i. e. there are some orientations of the wire magnetism with respect to the pole pieces of the reproducer 12, for which the voltages derived from leads 60 and 61, respectively, are in phase, and there are other orientations of the wire magnetism, for which these two voltages are in phase opposition. Therefore, I am employing the ring modulator 166 as a reversing switch in order to reverse the phase of the voltage derived from leads 60 for certain orientations of the wire 10 in such a manner that, irrespective of the twisting motion of the wire 10, the two voltages derived from leads 60 and 61, respectively, will always add together in a complete phase coincidence, so as to produce a resultant voltage that is larger than either of the two component voltages.

Referring now again to Fig. 1, it is seen that the input to the ring modulator 166 is supplied by part of the current derived from the leads 60, and the output of ring modulator 166 is applied through the transformer 200. The secondary winding of the transformer 200 is provided with two terminals 201 and 202. The terminal 202 is connected through the lead 203 to one of the output terminals of the amplifier 63, while the other terminal of the amplifier 63 is connected through the lead 204 to the terminal 205. Consequently, across the terminals 200, 205 there appears a voltage that represents the sum of the output of the amplifier 63 and of the output of the modulator 166.

It is therefore apparent, that the voltage derived from the terminals 200, 205 consists of a signal supplied by the output of the amplifier 63 connected in series with signal supplied from the output of the amplifier 62 and transmitted through the ring modulator 166 which acts as a reversing switch. The phasing of the whole circuit is adjusted so that, when the outputs of the amplifiers 62 and 63 are in phase the ring modulator 166 is polarized in such a way as to provide a straight through connection and, at the terminals 200, 205 appears therefore a signal representing the sum of voltages supplied by the leads 60 and 61. Furthermore, when the wire 10 twists, and as a result of that the phase between the voltages derived from the leads 60 and 61 reverses, the ring modulator 66 provides a polarizing voltage to the ring modulator 166 of such a polarity that the connections are reversed and again the voltage derived from the terminals 200, 205 represents the arithmetic sum of the voltages supplied by leads 60 and 61 respectively.

It is apparent, that when the device is in operation, the coils 57, 59 and 56, 58 are arranged to respond continuously to the magnetism of the wire and to produce the two component voltages applied to leads 60 and 61, respectively. It is also apparent, that as the wire twists, there are some orientations of the magnetism of the wire which cause either of the two component signals to be zero. There is, however, no orientation of the magnetism of the wire 10 which would cause

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both component signals to be zero simultaneously, since at the instant when one component signal is zero, the other is maximum. Consequently, the sum of the two component signals represented by the voltage across the terminals 200, 205 can never be zero. The two component signals are arranged to respond in such a manner so as to aid each other continuously. As the wire twists, the orientation of the magnetism changes automatically, and, under such conditions, the two components that are picked up by the pick-up device are both utilized and combined in the proper polarity to aid one another continuously. Furthermore, it is apparent, that the instant of the automatic switching action by means of the ring modulator coincides with the instant when either of the pairs of coils 56, 58 and 57, 59 supplies zero voltage. Consequently, the switching operation is noiseless and free from external disturbances.

Consider now more in detail the operation of the arrangement of Fig. 1, as a recorder and as a reproducer. The operation is controlled by three switch units designated by numerals 17, 34 and 64. When it is desired to impress sound upon the wire 10, the switch 17 controlling the erasing head 13 and the switch 64 controlling the reproducing head 12 are open, and the switch 34 controlling the recording head 11 is closed. The wire is assumed to be wound upon the spool 4 and the motion of the wire in the direction indicated by the arrow is being produced by unwinding the wire from the spool 3 and winding it upon the spool 4. Sound waves are arranged to impinge upon the diaphragm of the microphone 35 and cause motions in the electrodynamic transducing mechanism which generate electrical currents that are representative of the sound waves. The speech currents are transmitted through the transformer 31 to the winding 25 and produce in the air gap 28 separating the pole pieces 26, 27 a magnetic flux which is a reasonably exact facsimile of the sound waves that impinge upon the diaphragm of the microphone 35. Before the wire enters into the air gap 28, it is assumed to be in demagnetized condition. It is apparent, that an extremely small portion of the wire which at a given instant is in the direct neighborhood of the pole pieces 25, 27, becomes magnetized in the direction perpendicular to the axis of the wire and to the extent dependent upon the strength of the magnetic flux at the instant under consideration. Therefore, after this portion of wire has left the air gap and proceeds in the direction of the arrow towards the spool 4, a subsequent portion of the wire enters the air gap and becomes subsequently magnetized in the direction perpendicular to the axis of the wire and to the extent dependent upon the strength of the magnetic field in the air gap at said subsequent instant. Because of the magnetic retentivity, each element of wire, after having passed through the air gap acquires a magnetic moment which is vectorially located in a plane perpendicular to the axis of the wire and the direction of which is determined by the position of the pole pieces 26, 27 with respect to the cross section of the elemental wire at the instant it was subjected to the magnetic field. The geometric relationship showing the direction of the magnetic force with respect to the position of the pole pieces and the cross section of the wire at the instant of magnetization is shown in Fig. 4.

It is therefore apparent, that as the wire 10 moves in the direction of the arrow and becomes

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wound upon the drum 4, it acquires and retains a succession of magnetic moments directed transversely to the length of the wire and representing the speech currents applied to the air gap 28. In order to reproduce the speech thus stored upon the wire, a back winding upon the spool 3 is necessary by means of the motor 20. Subsequently, the wire is being moved again in the direction of the arrow and the unwinding motion of the drum 3 recommences.

We shall show at present that the magnetic structure represented by the head 11 can be used for recording of signals only, and cannot be used for the reproduction of the magnetic impressions from the moving wire 10. It is apparent, that when the magnetized section of the wire passes again through the air gap 28 of the electromagnet 11, the relative position of the retained magnetic moment with respect to the pole pieces 26, 27 is not any more the same as shown in Fig. 4A. Because of the twisting of the wire during its winding and unwinding motion, the cross section of the element of the wire that repasses through the air gap 28 does not occupy an identical position to the one during the instant of magnetization. The direction of the magnetic moment vector is usually inclined with respect to the axis joining the pole pieces by an angle that may be designated as α as illustrated in Fig. 4B. Consequently, the amount of flux interlinking with the coil 25 that is caused by the magnetic moment of the elemental wire depends upon the value α , where α indicates the relative value of twist, i. e. the change in angular displacement of the elemental section of wire at the instant it repasses through the air gap 28 as compared to the reference value of the angular displacement of the same section of wire at the instant at which the magnetic impression was made. When $\alpha=0$ or when $\alpha=180^\circ$, the magnetic flux derived from the wire and interlinking with the coil 25 is maximum, when $\alpha=90^\circ$ or $\alpha=270^\circ$, this flux is zero, and for any intermediate values of α this flux is between a maximum and zero. Consequently, the electromagnet 11 cannot be used for purposes of reproducing the signal impressed magnetically upon the moving wire 10, since, for some angular positions caused by the twisting of the wire there is no flux interlinking with the electromagnet 11, and, therefore, the electromagnet does not respond at all to the signal impressed upon the wire.

Therefore, in order to reproduce the signal impressed magnetically upon the moving wire 10, the switch 34 is open in order to render the recording head 11 inoperative, and the switch 64 is closed thus permitting the magnetized wire to energize the reproducing head 12.

The reproducing head 12 consists of two pairs of pole pieces 41, 43 and 42, 44 arranged at 90 degrees one with respect to another. Consider now the succeeding elemental sections of wire that traverse the opening 51 of the ferromagnetic diaphragm 50 of the reproducing head. Each of these sections will act as a small magnet and will supply a magnetic flux traversing the diaphragm 50, the pole pieces and the circular ring 40. It is therefore apparent, that the pair of pole pieces 41, 43 and the pair of pole pieces 42, 44 will each supply a convenient magnetic path for the changing flux resulting from the passage of the magnetized wire, and cause this flux to interlink with the associated coils. This changing flux generates two voltages in the pair of coils 56, 58 and in the pair of coils 57, 59,

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respectively, the magnitudes of these voltages depending upon the interlinking of the magnetic flux caused by the moving wire and the associated coils. Assume a more specific case in which the wire 10 passes through the hole 51 of the reproducing head. Let the relative position that the cross section of the wire occupies with respect to the pole pieces be the one shown in Fig. 5. As shown in Fig. 5, the magnetic vector of the elemental section of the wire has a direction represented by an arrow A and forms an angle β with the line joining the pole pieces 41, 43 and angle $(90-\beta)$ with the line joining the pole pieces 42, 44. It is apparent, that when $\beta=0^\circ$ or $\beta=180^\circ$ the magnetic flux created by the wire and interlinking with the coils 56, 58 is maximum whereas the magnetic flux interlinking with the coils 57, 59 is zero. On the other hand, when $\beta=90^\circ$ or $\beta=270^\circ$ the magnetic flux interlinking with the coils 56, 58 is zero and the magnetic flux interlinking with the coils 57, 59 is maximum. For intermediate values of β the magnetic flux interlinking with coils 56, 58 is proportional to $\cos \beta$ and the magnetic flux interlinking with the coils 57, 59 is proportional to $\sin \beta$.

The essential and fundamental feature of my invention consists in deriving by means of the reproducer 12 a signal that is substantially proportional to the magnitude of the magnetic effect stored in the elemental section of the wire, and that is substantially independent of the angle β . Such a signal is represented by the voltage derived from the terminals 201, 205, and it represents the result of the arithmetical addition of the two pick-up voltages that are derived from the coils 57, 59 and 56, 58, and that are applied across the leads 60 and 61, respectively. By an arithmetical addition I understand the addition in which both pick-up voltages aid each other, i. e. they are assumed to be always positive as if they were always aligned in phase. Whereas, in an algebraic addition the reversal of phase of one of the pick-up voltages changes the value of the sum, in an arithmetical addition the sum remains unchanged, because both pick-up voltages are made always to be positive, irrespective of their phase relationships and irrespective of their phase reversals. Consequently, in an arithmetical addition I am adding absolute magnitudes of the two pick-up voltages.

Consider now again Fig. 5, and assume that for the orientation of the wire indicated by the angle $\beta=\beta_1$ the voltages derived from the leads 60 and 61 are in phase. Then the polarizing voltage derived from the modulator 66 is such as to render by means of the modulator 166 a straight through connection for the voltage derived from leads 60, and, subsequently, both voltages derived from leads 60 and 61 are added, and provide across the terminals 201, 205 a composite voltage that is substantially equal to

$$K_1 \cos \beta_1 + K_1 \sin \beta_1$$

where $K_1 \cos \beta_1$ represents substantially the contribution picked up by the coils 56, 58 and derived from the leads 61, whereas $K_1 \sin \beta_1$ represents substantially the contribution picked up by the coils 57, 59 and derived from the leads 60. It is apparent that for $\beta=90^\circ$ the contribution derived from the leads 56, 58 is zero, whereas the contribution derived from leads 57, 59 is K_1 , and consequently, the composite voltage is equal to K_1 . If β is larger than 90° and is equal to, say, 90° , then the contribution picked up by the coils

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56, 58 and derived from the leads 61 is equal to $-K_1 \cos \beta_2$ (note the reversal of sign) whereas the contribution picked up by the coils 57, 59 and derived from the leads 60 is equal to $K_1 \sin \beta_2$. Under these conditions the voltages derived from leads 60, 61, respectively, are in phase opposition. Then the polarizing voltage derived from the modulator 66 is such as to render by means of the modulator 166 a reversed connection for the voltage derived from leads 60, and subsequently, both voltages derived from leads 60 and 61 are added, and provided across the terminals 201, 205 a composite voltage that is substantially equal to

$$K_1 \cos \beta_2 + K_1 \sin \beta_2$$

Assume now, that initially, the orientation of the wire corresponded to $\beta=\beta_1$. Then, as the wire progressed in the direction of the arrow, it underwent a twisting motion, and therefore assumed an orientation $\beta=90^\circ$ and a subsequent orientation $\beta=90^\circ+\beta_2$. Assume also, for the purposes of simplification of our reasoning, that the signal impressed upon the wire had a constant intensity that did not vary with time and that corresponded to the value K_1 .

Then the voltage derived from the terminals 201, 205 had an initial value $K_1 \cos \beta_1 + K_1 \sin \beta_1$ which became subsequently changed to the value K_1 and finally became $K_1 \cos \beta_2 + K_1 \sin \beta_2$. We may therefore state that, for any orientation that may occur during the twisting motion of the wire the value of the voltage is

$$|K_1 \cos \beta| + |K_1 \sin \beta|$$

where β may have any value between 0° and 90° . By inspecting this formula it becomes apparent that the output voltage derived from the terminals 201, 205 can never be zero. It is always contained between a minimum value of K_1 (corresponding to $\beta=0^\circ$) and a maximum value of $1.41 K_1$ (corresponding to $\beta=45^\circ$).

The wire may, of course, be operated at various speeds by merely varying the speed of the driving motor in any convenient manner. One notable feature of this system, however, is the slowness with which the wire can be operated to give satisfactory quality. At eight inches per second or even less, speech is not only intelligible but also of a very good natural quality and quite satisfactory for most purposes. For recording music or other sounds involving higher frequencies, a somewhat greater speed is desirable, if high quality is required.

The following paragraphs shall illustrate the manner in which the two input voltages influence the output voltage of the modulator 66, i. e. it shall be shown that when the two input voltages are in phase, the polarity of the output voltage is positive, and when they are out of phase, the polarity is negative.

Consider now the ring modulator circuit contained in the rectangle 66. The circuit shown therein comprises a bridge circuit consisting of four rectifiers 81, 82, 83, 84, each of the said rectifiers constituting a separate arm of the bridge circuit and arranged so that the current can flow only in an anticlockwise direction. The upper corner of the bridge 85 and the lower corner of the bridge 86 are respectively connected to the input terminals 70a, 70b and are also connected one to another by means of equal resistances 87 and 88 in series. The other corners of the bridge 89, 90 are respectively connected to the output terminals 76a, 76b, and are also con-

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nected one to another by a pair of equal resistances 91, 92 in series. The other input terminals 71a, 71b of the ring modulator are respectively connected to the point 93 connecting the resistances 87, 88 and to the point 94 connecting the resistances 91, 92.

With the circuit as described, current derived from the terminals 70a, 70b may flow either through the rectifiers 82, 83 or through the rectifiers 84, 81 depending upon its direction, but it can never flow through all the four rectifiers at the same time, since the rectifiers 82, 83 on one hand and the rectifiers 84, 81 on the other hand are arranged to flow in opposite directions.

Suppose now, for purpose of illustration, that the voltage derived from the terminals 71a, 71b and the unbalance voltage derived from the terminals 70a, 70b are simultaneously applied, and suppose that both voltages are in phase, i. e., the terminal 70b becomes positive as compared to the terminal 70a and at the same time the terminal 71a becomes positive as compared to the terminal 71b. Then one part of the current tends to flow from the terminal 71a to the terminal 93 and through the resistor 87 to the terminal 85 and then through the rectifier 82 and through the resistor 91 back to the terminal 71b. The other part of the current tends to flow from the terminal 71a to the terminal 93 and through the resistor 88 back to the terminal 86 and through the rectifier 84 and through the resistor 92 back to the terminal 71b. The currents flowing through the resistors 91, 92 are equal and of opposite directions.

It is apparent that, under the conditions described in the preceding paragraph, the polarity of the terminals 85, 86 will be positive with respect to the polarity of the terminals 90, 89. Consequently, positive voltages are applied to rectifiers 82, 84. Therefore, these rectifiers will lose their ability of rectifying currents, and will allow currents to traverse them in both directions. At the same time, negative voltages are applied to the rectifiers 81, 83. Consequently, the rectifiers 81, 83 will retain their rectifying ability and will block currents attempting to traverse them in the negative direction. Therefore, the rectifiers 82 and 84 are conductive in both directions, and consequently, when the unbalance voltage is being developed across the terminals 70b, 70a, we find that a current tends to pass from the terminal 70b to the terminal 85 and then through the rectifier 82 through the resistors 91 and 92 to the terminal 90 then through the rectifier 84 back to the terminal 70a. This current superposes itself upon the current which is already flowing through the resistors 91 and 92 and consequently the resultant current passing through the resistor 91 becomes larger than the current passing through the resistor 92; consequently, the balancing that existed before is offset because there is a situation where the current flow through the resistor 91 is increased as compared to the current flow through the resistor 92. Thus the voltage drop across the resistor 91 becomes greater and a positive overall voltage is developed across the terminals 76a, 76b. It can be also readily seen that when the unbalance voltage applied across the terminals 70b, 70a increases in magnitude the corresponding resultant voltage obtained across the output terminals 76a, 76b increases in magnitude also.

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It can be shown, that if the polarity of the first input voltage would reverse with respect to the second input voltage, i. e., if we suppose that the terminal 71a becomes positive as compared to the terminal 71b and the terminal 70b becomes negative as compared to the terminal 70a, then the balance becomes offset in the opposite direction, because there is a situation where the current flow through the resistor 92 is increased as compared to the current flow through the resistor 91. Then the voltage drop across the resistor 91 becomes smaller as compared to the drop across the resistor 92 and the overall voltage developed across the output terminals 76a, 76b has a polarity opposite to the case described above.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:

1. In a magnetic reproducing device for reproducing signals impressed magnetically upon a moving wire substantially transversally to said wire, said wire producing in its neighborhood a magnetic field that varies longitudinally in accordance with said signal and simultaneously varies as a function of the angular position of the wire, means responsive to the magnetic field as it moves in the neighborhood of a fixed point for developing two signals respectively representative of angularly displaced portions of the magnetic field at said fixed point, an electrical transducer, and a switching element inserted between said means and said transducer for variably connecting said means to said transducer.

2. In a magnetic reproducing device for reproducing signals impressed magnetically upon a moving wire substantially transversally to said wire, said wire producing in its neighborhood a magnetic field that varies longitudinally in accordance with said signal and simultaneously varies as a function of the angular position of the wire, means responsive to the magnetic field as it moves in the neighborhood of a fixed point for developing two signals respectively representative of angularly displaced portions of the magnetic field at said fixed point, an electrical transducer, a switching element inserted between said means and said transducer for variably connecting said means to said transducer, and means responsive to said signals for controlling said switching element.

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