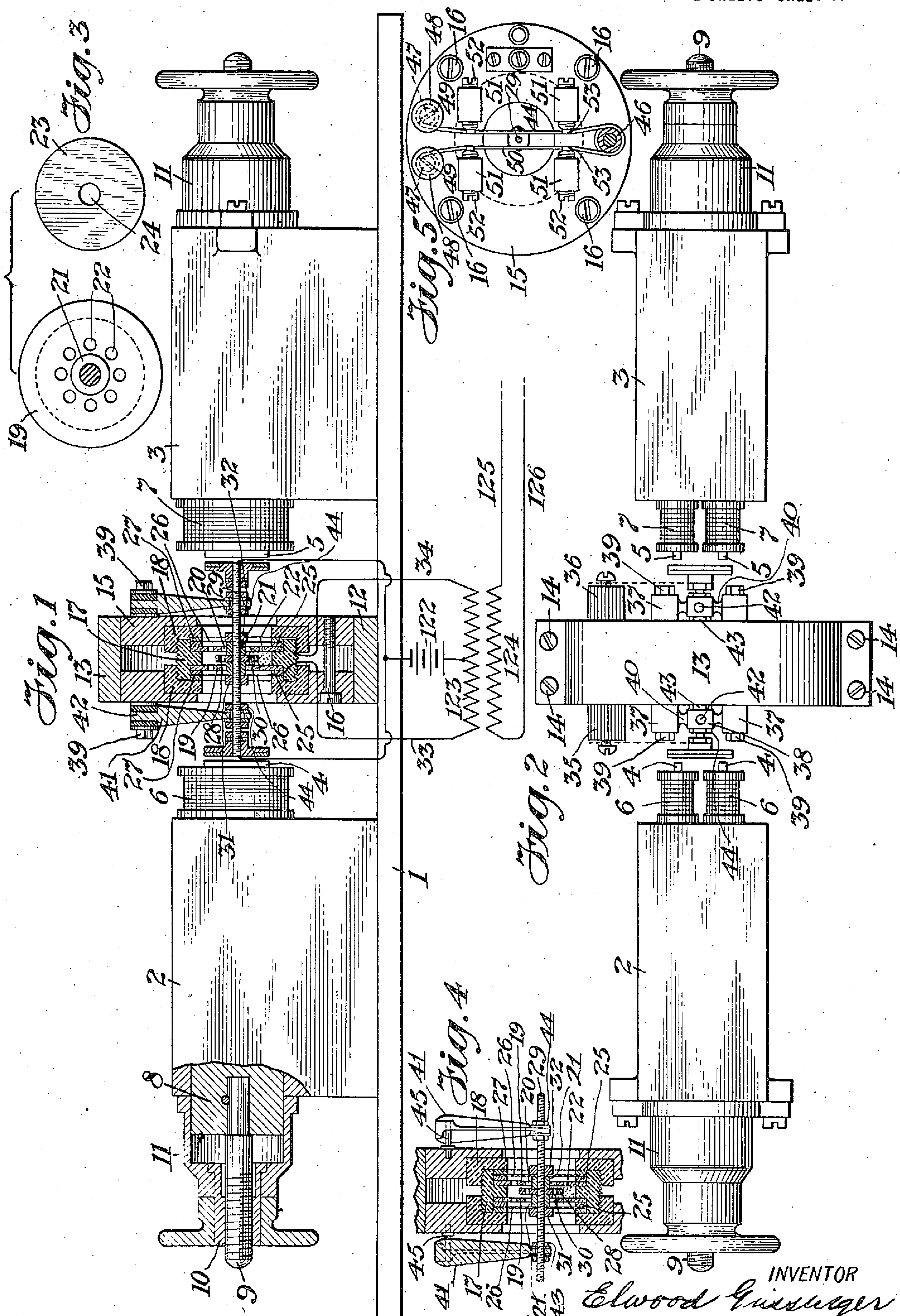
E. GRISSINGER.

TELEPHONE REPEATING SYSTEM.

APPLICATION FILED JUNE 3, 1916.

1,219,727. Patented Mar. 20, 1917.

2 SHEETS—SHEET 1.



INVENTOR
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2 SHEETS—SHEET 2.

Fig. 8

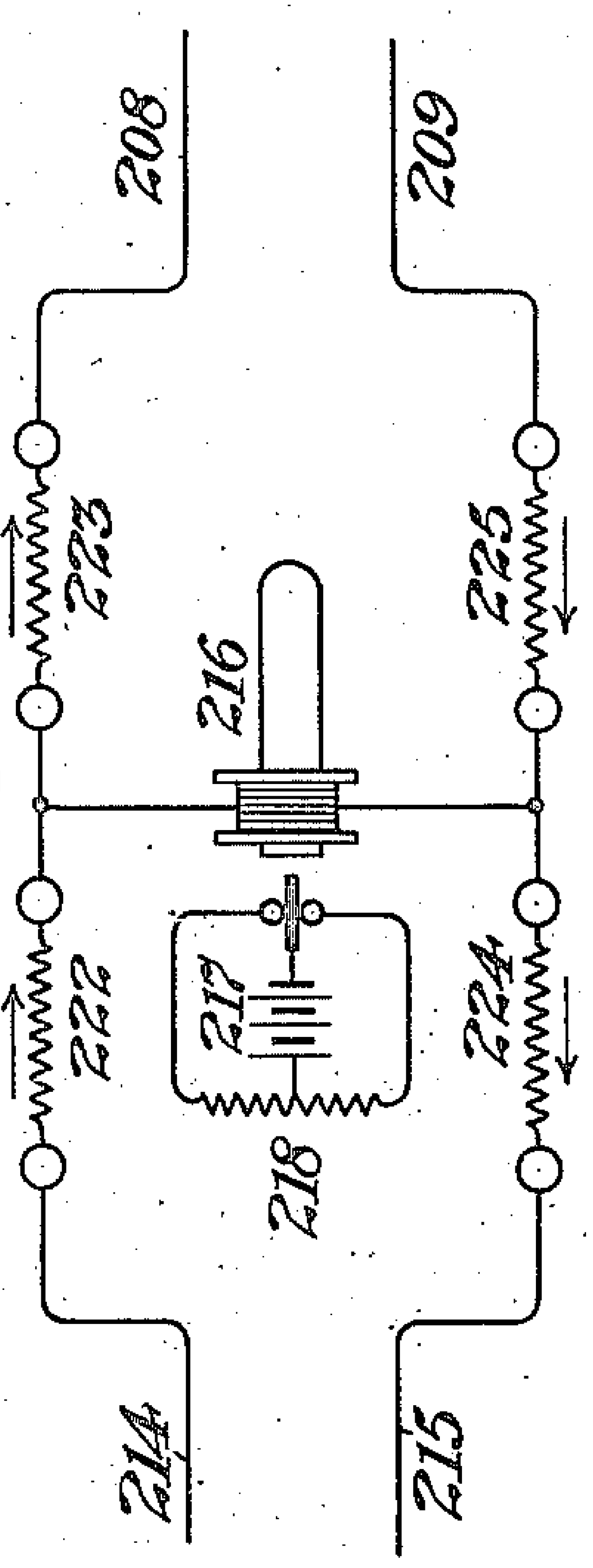


Fig. 9

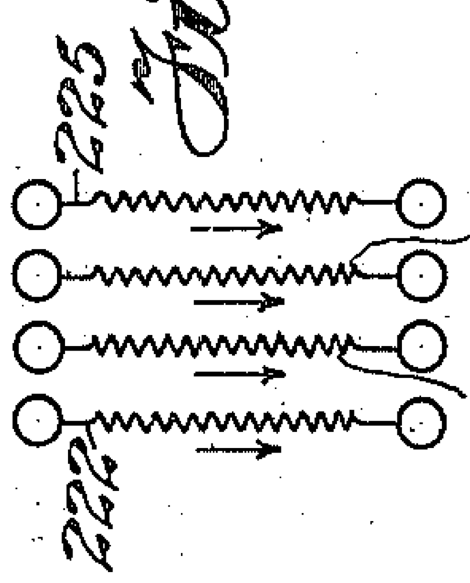


Fig. 7

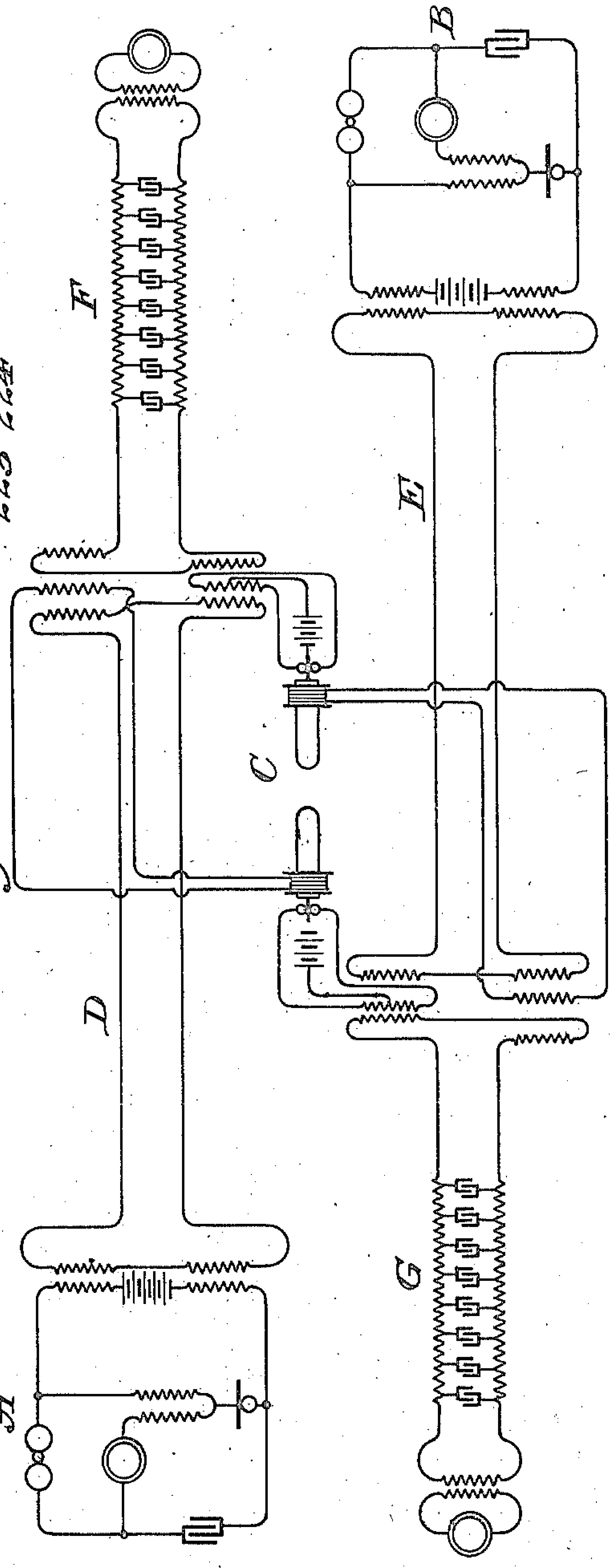
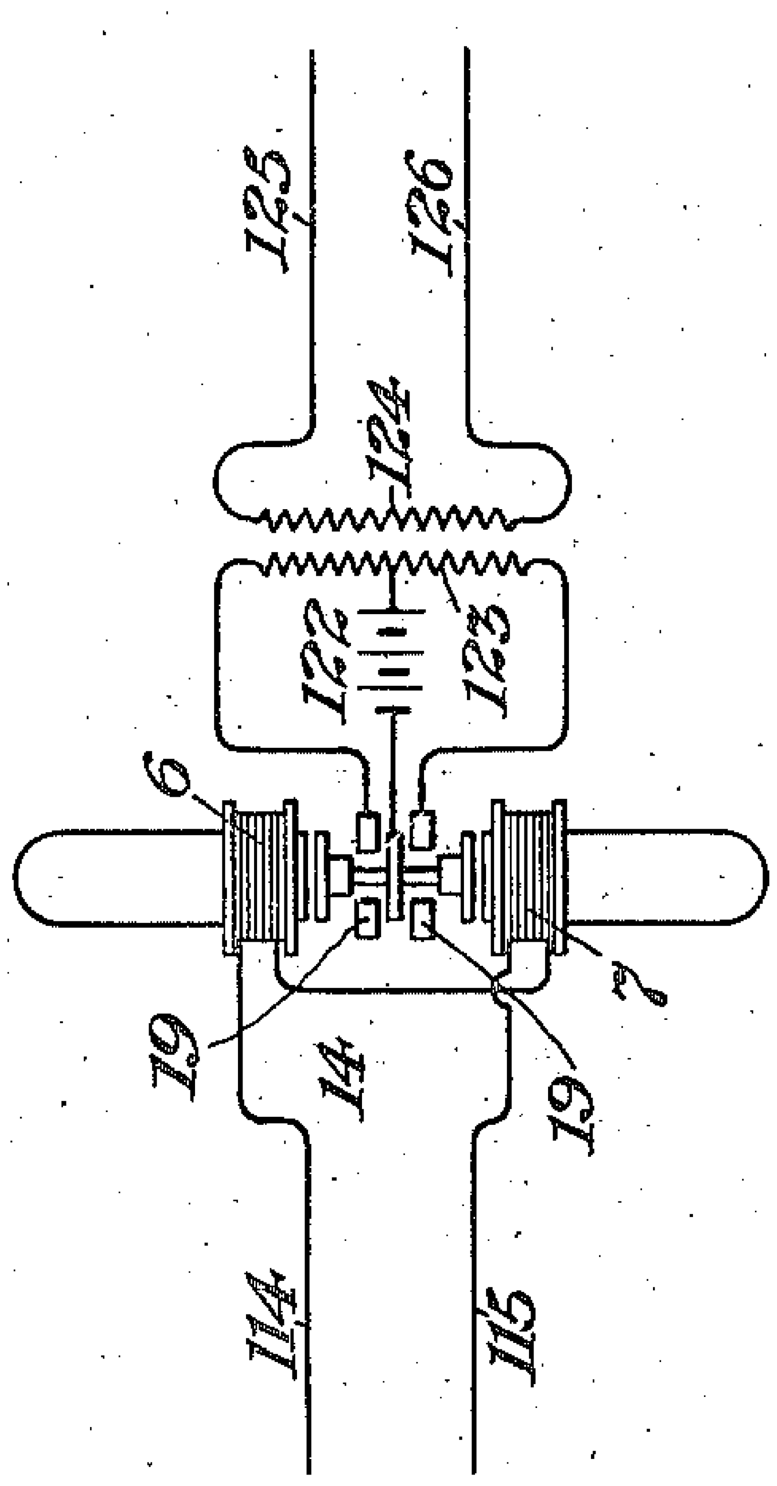


Fig. 6



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UNITED STATES PATENT OFFICE.

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TELEPHONE REPEATING SYSTEM.

1,219,727. Specification of Letters Patent. Patented Mar. 20, 1917.

Application filed June 3, 1916. Serial No. 101,453.

To all whom it may concern:

Be it known that I, ELWOOD GRISSINGER, a citizen of the United States, and resident of Buffalo, in the county of Erie and State of New York, have invented certain new and useful Improvements in Telephone Repeating Systems, of which the following is a specification.

This invention relates to telephonic speech transmission, with particular reference to long distance working; and it has for its object the increase in the length of lines over which speech can be successfully transmitted or the improvement in the efficiency of existing transmission circuits or both, coupled with the ability to reduce the investment and maintenance cost of transmission lines for the transmission of speech.

One object of the invention is to provide telephone repeaters in which the difference in phase between the exciting force (represented by speech waves) and the displacement of the vibratory system is controlled within a desired range.

Another object is to provide a reciprocal talking telephonic repeating circuit with twin repeaters, the repeaters so constructed and related to one another that, in respect to the displacement of the vibratory element of each repeater under the influence of speech waves (exciting forces), the relative differences in phase between the displacement of the vibratory system and the exciting force in each repeater will be approximately neutralized with reference to one another.

Another object is to provide a repeater for a reciprocal talking telephonic repeating circuit employing a single repeater connected in "booster" relation; the repeater so constructed that, in respect to the displacement of its vibratory element under the influence of speech waves (exciting forces), the difference in phase between the two will be such that the wave forms generated by the repeater because of the movement of its vibratory element, will the more closely coincide and hence be the more nearly accurately phased with the original waves traversing the main line circuit.

I employ repeater apparatus of the electromagnet-microphone type in which the mechanical vibrator or vibratory system has physical movements or vibrations corresponding to the electrical waves representing articulate speech; and a fundamental feature of my invention is so constructing this vibrator that it has a very definite free period or natural frequency of free mechanical vibration. Hence it will resonate strongly in response to exciting forces of frequencies approximating the natural frequency, and the resonant response will be greater according as the frequency of the exciting force more nearly approaches said natural frequency. Moreover, my construction is such that the vibratory system behaves like a theoretical vibratory system having only one degree of freedom, in that it has only one natural frequency range or region of resonant response below 2000 periods per second. Preferably, it is approximately 1000 periods or more per second. Where the repeaters are used in pairs they are constructed so that the corresponding parts of their respective vibratory system are substantially identical. Reference is made here to my Patents No. 1,203,325, dated October 31, 1916; No. 1,203,326, October 31, 1916; No. 1,198,345, September 12, 1916; and No. 1,205,618, November 21, 1916, on telephone repeaters and transmitters; in which patents I have carefully outlined the theory and practice of the fundamental characteristics of the vibratory elements of telephone apparatus. The present invention is closely related to the same subjects-matter.

Other features and objects of my invention will be evident from the following detailed description in connection with the accompanying drawings in which—

Figure 1 is a side elevation partly in section and Fig. 2 is a top plan view of a repeater adapted for the practice of my present invention.

Fig. 3 is a face view of details of the microphone shown in Fig. 1,

Fig. 4 is a detailed vertical section through a microphone cell similar to that shown in Fig. 1, but illustrating a different form of elastic suspension for the vibratory element of the microphone,

Fig. 5 is a face view illustrating a third form of suspension of the microphone cell,

Fig. 6 is a diagram illustrating some of the principles of my invention,

Fig. 7 is a diagram of a complete reciprocal two-repeater circuit in accordance with my present invention,

Figs. 8 and 9 are diagrams illustrating a modified arrangement of a repeater in booster relation to its circuit.

The repeater shown in Figs. 1 and 2 has the same general structural arrangement as that shown in my Patents No. 1,203,326 and No. 1,205,618, differing from the latter however in certain details of the microphone cell and the vibratory element therein. This repeater structure includes a relatively rigid base 1, of brass or similar material, standards 2 and 3 each carrying magnets preferably of the telephone receiver type having oppositely arranged pairs of poles 4—4 and 5—5, energized by coils 6—6 and 7—7. These magnets are carried by solid slides, as 8, which are accurately guided in said standards and adjustable by the screw threaded extensions 9 engaging nuts 10, swiveled in the stationary supports 11. These magnets afford a balanced magnetic field for the vibratory member of the microphone cell which is interposed between them.

The microphone cell is mounted in a standard of which the base section 12 and the top section 13 are secured by screws 14 constituting a circular clamping support for the rings 15, which, in turn, support and laterally clamp the microphone cell by means of screws, one of which is shown at 16.

The microphone cell has been designed to give compactness in structure, ease of assembly, cheapness of construction and what is more important, a material reduction in the mass or inertia of the movable element thereof.

It is composed of a central annulus 17 threaded exteriorly and made of bakelite or a similar insulating compound or synthetic composition. Caps 18—18 of the same compound are threaded one upon each end of the part 17. The part 17 has a central opening and two oppositely disposed recesses. In the recesses, carbon disks 19 are seated. These carbon disks are of such thickness as to be practically non-vibratory. Each such carbon disk has a clearance aperture 20, somewhat larger than the diameter of an aluminum lock nut 21. Each such carbon disk has also the clearance holes 22 placed there for the purpose of increasing the sensitiveness of the microphonic element and also to prevent what is usually termed packing. The outer side of each disk 19 is covered with a soft, thin silken disk 23 having a central opening 24. The silken disk is used for the purpose of preventing the carbon granules in the resistance chamber from coming through the holes 22. The central opening 24 of the silken disk is made just large enough so that it will fit closely over the aluminum lock nut 21. If desired, the silken disk could be dispensed with and a very light packing of cotton or similar material placed between the nut 21 and the inner edge of the clearance aperture 20 in the carbon diaphragm.

The silken disk may be pasted to the carbon disk 19 or it may be held in place on the surface of 19 by means of a second thin diaphragm as of mica.

Next the outside of each disk, is placed a ring 25 which is of brass or other conducting material. Next to the ring 25 is placed a thin mica or other moisture proof diaphragm 26 for the purpose of properly inclosing the microphonic element chamber and making the same airtight and moisture proof. On the outside of the mica diaphram 26 is placed a clamping ring 27. All of the parts 19, 25, 26 and 27 are securely and rigidly held in the annulus 17 by means of the caps 18. The inner side of the carbon disk 19 is highly polished.

A central carbon electrode 28, highly polished on both sides is mounted on a threaded aluminum alloy rod 29. A central hole in the carbon electrode is provided for this purpose. Clearance holes 30 are also placed in this central carbon electrode for the same reasons as stated for the clearance holes 22 in the stationary carbon electrodes 19.

The vibratory carbon electrode 28 is held securely on the rod 29 by means of the aluminum lock nuts 21. The last named lock nuts have their periphery coated with an insulating compound or layer to prevent the leakage of currents from them to the carbon granules in the microphonic chamber. A small central hole is provided in the mica diaphragm 26 for the passage of the rod 29. Lock nuts 31—32 of an aluminum alloy are threaded on the rod 29 and serve to bind the diaphragms 26 to the lock nuts 21 and thus support the movable electrode in the center of the microphonic chamber.

The spacers and washers noted as 25 and 27 may be made of metal, in which event leading in wires as 33 and 34 passing through openings in the part 17 are soldered to them constituting terminals of the primary or local circuit of the variable resistance medium. If the rings as 25 or 27 are made of bakelite or similar non-conducting material, as they may well be, then, the edge of the carbon disks 19 are preferably electroplated with copper, to which part, the leading in wires 33 and 34 can be soldered.

The complete element can be mounted in any of the suspension rings which I have shown in my patents, with the only difference that the rod 29 in the type shown herein need not be insulated from the rings, but may constitute a common electric terminal with said rings or with the base of the instrument. The two leads 33 and 34, are however, insulated from the rings and from the base of the instrument. Conducting connections for the purpose of carrying current to the movable electrodes are omitted in this design and lightness of weight for the vibrator is secured by using a single all carbon electrode. A further reduction in mass may be secured by making the movable electrode 28 in the form of a sector without sacrificing other qualities of the microphonic element.

The caps 18 may be sealed to 17 and to the rings 27 and the rings 27 may be sealed to the outer mica diaphragms 26. The nuts 31—32 can be sealed to the rod 29 and to the mica diaphragms. For this purpose I have successfully employed flexible collodion. This sealing is done to make the chamber airtight and moisture proof.

When in operative condition the granular variable resistance chamber is about half filled with granular carbon or some other similar variable resistance medium.

The means utilized in this form of transmitting element for a telephone repeater to raise the free period of the vibratory element to a desired periodicity, preferably approximating 1000 P. P. S. or greater, is a rod or equivalent member resisting displacement through torsional tendencies. The construction herein referred to comprises the rings 15, having the screws 16 for the fastening of one ring to another and the terminal blocks 35 having electrical connections such as 36. The ring is provided near its periphery at one side with projections or lugs 37. These projections have circular apertures through them to receive the enlarged portions or fixed diameters of torsion rod or tube 38. As more fully explained in my Patent No. 1,205,618, the enlarged portions of the torsion member have apertures extending through them so that such parts of the torsion member can be securely and rigidly fastened within the lugs 37 by means of screws 39 passing through the torsion member and engaging the lugs 37. The torsion member is also formed with a central portion of enlarged diameter with an aperture extending therethrough. Between the enlarged diameters the torsion member takes on a smaller diameter such as 40. A webbed leverage member 41, made from preferably an aluminum alloy and having a circular aperture in its free end, is securely and rigidly fastened to the enlarged diameter of the torsion member by a driving fit of the slightly tapered shank 42. The torsion member being securely fastened to the lugs 37 on the rings 27 any displacement of the smaller free end of the lever 41 is resisted by the torsional tendencies of the sections 40 of the torsion member. The lever and the torsion member being substantially rigid against transverse flexing or wabbling, and all the elastic flexing being substantially confined to the torsion around the axis of the rod or tube 38, and substantially localized at the points 40—40, the free or natural vibrations of the systems are substantially pendulum-like, or single-frequency, simple harmonic in character.

When it is desired to impose an initial strain upon the torsion member, such an effect can be produced by screwing the nuts 43—43 outward or the nuts 44—44 inward on the rod 29 against the lower extremities of the members 41—41, moving the companion nuts in either event correspondingly. By designing the torsion member properly with relation to the mass and inertia of the entire essential vibrating system, the resultant free period of such vibratory system can be made to equal or exceed 1000 P. P. S. The precaution to be observed is that there shall be no flexure in the member 41 or in the unclamped portions of the torsion rod 38. It is believed that the remaining operative characteristics of such a transmitting element have been fully set forth in my prior patents.

In Fig. 4, I have shown an arrangement wherein the transverse bending stress of a pair of steel pins 45—45 is used as the elastic element of the vibratory electrode system, the remaining parts of the structure being substantially the same, having substantially similar functions, methods of adjustment and uses.

In Fig. 5, I have shown an arrangement of stretched wires for giving the vibratory system a definite frequency. The structure is substantially identical with that shown in Fig. 5 of my Patent No. 1,198.345. In this case, the microphone supporting ring is provided at its lower side with a screw 46 which is threaded into the case and projects above the surface where it carries a hardened steel grooved roller. The top of the ring is provided with a pair of hardened steel tapered pins 47 fitting corresponding recesses in the frame and provided at their outer ends with capstan heads 48. Each of the pins 47 has a transverse aperture 49 receiving the end of a steel piano wire 50 which extends around the roller on screw 46. The outer face of the frame is provided with four lugs 51 within each of which there is an adjusting screw 52. Each of the adjusting screws 52 has in its end an opening to receive a cylindrical hardened steel pin 53 which is free to rotate therein and which has in its end a groove to receive the piano wire 50.

The parallel wires are clamped by the nuts 43—44 on the threaded rod 29 of the microphone vibrator element. In this device, the tension can be adjusted by varying the lateral pressure of the screws without the necessity of changing the position of the lock nuts on the vibrator although the latter may be also adjusted after the manner described in connection with Fig. 1.

In assembling the parts and adjusting the wires, care should be taken that the two wires of a pair lie in the same plane, that the two pairs lie in parallel planes; also the wires and the sections thereof above and below the nuts 43 and 44 should be of equivalent, (and preferably exactly similar) length, weight and tension, so that they will have substantially the same free period or natural frequency. Otherwise the simple harmonic character of the free vibrations of the system may be impaired by the introduction of other frequency components which may cause a plurality of regions of resonant response, and may give rise to one or more "beat" frequencies which may produce disturbing audible effects at the receivers.

These various elastic suspension means which are capable of giving the desired periodicity to the vibratory system are utilized in connection with the further feature of my invention which is described hereafter.

In Fig. 6 I have diagrammatically indicated one form of my said telephone repeaters with its local circuit. The local electrical circuit is made up of a battery 122 and the differentially connected primary winding 123 of an induction coil. The secondary winding 124 of the induction coil is connected to leads 125—126. The exciting coils 6, 7 on the magnets 4, 5 are connected together by the wire 14 and to leads 114—115.

If the local battery circuit is completed and we then connect the lead 125 to 114 and 126 to 115, the repeater, if adjusted, will emit a steady tone. If the pitch of this tone is low, it will be found that, upon reversing the polarity of the battery or reversing the connections of the wires 125—126 to 114—115, the tone will change to one of higher pitch. The phenomena is explainable by the difference in phase between the physical displacement of the vibratory system and the exciting force represented by the current wave traversing the coils 6, 7. The object of this part of the invention is to recite the above giving the cause and effect and then to show a means of controlling such phase displacement within desirable limits.

In each of the forms of telephone repeaters disclosed herein, the means for predetermining and adjusting the elasticity (stiffness) of the vibratory system constitute means for controlling such phase displacement. Because, if we assume a constant mass to the movable system, then for each change made in the free period of the vibratory element, we will alter the phase displacement referred to. In the case of the wire suspension, the free period can be altered by means of the initial tension on the wires and further, when such initial tension is given, additional alterations in the tension can be effected by bowing the wires inward or outward or by bringing them closer together, or by both the last named means. In the torsional device, the free period can be altered by imposing initial torsional strains on the torsional member accomplishing this by moving the lever arm attached to the torsional member inward or outward along the threaded rod aided by the threaded nuts. A mathematical exposition of such phenomena in connection with the dynamics of elastic bodies will be found in "*The Dynamics of Particles and of Rigid, Elastic and Fluid Bodies*," A. G. Webster, second edition, Teubner—Leipzig, 1912, pages 152 to 155, section 44. It being there shown that—

(*a*) The free vibration has its period determined solely by the nature of the system. The forced vibration takes the period of the force.

(*b*) If there is damping, the free vibration dies away, while the forced vibration persists unchanged.

The motion of any system possessing n degrees of freedom (more than one) slightly displaced from a position of stable equilibrium may be summarized as follows: Each coördinate performs the resultant of n damped harmonic oscillations of different periods.

The importance of having a vibratory system with one degree of freedom is apparent. The actual angle of phase displacement between the vibrating system and the exciting force is determined by the relation between the stiffness h and the inertia. For articulate speech the natural frequency of the vibrating system need not be higher than 1000 P. P. S., because that is above any of the dominant frequencies of articulate speech. The precise angular phase displacement may be varied between wide limits for articulate speech and still have the proper free period to the system. However, as we increase inertia, we must increase stiffness and as we increase stiffness, we lose volume of transformed energy for the same primary volume. Conversely, as we decrease inertia, we can increase power, but we then approach a construction difficult to assemble and lacking in qualities of permanency of adjustment. Nevertheless, as already pointed out, my constructions permit of a control of the phase displacement either by original design and assembly, or by subsequent adjustment. This will be shown to possess certain operative advantages respecting a form of phase displacement in a two wire reciprocal talking telephone repeating circuit employing twin repeaters as already disclosed in certain of my patents. It is believed to be unnecessary for me to explain in detail how the circuit operates for reciprocal talking as that has already been done. What it is desired to refer to here is the effect which the difference in phase between the displacement of the vibratory system and the exciting forces in the relay magnets has upon the behavior of the circuit under certain conditions.

With respect to the circuit as shown in Fig. 7, it is sufficient to say that A and B are subscribers' stations at distant ends of a long distance line requiring the use of repeaters. The line between the stations is divided at a relay station C into two sections D and E. The line sections D and E have current and phase balancing extensions F and G respectively, the extension F having the same electrical characteristics as the section D and the extension G having the same electrical characteristics as the line section E. The artificial resistance, inductance and capacity elements necessary for this purpose may be distributed in groups so as to simulate the distributed characteristics of the real line with any required degree of accuracy. The twin-repeater circuits are inductively connected between the sections at the neutral or balancing points of each in such manner as not to disturb that balance, the connection being through the medium of three-limb repeating coils which are connected so as to neutralize the effect of the wave forms from the output side of one repeater upon the input side of the other repeater. The further details of such circuit and its method of operation are fully set forth in my Patents No. 1,198,212 and No. 1,198,214, dated September 12, 1916.

It is assumed that in the circuit shown in Fig. 7, the two repeaters are adjusted to sensibility or maximum power and that in this condition they are operating on a telephone circuit of appreciable length. The balancing sections have been designed as fitting the main circuit sections with a reasonable degree of approximation; as a result whereof the circuit will permit of conversation in reciprocal relation in a commercially satisfactory manner. We will now assume that for some reason the lines become unbalanced, then if the degree of unbalance becomes sufficiently great, the repeaters will just begin to sing, or will emit a beat after some particular wave form has passed through—a tendency to hang on as it were. An examination or an adjustment of the repeaters for the singing test as described in connection with Fig. 6 may show that each repeater will emit a short circuit tone of approximately the same pitch. Then if we reverse the leads of the exciting coils or the polarity of the local battery supply for either of the repeaters, it will be found that the above tendency to hang on will no longer exist. What has been done to correct the above described tendency has been merely to neutralize the effects of phase displacements in the individual repeaters among themselves. The net result is that for constant repeater power, the circuit will stand a greater degree of unbalancing or, in other words, the degree of balancing need not be so accurate. Moreover, repeaters of large volume can be used on shorter circuits than would otherwise be the case. At the same time, the flexibility of this arrangement will take care of wide variations in actual main line conditions upon either side of a repeating station.

The preferred form of circuit (Fig. 7) is that in which there is utilized the method of so connecting twin repeaters in a reciprocal circuit, that they shall be in individually opposite phase relation.

The above explained theory and limitations respecting a form of phase displacement is made use of here in connection with the circuit shown in Figs. 8 and 9 which is a two wire reciprocal talking telephone circuit, using a single repeater in what is commonly termed "booster relation", branched or bridged.

There is the usual repeater device 216 with its exciting coils bridged across the two line wires in a manner similar to that shown in the figure. A battery 217 supplies local energy to the repeater through primary winding 218 of the repeater induction coil. There is a multiple (four winding) secondary winding on the repeater induction coil inductively related with the primary winding. The terminals of the different secondary windings are connected as shown in Figs. 8 and 9. It will be assumed that the line wires 208—209 lead to one subscriber and 214—215 to another. The main circuit sections on each side of the bridge connection of the repeater coils must have approximately the same electrical characteristics so that when the amplified waves from the repeater are inductively transferred to the main line through the four secondary windings of the induction coil and are thus superposed on the original waves traversing the main line, there will remain approximately zero potential across the bridge connection of the repeater exciting coils. It is also necessary that the phase relations of the new waves shall approximately coincide with the original. In a real line, however, the characteristics of the two main line sections will not usually be the same and while the zero potential can be secured by balancing to get equal current values, the dissimilar electrical reactances distributed along the respective main line sections and the unavoidable phase displacement attending the transformer reactions in the induction coil render it impossible to superpose the amplified waves on the original waves with sufficient accuracy of phase relation, by merely balancing the electrical characteristics of the two main line sections; and my present invention involves recognition of and correction for the inherent difference in phase displacement between the vibratory system of the repeater and its exciting force for the essential wave forms of articulate speech. This correction considers inertia, resistance to displacement and free period. By properly proportioning the repeater parts so as to keep the free period at 1000 P. P. S., or over, the phase displacement can be controlled sufficiently to bring about an electrical phase relation at the repeater terminals of such a character as to minimize distortion of the wave forms which otherwise exists.

The proper proportioning in accordance with the principles disclosed above consists in varying the values of elasticity (stiffness) and inertia which determine the frequency of the vibratory element of the repeater without impairing its quality of vibration, which, as I have stated, is practically like that of a theoretical vibratory system having a single degree of freedom, and without unduly lowering the natural frequency of the vibrator, which, as before stated is preferably 1000 periods per second, or more. In practice, the desired result may be achieved by employing a vibratory armature-electrode structure of the proportions shown in Fig. 1 made of the materials and construction described above and weighing say 10 or 15 grams. Such a vibrator will insure minimum inertia with maximum efficiency. The elastic member (torsion rod, flexing pin or stretched wires) will then be designed and adjusted for the minimum stiffness necessary to impart to the system the necessary high frequency of free period or natural elastic vibration. The repeater may then be connected into its shunt across the line, and the current balance giving equal potential and zero current across the shunt secured by inserting a suitable non-inductive resistance or resistances in the main line connection to the shunt. The correctness or incorrectness of the phase relation between the main line wave forms and the amplified wave forms flowing from the repeater may be determined by ear test for clearness of articulation. If the transmitted speech is clear, it will be understood that the proper values for elasticity and inertia of the vibratory member of the repeater were correctly hit upon at first trial. Otherwise, however, the elasticity (stiffness) may be gradually increased in any of the ways above described until articulation becomes clear, thus showing that the amplified waves from the repeater are correctly superposed upon the waves in the line. It is of course, conceivably possible to make the vibrator of adjustable weight and to change the inertia stiffness ratio by decreasing the weight, but in practice, it is far preferable to make the vibrator of as small mass as possible in the first instance and to change the ratio by increasing stiffness and raising the frequency.

If desired, the repeater may be approximately, and in some cases perfectly, adjusted at the factory by impressing upon it a simple harmonic wave having the frequency approximating the natural frequency of the vibrator, say 1000 per second and taking photographs (oscillographs) of the resultant wave forms produced by superposition of the repeater output current upon the original exciting current. The adjustment at which the oscillographs show that the resultant wave most nearly approximates simple harmonic form at the 1000 frequency will be approximately correct for use in connection with the human speech waves of the real line across which the repeater is to be connected in booster relation.

It will be noted that this latter procedure is more difficult in practice and less satisfactory in result than that described for the two-way talking two-repeater sectional circuit shown in Fig. 7, in which the phase relation adjustment of the repeaters can always be effected with perfect accuracy at the factory by simply tuning the vibratory systems of all the repeaters to the same natural frequency. This tuning may be facilitated by short circuiting the instruments and causing them to "sing", that is, emit a continuous audible note. This singing note will be of high or low pitch according to how the circuit connections are made and when either the high note or the low note is produced, the other note may be produced from the same repeater by merely reversing the terminal connections either of the battery or of the short circuiting connection. The higher of the two notes is always approximately the same pitch or frequency as the natural frequency of the vibratory system and hence the sound furnishes a very convenient indication whereby the vibratory system of a repeater may be tuned to a desired high pitch and the several repeaters very accurately tuned to the same pitch. I distinguish between same pitch and high pitch because so far as concerns compensating or balancing the phase displacement in one repeater against the phase displacement of the other, the definite simple harmonic character of the vibration and the identities of the frequencies rather than their numerical values, are the important factors. The high pitch (say 1000 per second) is preferable for the entirely distinct reason explained elsewhere, namely, it brings the region of mechanical resonance above the important frequencies of human speech and so avoids the undue resonant magnification of any of them.

The vibrators of all the repeaters being thus tuned to the same natural frequency, they are ready to be connected in pairs in the repeater circuits between the phase balanced line sections at each repeater station, the only precaution being the reversal of the battery or line connections of the one repeater with respect to those of the other, so that if caused to sing, as by extreme unbalancing of the line sections, one repeater will sing in the characteristic high note while the other will sing in the characteristic low note so that when both are singing, the result will be a composite of both notes.

These two simple easily practised expedients will result in a perfect compensation or balance of the phase displacement of the one repeater with respect to the phase displacement of the other repeater of the same pair, and they are expedients which may be practised even by mechanics or electricians having no understanding or conception of the complicated mechanical and electrical principles and quantitative values actually involved.

Referring again to the booster arrangement of repeater described in connection with Fig. 8, the best results can be secured only by utilizing in this connection the discovery which I have made with respect to all circuits in which the repeater is used in booster relation, namely the superposition of the waves from the repeater, on the original waves, cannot be equally perfect for talking in both directions unless the two subscribers' stations at opposite ends of the lines are identically arranged and identically connected to the main line wires as to all their parts and particularly as to the polarities of the local batteries and direction of flow of the currents through the primaries of the usual repeating coils at the subscriber's station, as well as the connections of the secondaries of said repeating coils to their respective sides of the line. So far as these polarity relations can be indicated in diagram, they will be covered by taking the subsriber's station as shown at A, Fig. 7, with its main line connections D and connecting directly and without any transposition of terminals to the wires 214, 215 of Fig. 8 and by taking the local subscriber's station B Fig. 7 and similarly connecting its main line wires E to wires 208, 209, Fig. 8. I mention this because in present commercial telephone practice, it has not been the custom to pay any attention to preserving identical character and polarity of the connections of these parts and where repeaters have been used in booster relation on such circuits the result has always been that the articulation was poorer in one direction than in the other.

Even when the subscribers' sets are identically organized and connected as above described there is still the possibility that the connections at switch boards or other points in the main line may be such as to give either one of the two possible polarity relations of the two sets with reference to each other and to the line. It is important that these connections be always the same since upon which of the two ways the connections are made will depend whether the booster repeater should have its battery and receiving coils connected for the high pitch howling tendency, or the low pitch howling tendency which I have explained above as characteristic of these repeaters. In practice, the fact as to which tendency is required for the repeater connection, is most simple and easily determined by trying the repeater with a battery connected one way in the circuit and then trying it with the poles reversed, and noting which connection gives the best articulation. Because, however perfect or imperfect may be the elasticity adjustment of the repeater for any given adjustment, the articulation will always be better when the correct howling tendency connection has been selected. Once the repeater is correctly connected and correctly adjusted, it is necessary to see to it that the line connections be not subsequently reversed.

The booster system shown in Fig. 8 may be used on short lines where only one repeater station is required and the divided section phase balanced twin repeater system of Fig. 7 is particularly adapted for use where a line is long enough to require subdivision into several sections with several repeater stations.

I would nevertheless particularly emphasize the fact that the system of Fig. 7, when organized in accordance with all of the novel features of construction, adjustment and coordination of parts hereinabove described, is preëminently adapted for indefinite expansion and that I have long since successfully used as many as six successive current balanced and phase balanced sections with twin repeater outfits constructed as above described and connected as above described, the intermediate sections being of course provided with similar phase balancing extensions at both ends, and only the end sections having the subscriber station outfit. By such use, I have demonstrated that by my present invention the number of sections and the number of repetitions practically attainable with substantial commercially perfect articulation is such that my system may be applied for telephonic communication over all distances required by the dimensions of the continental areas existing on the earth's surface.

In this same connection I would particularly emphasize the fact that by attaining the desired high frequency for the vibratory systems of the repeaters, say 1000 periods per second or more, by a construction involving very small inertia, say as light or lighter than 10 or 15 grams for the vibratory armature-electrode-structure, the range of the resonant response of the system for frequencies on each side of 1000 periods per second, is considerably increased and the curve of approaching resonance is more gradual. The great advantage of this, aside from the ordinary mechanical advantage of moving slight mass instead of large mass, is that the curve representing the values of resonant response for varying frequencies extends far down the range among the resonant frequencies characteristic of the vowel sounds of articulate speech. Thus the resonance curve of increasing mechanical resonace causing increasing magnifying distortion of the higher of these vowel frequencies tends to compensate for and correct the opposite attenuating distortion which attends transmission over long lines. This characteristic action of my repeaters in correcting by mechanical resonance the distortion due to the characteristics of the line is so marked that loading coils now commonly used for preventing line distortion have been proved by me to be entirely unnecessary for transmission over distances up to many thousands of miles. Obviously, my method of correction of such distortion is enormously less expensive than the loaded line method of prevention. Moreover, as I have pointed out in my Patent No. 1,198,214, the great power of the reproduced currents from my repeaters, renders practicable and useful the correction of line distortion by the leakage method, in lieu of by the inductance, or loading coil method.

In case of the application of my invention to existing commercial lines already loaded with inductance coils should result in any undue magnification of the resonant vowel frequencies, this may easily be corrected by raising the free period of the vibratory system so as to raise the entire range of the frequencies of resonant response to a required degree. A possible but less desirable method of correction is to increase the inertia of the vibratory system thereby sharpening the resonance curve and thereby raising the lower limits of resonant response to a higher range; although in practice a judicious combination of increasing tension to raise the frequency and increasing weight to sharpen the resonance curve and thus raise the lower limit of the range of resonant response, may sometimes be employed to advantage.

I claim:

1. In a two-way talking telephone system, and in combination with the various elements thereof including transmitter, receiver and line, a repeater of the electro-magnet-microphone type having a mechanically vibratory element or system having a definite free period of practically simple harmonic vibration and means for supplying current to said microphone, the polarity of the connections of the repeater with said current supply and with the line being selected so that the mechanical phase displacement in the repeater will be in the direction to balance or compensate for phase displacement elsewhere in the system.

2. In a two-way talking telephone system, and in combination with the various elements thereof including transmitter, receiver and line, a repeater of the electro-magnet-microphone type having a mechanically vibratory element or system having a definite free period of practically simple harmonic vibration at frequencies as high as one-thousand or more periods per second, and means for supplying current to said microphone, the polarity of the connections of the repeater with said battery and with the line being selected so that the mechanical phase displacement in the repeater will be in the direction to balance or compensate for electrical phase displacement elsewhere in the system.

3. In a two-way talking telephone system, and in combination with the various elements thereof including transmitter, receiver and line, a repeater of the electro-magnet-microphone type having a mechanically vibratory element or system having a definite free period of practically simple harmonic vibration and a battery for supplying current to said microphone, the polarity of the connections of the repeater with said battery and with the line being selected so that the mechanical phase displacement in the repeater will be in the direction to balance or compensate for electrical phase displacement due to the electrical characteristics of the system.

4. In a two-way talking telephone system, and in combination with the various elements thereof including transmitter, receiver and line, a repeater of the electro-magnet-microphone type having a mechanically vibratory element or system having a definite free period of practically simple harmonic vibration and a battery for supplying current to said microphone, the polarity of the connections of the repeater with said battery and with the line being selected so that the mechanical phase displacement in the repeater will be in the direction to balance or compensate for electrical phase displacement due to the electrical characteristics of the system.

5. In a reciprocal or two-way talking, two repeater circuit, separate main line sections provided with phase balancing and current balancing extensions, twin repeaters and circuits connected in reciprocal relation between the balanced main line sections in such manner as not to disturb their balance, and so as to neutralize on the receiving side of each repeater the retransmitted current from the output side of the other repeater, said repeaters being of the electro-magnet-microphone type having mechanical vibratory systems of practically the same natural frequency, the connections of one repeater to its battery or to its supply circuit being reversed with respect to the corresponding connections of the other repeater; thereby establishing electromechanical phase relations in the two repeaters such that in case of singing, one of them will generate its characteristic high note and the other its characteristic low note.

6. In a reciprocal or two-way talking, two repeater circuit, main line sections provided with phase balancing and current balancing extensions, twin repeaters and circuits connected in reciprocal relation between the balanced main line sections in such manner as not to disturb their balance, and so as to neutralize on the receiving side of each repeater the retransmitted current from the output side of the other repeater, said repeaters being of the electro-magnet-microphone type having mechanical vibratory systems comprising practically identical values and identical relations of their inertia and elasticity elements, the connections of one repeater to its battery or to its line circuit being reversed with respect to the corresponding connections of the other repeater, so that the electromechanical phase displacement in the one compensates for and balances the electromechanical phase displacement in the other.

7. In a reciprocal or two-way talking, two repeater circuit, main line sections provided with phase balancing and current balancing extensions, twin repeaters and circuits connected in reciprocal relation between the balanced main line sections in such manner as not to disturb their balance, and so as to neutralize on the receiving side of each repeater the retransmitted current from the output side of the other repeater, said repeaters being of the electromagnet-microphone type having their respective mechanical vibratory systems composed of practically identical, identically related inertia and elasticity elements so organized that they have practically the same free period and practically but one and the same region or range of resonant response, and that, at a minimum frequency of approximately one thousand periods per second, the connections of one repeater to its battery or to its supply circuit being reversed with respect to the corresponding connections of the other repeater, so that the electromechanical phase displacement in the one compensates for and balances the electromechanical phase displacement in the other.

8. In a reciprocal or two-way talking, two repeater circuit, main line sections provided with phase balancing and current balancing extensions, twin repeaters and circuits connected in reciprocal relation between the balanced main line sections in such manner as not to disturb their balance, and so as to neutralize on the receiving side of each repeater the retransmitted current from the output side of the other repeater, said repeaters being of the electromagnet-microphone type having substantially identical, identically adjusted mechanical vibratory systems both constructed so as to have but one region or frequency range of resonant vibration, the connections of one repeater to its battery or to its line circuit being reversed with respect to the corresponding connections of the other repeater, so that the electromechanical phase displacement in the one compensates for and balances the electromechanical phase displacement in the other.

9. The method of telephonic transmission of speech and correction of distortion in long telephone lines which method consists in countervailing the electrical distortion occurring in the line by mechanical resonance of one of the electrical translating devices of the system.

10. The method of telephonic transmission of speech and correction of distortion in long telephone lines which method consists in countervailing the electrical distortion occurring in the line by utilizing current traversing the line to generate and transmit amplified waves of similar form through the medium of a simple harmonic vibratory element having a range of increasing mechanical resonant response for the higher of the resonant frequency components of the vowel sounds of articulate speech.

11. The method of speech transmission and correction of distortion in telephone lines which consists in opposing the electrical distortion of the line by the distortion of mechanical resonance.

12. The method of speech transmission and correction of distortion in telephone lines which consists in opposing the electrical distortion of the line for higher speech frequencies by the distortion of mechanical resonance for such frequencies.

13. The combination with a telephone line and a source of current, of a repeater provided with a mechanical vibratory element, and connections for the repeater to the line and current source, said repeater

and connections including means whereby the mechanical phase distortion in the repeater will be in the direction to compensate for electrical phase distortion elsewhere in the system.

14. The combination with a telephone line and a source of current, of a repeater provided with a mechanical vibratory element having a definite free period of practically simple harmonic vibration, and connections for the repeater to the line and current source, said repeater and connections including means whereby the mechanical phase distortion in the repeater will be in the direction to compensate for electrical phase distortion elsewhere in the system.

15. In a telephone circuit, balanced line sections, twin repeaters and circuits connected in reciprocal relation between the line sections so that their balance is not disturbed, said repeaters having mechanical vibratory systems comprising practically identical values and identical relations of their inertia and elasticity elements, and line and battery connections for the repeaters, the connections of one repeater to its battery or to its line circuit being reversed with respect to the corresponding connections of the other repeater so that the electromechanical phase displacement in one compensates for the electromechanical phase displacement in the other.

Signed at New York city in the county of New York and State of New York this 2d day of June A. D. 1916.

ELWOOD GRISSINGER.