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APPARATUS FOR LOADED TELEPHONE LINE SYSTEMS.

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Fig. 3.

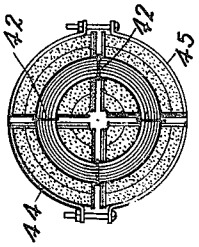


Fig. 1.

Fig. 2.

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UNITED STATES PATENT OFFICE.

THOMAS SHAW, OF HACKENSACK, NEW JERSEY, AND WILLIAM FONDILLER, OF NEW YORK, N. Y., ASSIGNORS, BY MESNE ASSIGNMENTS, TO WESTERN ELECTRIC COMPANY, INCORPORATED, A CORPORATION OF NEW YORK.

APPARATUS FOR LOADED-TELEPHONE-LINE SYSTEMS.

1,289,941. Specification of Letters Patent. Patented Dec. 31, 1918.

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To all whom it may concern:

Be it known that we, THOMAS SHAW and WILLIAM FONDILLER, citizens of the United States, residing at 306 Lookout avenue, Hackensack, in the county of Bergen and State of New Jersey, and at 43 Christopher street, New York, in the county of New York and State of New York, respectively, have invented certain new and useful Improvements in Apparatus for Loaded-Telephone-Line Systems, of which the following is a full, clear, concise, and exact description.

This invention relates to loaded telephone lines, and more particularly to loaded phantom line systems. Its object is the maintenance of constant or nearly constant characteristics of the line conductors under varying conditions met in practice, whereby the circuits are rendered suitable for the application thereto of amplifying repeaters and more satisfactory for superimposed telegraph working.

Difficulty has been experienced heretofore in the application of amplifying repeaters to loaded lines, particularly in phantom systems using open-wire lines. Owing to the exposure of the line conductors to lightning or other source of strong foreign currents, the loading coils available were subject to considerable changes in inductance to telephonic currents, resulting in "singing" of the repeaters. Another difficulty arose from transient changes in the resistance of the loading coils when telegraph currents were superposed upon the telephone currents, this resulting in serious impairment to telephonic transmission.

In long distance telephony it is a desirable practice to divide the line between distant stations into two or more sections and to provide at each point of division an amplifying system preferably comprising two amplifiers, one for repeating in each direction. To render such a sectional line suitable for the amplifiers, an artificial line or "balancing network," as it is sometimes called, is connected to the terminus of each section at each such point, the purpose of the artificial line being to neutralize the section to which it is joined to currents tending to cause singing of the amplifying apparatus. The artificial line itself is maintained constant as to its electrical characteristics since it is not subject to outside disturbances, and the introduction of loading coils in the external line sections has been unsatisfactory in such systems because transient changes in the characteristics of the loading coils in these sections is not or cannot be offset by corresponding changes in the artificial line sections without frequent adjustment of the artificial line.

It has been found that the changes in inductance referred to are caused by excessive residual magnetism in the cores of the loading coils, which varies from time to time and variably reduces or changes the winding inductances to very small magnetizing forces, such as those produced by telephonic currents. The result in general is a continual variation or irregularity which has imposed a serious limitation in the application of amplifying repeaters and telegraph instruments to loaded lines. For successful repeater or simultaneous telegraph working, it is necessary to maintain constant or nearly constant line characteristics.

Furthermore, in loaded phantom systems it is necessary that there be a close electromagnetic, as well as electrostatic balance in the loading coils, as provided for in accordance with the Campbell & Shaw Patent No. 980,921. Such a balance is not possible with loading coils made as described in Pupin Patents Nos. 652,230 and 652,231, not only because their windings are not properly distributed to obtain the balance necessary in phantom circuits, but also because an air-gap in the core, as indicated in the Pupin patents, even if the windings are distributed on the core in accordance with the Campbell & Shaw patent, would produce an unbalanced condition resulting in serious crosstalk between the circuits. The purpose of the gap in the Pupin coil is, as stated in the Pupin patent, solely to reduce the permeability of the magnetic circuit and so to keep down the magnetization and the accompanying losses as much as possible.

The difficulties referred to have been successfully overcome, in accordance with this invention, by introducing into the external line sections loading coils having cores of high magnetic permeability but constructed to present an interrupted magnetic circuit, whereby permanent changes in the magnetic characteristics of the core and consequent

changes in the inductance of the loading coils are avoided and balance is maintained substantially constant between the external line section and the artificial line connected thereto, thus insuring fixed operating characteristics of the amplifying apparatus.

In a phantom system for telephone lines the core of the phantom circuit loading coil, and preferably also of the side circuit loading coil, may be provided in accordance with this invention with a plurality of air-gaps uniformly distributed about the core. Furthermore, although there is a slight increase in the ohmic resistance of the winding conductors, due to the air-gaps, there is, to offset this, a diminution of the effective resistance due to a reduction in hysteresis and eddy current losses in the core. More than this, the air-gap coils constructed in accordance with this invention give a very large net gain in line efficiency by permitting the use of repeaters adjusted to a very high degree of amplification, and by permitting more satisfactory telephonic transmission under the condition of superposed telegraph working.

A type of phantom circuit loading coil, to which the invention has been applied, consists of eight windings grouped upon a toroidal core. The core is divided by winding separators into four quarter sections or quadrants, and each quadrant has an inner and an outer winding. The inner winding of one quadrant is connected to the outer winding of the opposite quadrant, and these two windings together form a single line winding, that is to say, one which is included in a single line conductor of the system. The side circuit loading coil preferably used in the system of the invention, consists of four windings grouped upon a toroidal iron wire core, the winding space being divided into two semi-circular sections, and the inner winding of one section being connected in series with the outer winding of the other section. The two sectional windings of the side circuit coil thus paired form together a single line winding of the system. The air-gaps introduced into the core of the phantom coil, in accordance with this invention, may separate the core into four quarter sections, corresponding to the four winding sections, although it is within the scope of this invention to employ a larger number than four or less than four, say two, likewise uniformly distributed around the core. Two air-gaps have actually been found sufficient and preferable under certain conditions for the phantom coil, and are also the preferred number for the side circuit coil.

Under all conditions, however, it is important that the gaps shall be symmetrically located with respect to the plurality of windings which go to make up the line windings of the coil.

The invention will be more fully understood by reference to the accompanying drawing, wherein—

Figure 1 illustrates diagrammatically a phantom telephone line system employing air-gap loading coils and amplifying repeaters;

Fig. 2 illustrates the core cutting step in the process of manufacture; and

Fig. 3 is a cross-section of a loading coil taken along the center line of its core.

Referring to Fig. 1, four line conductors 1, 2, 3, 4 are arranged to provide three circuits, one a side circuit of conductors 1 and 2 extending between telephone stations 5 and 6; another also a side circuit of conductors 3 and 4 extending between stations 7 and 8, and a third or phantom circuit of conductors 1, 2 and 3, 4 extending between stations 9 and 10.

The circuit of conductors 1, 2 is provided with side circuit loading coils 11 and 12, and an amplifying system comprising repeaters 13 and 14. The circuit of conductors 3 and 4 is likewise provided with side circuit loading coils 15 and 16, and an amplifying system comprising repeaters 17 and 18. The phantom circuit is provided with phantom loading coils 19 and 20 and an amplifying system comprising repeaters 21 and 22. Each of the phantom loading coils, 19 for example, is provided with a core 23, with a plurality of air-gaps 24, and eight windings 26 to 33 inclusive distributed around the core in quarter sections or quadrants, with the outer winding, say 26, of one quadrant being in series with the inner winding 32 of the opposite quadrant. The air-gaps 24 are uniformly distributed around the core. As shown, they may separate the core into four quadrants corresponding to the four winding sections.

Each of the side circuit coils, for example 11, is provided with a core 34 having two diametrically opposite air-gaps 35 and 36. On this coil there are but four windings 37 to 40 inclusive, distributed as shown on the two half core sections, the outer winding, say 37, being connected in series with the inner winding 40 of the other half section.

The loading coils are preferably manufactured according to the following process. The core is first made up of fine iron wire into a toroidal shape. The windings are then placed on the core leaving spaces between the sections for the cutting operation, which is performed in any desired manner, for example, by a band-saw 41 as shown in Fig. 2. After the coil is thus separated into sections, sheets of insulating material 42 are inserted in place of the gaps. The whole is then held together by clamps 44, 45 as shown in Fig. 3. These clamps may be of German silver or some other non-magnetic material having high resistance or insulating char-

acteristics so as to avoid losses therein due to stray magnetic fields from the coil windings.

The principal function of the air-gaps, when used in loading coils, is to insure that the electrical constants of the coil for telephone conditions will not be materially altered by any degree of magnetization that may be superposed on the core along with the small forces due to the telephone currents themselves. The air-gaps impart to the magnetic circuit not only resistance to magnetization but also the property of self-demagnetization, in consequence of which the removal of the residual magnetism is accomplished when the superposed magnetic force is withdrawn.

These effects depend on the proportion of the air-gaps to the iron circuit, and are greater as the length of the gap is increased. Since an increase in the demagnetization factor results also in a reduction of the effective permeability of the core, and consequently in an increase of the amount of copper necessary to give the same inductance as well as an increase in the size and cost of the iron case, the best length of the gaps will be that which just gives a sufficient demagnetizing effect to insure that under any conditions of superposed magnetization that may arise in practice, the electrical constants of the coil will not vary more than an amount known not to be harmful.

If the air-gap is too small the demagnetizing effect will be insufficient to secure the required constancy, and if too great a large and unwieldly coil and case results in which a great sacrifice of efficiency has been made with no valuable gain in constancy.

It has been found that there is a saturation value of the residual magnetism of a closed circuit core, which is reached upon the application of magnetic force sufficient to magnetize the core to a point just above the knee of the curve of induced magnetism, and that any further increase in the magnetizing force will not substantially increase the residual magnetism.

For a core having air-gaps there exists a similar saturation value of the residual magnetism, but on account of the self-demagnetizing properties of the circuit this value is always smaller than for the closed core, and by varying the proportions of the gaps may be reduced to any desired extent. The maximum residual magnetization that can exist in a magnetic circuit having air-gaps may be determined from the hysteresis, or, as it is generally termed, the B—H, loop for the material itself, provided that in the determination of the loop the magnetic force has been raised sufficiently to insure that the residual magnetization reaches its saturation value.

The relationship between the proportions of the air-gaps and their demagnetizing effect is shown by the equation

$$H = H' - B\frac{n\Delta L}{L\left(1+\frac{\Delta A}{A}\right)}$$

in which

H = true magnetic force in the iron
H′ = applied force due to magnetizing coils
B = flux density in the iron
n = number of air-gaps
$n\Delta L$ = total length of air-gaps
L = mean length of magnetic circuit in iron
ΔA = increment of cross-section due to fringing of magnetic lines at the air-gaps
A = cross-section of path in iron

The term

$$B\frac{n\Delta L}{L\left(1+\frac{\Delta A}{A}\right)},$$

in which the coefficient of B for a given core having small gaps suitable for the purposes of this invention is substantially proportional to the length of the gap, represents a magnetic force of opposite sense to the applied force tending to demagnetize the iron or to prevent its attaining to the full magnetization under any given force.

The proper proportions of the air-gap in each case are best determined directly by experiment. This may be done by observing for various lengths of gap the total range of change of the effective permeability of the whole magnetic circuit to the small forces due to the telephone currents after the coil has been subjected to various cycles of strong magnetization, such as may be met with in practice. The proper air-gap will be chosen from these observations as that for which the total variation does not exceed the limiting value, say 5%, imposed by the working requirements of the telephone line. A similar method may be followed to determine the most suitable gap to use in cases where the variation of the effective resistance of the coils is the limiting requirement, such as the case of simultaneous use of the line conductors for telephoning and telegraphing.

The amplifying repeaters referred to may be of the audion type, each, for example 13, comprising a cathode in the form of a heated filament 46, an output electrode or plate 47, and an input electrode or grid 48. The filament is heated by a battery 49. A battery 50 is provided in the output circuit, which includes also the primary winding 51 of an output repeating coil. A battery 52 is included in the input circuit, which also includes the secondary winding 53 of an input repeating coil. The secondary windings 54

of the output repeating coil are included serially in a part of the circuit system of conductors 1 and 2, this part being electrically balanced at the amplifying apparatus by a line network 55. The primary windings 56 of the input repeating coil are bridged across the other part of the circuit system of conductors 1, 2, and this other part is likewise balanced by a line network 57.

The repeater 13 is adapted to repeat telephonic currents transmitted from station 5 to station 6. In the same manner the repeater 14 is adapted to repeat from station 6 to 5. It will be noted that the phantom circuit, through the amplifying system including the audions 21, 22, is completed by way of conductors 58, 59, 60 and 61 tapped from the middle points of the windings 56 of the other two circuits.

Although only one set of amplifiers and two sets of loading coils are shown for each circuit, it is to be understood that a greater number of each may be and ordinarily would be used in practice.

Whenever the loading coils are invaded by strong foreign currents, the demagnetizing poles, due to the plural air-gaps, may be relied upon to maintain the line characteristics practically constant and a practically perfect balance between the several parts of the circuits and their line networks. It is therefore possible to use very powerful repeaters adjusted to their maximum degree of amplification and to give satisfactory telephone service under the severest conditions of simultaneous telegraph working.

What is claimed is:

1. A loading coil for telephone lines having a toroidal core with a plurality of symmetrically arranged non-magnetic gaps.

2. A loading coil for telephone lines having a toroidal core with non-magnetic gaps at diametrically opposite points.

3. A loading coil for telephone lines having a plurality of core sections separated by non-magnetic gaps, the ratio of total length of gap to total length of core circuit being such that under varying degrees of residual magnetism the initial permeability to telephonic currents of the core material will not be materially altered.

4. A phantom loading coil having a toroidal core and four sets of line windings distributed symmetrically upon four core sections, said core being separated by non-magnetic gaps into sections corresponding to the winding sections.

5. A phantom loading coil having a toroidal core and inner and outer windings on a plurality of sections thereof, each line conductor through the coil including the inner and the outer windings respectively of opposite core sections, the said core having a plurality of non-magnetic gaps uniformly distributed about the core and equal in number to the winding sections thereof.

6. A loading coil for telephone lines comprising a toroidal core of magnetic material divided into sections, non-magnetic separators between said sections and a clamping device for retaining the said core sections and separators in position.

7. A loading coil for telephone lines comprising a toroidal core of magnetic material divided into sections, non-magnetic separators between said sections and a clamp of non-magnetic metal and having high electrical resistance for holding said core sections and said separators in position.

8. The method of manufacturing loading coils for telephone lines which consists in assembling a toroidal core, placing windings thereon in sections, cutting gaps in said core between the winding sections, placing non-magnetic separators in place of the gaps and clamping said sections and said separators together.

9. A loading coil having a core of generally toroidal form, said core being in circumferential sections separated from one another by symmetrically arranged non-magnetic material.

10. A loading coil having a core of generally toroidal form, said core being in circumferential sections separated from one another by symmetrically arranged non-magnetic solids.

11. A loading coil having a core of generally toroidal form, said core being in circumferential sections separated from one another by a non-magnetic solid, windings upon the core, and means surrounding the windings for maintaining the core sections and separating material in position.

12. A loading coil having a core of generally toroidal form, said core being in circumferential sections separated from one another by non-magnetic material, and windings upon the core symmetrically arranged with respect to the sections.

13. A loading coil of generally toroidal form, a magnetic core therefor, a plurality of symmetrically arranged windings on said core, and non-magnetic means between the winding sections to break the continunity of the magnetic circuit.

14. A loading coil of generally toroidal form, a magnetic core therefor, a plurality of symmetrically arranged windings on said core, and a non-magnetic gap in the core located at a junction between two winding sections.

15. A loading coil of generally toroidal form, a magnetic core therefor comprising a plurality of separate sections, a plurality of symmetrically arranged windings on said core sections, and non-magnetic material between said core sections.

16. A loading coil of generally toroidal

form, a magnetic core therefor comprising a plurality of separate sections, a plurality of symmetrically arranged windings on said core sections, non-magnetic material between said sections, and a clamp of non-magnetic material for holding said windings and core sections in position.

In witness whereof, we hereunto subscribe our names this 10th day of September A. D. 1914.

THOMAS SHAW.
WILLIAM FONDILLER.

Witnesses:
SAMUEL RACCINSIR,
ROBERT S. SUTLIFFE.