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W. A. SCHAPER
PERMEABILITY TUNING
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2,213,328

Fig. 1.

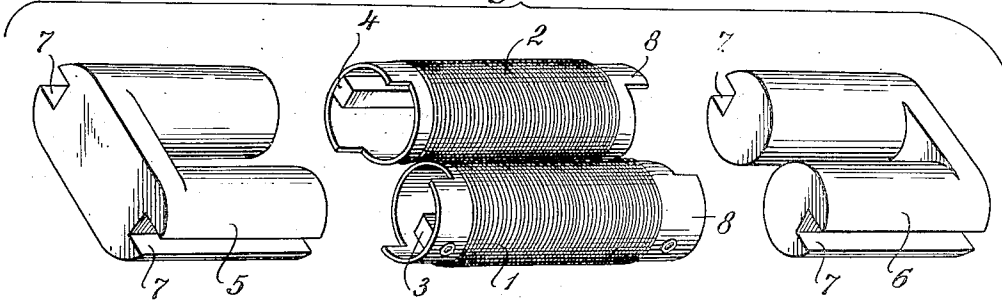


Fig. 2.

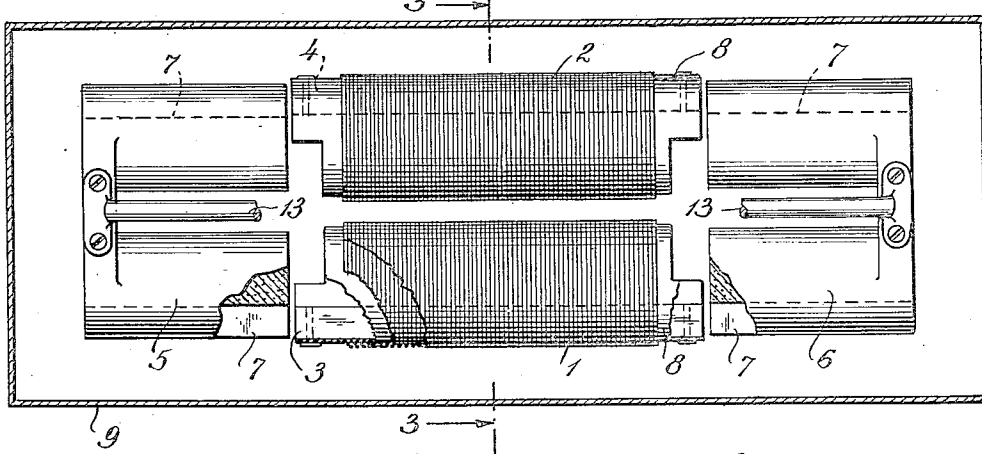


Fig. 3.

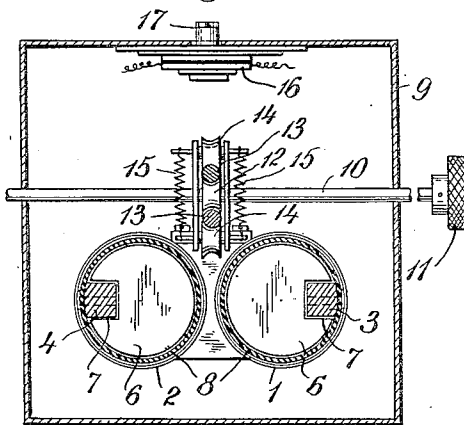
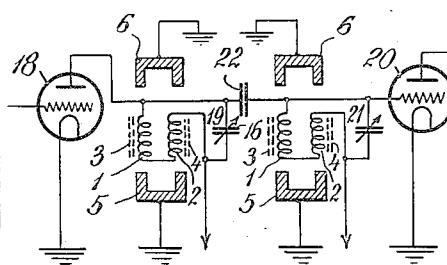


Fig. 4.



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PERMEABILITY TUNING

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11 Claims. (Cl. 171-242)

This invention relates to variable inductors, and more particularly to variable inductors suitable for use in high-frequency resonant circuits, arranged to be adjusted to any frequency within a relatively wide band. Variable inductors of this type may be employed, for example, in radio receivers.

The variable inductor of the present invention is of the type having ferromagnetic core members arranged to be movable relatively to the coil with which they are associated, the relative motion of the coil and core members producing changes in inductance which permit tuning the resonant circuit of which the inductor may form a part, without capacitance variation, although variable capacitance may be employed in addition to the inductance variation if desired.

An object of the invention is to provide a variable inductor having a high ratio of inductance to resistance, or L/R, for use in the variably tuned resonant circuits of radio receivers and similar apparatus. Another object is to provide a compact form of inductor having a wide range of inductance variation.

An additional object of the invention is to provide an improved variable inductance device which not only has excellent performance at any single frequency but also maintains the selectivity of a resonant circuit of which it may form a part substantially constant over a wide range of frequencies.

These and other objects are realized in accordance with the invention by employing small fixed core members for improving the efficiency of an air-core coil at the low-inductance end of the inductance range to be covered, and then inserting movable core members to increase the inductance and the resistance of the improved coil simultaneously. By proper division of the total core structure between the fixed and movable portions, the variable inductor may provide a high initial L/R ratio without sacrifice of the desired range of inductance variation. By proper choice of the movable core members, the L/R ratio of the device, and hence the selectivity of a resonant circuit in which it may be used, may be maintained substantially constant as the inductance is increased.

The use of a fixed ferromagnetic core to improve the performance of an air-core coil is disclosed in United States Patent No. 1,982,690 to Polydoroff. A movable ferromagnetic core suitable for maintaining the L/R ratio of a variable inductor substantially constant over a range of inductance variation is disclosed in United

States Patent No. 1,940,228, also to Polydoroff. The advantageous results of employing ferromagnetic cores in accordance with these two patents obviously cannot all be realized with a single core, since one result requires that the core increase the inductance of the coil more than its resistance, while the other result requires that the increase in the resistance of the coil due to the core shall be at least equal to the increase in the inductance of the coil due to the core.

The invention and its several advantages will be better understood if the following description is read in conjunction with the accompanying drawing, in which:

Fig. 1 is a drawing in perspective of the essential parts of a variable inductor embodying the invention, in an exploded view to better show the forms of the various parts;

Fig. 2 is a plan view, partly in section, of the variable inductor embodying the parts shown in Fig. 1;

Fig. 3 is a section taken on the line 3-3 of Fig. 2; and

Fig. 4 is a schematic diagram of devices of the type shown in Figs. 1, 2 and 3, appropriately connected in a radio amplifying circuit.

Referring to Fig. 1 of the drawing, the variable inductor consists essentially of coils 1 and 2 in binocular relation, fixed magnetic core members 3 and 4, and movable magnetic core members 5 and 6, which are arranged to slide readily into and out of coils 1 and 2 from opposite ends thereof. Movable core members 5 and 6 are provided with slots 7 to receive fixed core members 3 and 4 when members 5 and 6 enter coil forms 8, to which members 3 and 4 are respectively attached. When fully inserted core members 5 and 6, in cooperation with core members 3 and 4, provide a substantially closed path for the flux produced by coils 1 and 2. When core members 5 and 6 are withdrawn, the effective permeability of the core structure is greatly decreased. Core members 3 and 4, however, are large enough to provide a substantial improvement in the efficiency of coils 1 and 2, since they increase the inductance of the coils more than the resistance of the coils. Core members 3 and 4 are not so large as to prevent core members 5 and 6 from producing the desired inductance increase when they are inserted in coils 1 and 2.

Coils 1 and 2 are connected in series-aiding relation, that is, in such a way that the field of one coil returns chiefly through the other coil. Each coil may consist of two layers of insulated

wire wound turn over turn in the same direction and having their adjacent ends connected together. The layers are separated by a layer of paper or other suitable material, not shown. In winding these coils, I preferably employ Litzendraht cable consisting of a plurality of strands of insulated wire, but other types of wire may be employed.

Core members 3, 4, 5 and 6 may be made in accordance with United States Patent No. 1,982,689 to Polydoroff or in other suitable manner. Each of the core members 5 and 6 is preferably molded in one piece, but may be made of several pieces, as for example two plugs and a yoke, suitably held together by cement or otherwise. Core members 5 and 6 are preferably of such composition as to provide the maximum effective permeability for a given bulk. Core members 3 and 4 are preferably so made as to provide the maximum improvement in the L/R ratio of coils 1 and 2 for a given bulk.

It is an additional feature of the invention to design core members 5 and 6 in such a way as to provide a desired variation in the characteristics of the resonant circuit including the inductance device as the frequency is varied by adjustment of the movable cores. If constant selectivity of the resonant circuit is required, it is necessary to so choose core members 5 and 6 that the L/R ratio of the inductance device will remain substantially constant throughout the tuning range. Cores of this general type are disclosed in United States Patent No. 1,940,228 to Polydoroff.

If tuning of a resonant circuit is accomplished entirely by inductance variation, a variable inductor which provides substantially constant selectivity will also provide substantially constant gain, since the dynamic resistance, or L/RC ratio, of the resonant circuit will also remain practically fixed in this case.

The arrangements of the present invention facilitate the accomplishment of this desired uniformity of performance, since two separate and independent means are provided for varying the resistance of the variable inductor as core members 5 and 6 are inserted to decrease the resonant frequency. Fixed core members 3 and 4 may be chosen to have a desired variation of losses with frequency, within limits, and movable core members 5 and 6 may be designed with respect to both their shape and their composition in such a way as to provide the necessary supplementary variation of losses with frequency. These and other modifications are within the scope of the invention.

In Figs. 2 and 3, the variable inductor is shown with its essential parts in normal operating relation, and suitably mounted in a shield can 9 of aluminum or other suitable conductive material. The actuating mechanism for moving the core members 5 and 6 includes shaft 10 which is provided with an adjusting knob 11 and a grooved pulley wheel 12. Rods 13, which are attached respectively to core members 5 and 6, are held into frictional engagement with opposite sides of wheel 12 by means of rollers 14 and springs 15. Guiding means, not shown, are also provided for maintaining rods 13 in proper alignment with respect to the axes of the coil forms 8. It will be understood that any other suitable mechanism for moving the core members 5 and 6 simultaneously in opposite directions may be employed.

Shield can 9 may also contain other apparatus associated with the variable inductor, as for ex-

ample adjustable tuning capacitor 16, which is arranged so that its adjusting screw 17 is accessible from without the shield can 9.

In operation, a desired minimum value of inductance is obtained when the core members 5 and 6 are completely withdrawn from coils 1 and 2. At this setting, the efficiency of the coils 1 and 2 is high because the presence of fixed core members 3 and 4 permits a smaller number of turns of wire to be used in each coil for a given value of inductance, with a resultant reduction of the losses in the windings. A further increase in efficiency over an air-core coil of similar dimensions and inductance is obtained by the positioning of the core members 3 and 4. In ordinary coils arranged in binocular relation, additional losses are present because the flux of each coil causes eddy currents to flow in the wire of the other coil. This is especially the case when the two coils are closely adjacent, as in the device of the present invention. By locating core members 3 and 4 in each coil form 8 as far as possible from the other coil, as clearly indicated in Fig. 3, the flux density near the inner side of each coil is greatly reduced, with a resultant substantial reduction in the additional eddy-current losses above mentioned.

The maximum inductance value is obtained when movable core members 5 and 6 are inserted all the way into coils 1 and 2. By inserting core members at each end of the windings and by a proper compromise between the cross-sectional areas of the fixed and movable core members, it is possible to realize a range of inductance variation of at least 7.5 to 1 in spite of the fact that the entire magnetic core structure is not movable with respect to the windings. Thus a highly efficient variable inductor capable of providing a desired range of inductance variation is obtained.

I have found that the efficiency of the tuning device is materially increased by the method of winding each coil in two layers turn over turn, with the layers connected in parallel. This arrangement provides the equivalent of a conductor having a large effective surface area, and yet permits sufficient turns to be wound upon a coil form of reasonable length. It is within the scope of the invention, however, to employ a different number of layers or other methods of connecting the layers to each other, or to use a single-layer winding.

Referring to Fig. 4 of the drawing, the output circuit of vacuum tube 18 includes a tuned circuit 19 comprising coils 1 and 2 in series shunted by adjustable capacitor 16. The input circuit of vacuum tube 20 includes a tuned circuit 21 comprising coils 1 and 2 in series shunted by adjustable capacitor 16. Circuits 19 and 21 are coupled by means of capacitor 22, and may be simultaneously tuned to the same frequency by mechanical linkages, not shown, between core members 5 and 6 of the first variable inductance device and core members 5 and 6 of the second device. This result may be achieved, for example, by making shaft 10 (Figs. 2 and 3) common to two or more of the inductance devices to be employed in a radio receiver or other apparatus.

In one successful embodiment of the invention, coil forms 8 have an inside diameter of 0.440 inch and an outside diameter of 0.464 inch. Coils 1 and 2 are 1.1875 inches long, and each consists of two parallel-connected layers composed of 148 turns of 30/46 Litz wire. Fixed core members 3 and 4 have a square cross-section 0.125 inch on a side and are 1.4375 inches in length. Movable

core members 5 and 6 are so shaped as to slidably enter the remaining space within coil forms 8. Aluminum shield can 9 is 1.5 inches by 1.75 inches by 4.25 inches.

Fixed core members 3 and 4 when used alone increase the inductance of binocular coils 1 and 2 by a factor of approximately 1.7, and the total inductance increase with core members 3 and 4 in place and core members 5 and 6 fully inserted is approximately 10.25 times, from which the inductance-increasing effect of the cores 5 and 6 is approximately 6 times. With the shield can 9 and core members 5 and 6 grounded and with core members 3 and 4 in place, the inductance-increasing effect of the core members 3 and 4 with the core members 5 and 6 withdrawn, is substantially the same as before, that is 1.7 times, but because of the capacitance effect between the cores 5 and 6 and the coils 1 and 2 when said cores are inserted in said coils, the apparent inductance increase due to said cores when fully inserted is approximately 7.7 times, which is sufficient to tune a resonant circuit including the inductance device over a range from 540 to 1500 kilocycles. This relatively high inductance increase is due to the fact that the insertion of core members 5 and 6 not only increase the individual inductance of each coil but also materially increases the coupling between the two coils, so that the over-all inductance change is substantially greater than the total which is realized in the individual coils.

Measured at 1500 kilocycles, coils 1 and 2 in series of the above-described embodiment without any cores have a $Q = \omega L/R$ of approximately 130; this value is increased to 249 by fixed core members 3 and 4. The use of properly located and proportioned fixed core members to improve the Q of the coils at the high-frequency end of the tuning range is therefore an important feature of the invention. The insertion of movable core members 5 and 6 increases the inductance of coils 1 and 2 in series by a factor of 7.7 and simultaneously increases the resistance by at least the same factor. Thus a second important feature of the invention is realized, namely, a variable inductance device capable of tuning a resonant circuit over a wide range of frequencies in such a way as to maintain its selectivity substantially constant.

Having thus described my invention, what I claim is:

1. A high-frequency variable inductance device for use in a resonant circuit having fixed capacitance and for tuning said circuit over a required range of frequencies, including in combination, a winding having two series-aidingly connected coils supported in closely adjacent binocular relation; means for materially increasing the inductance-to-resistance ratio of said winding comprising two bar-shaped low-loss ferromagnetic members longitudinally positioned remote from each other and respectively within and adjacent the inner surfaces of said coils, each of said members having a transverse cross-sectional area which is only a fractional part of the cross-sectional area within the corresponding coil; and relatively high-loss ferromagnetic cores movable in and relatively to said coils and to said members, for increasing the total effective inductance of said winding beyond the increased value resulting from said members, to values adequate to tune said circuit over said range of frequencies, and for simultaneously so increasing the total effective

resistance of said winding as to maintain said inductance-to-resistance ratio substantially at its said increased value resulting from said members, said cores being shaped to occupy substantially the entire remaining space within said coils when fully inserted therein.

2. A high-frequency variable inductance device for use in a resonant circuit having fixed capacitance and for tuning said circuit over a required range of frequencies, including in combination, a winding having two series-aidingly connected coils supported in closely adjacent binocular relation and each having two parallel-connected layers; means for materially increasing the inductance-to-resistance ratio of said winding comprising two bar-shaped low-loss ferromagnetic members longitudinally positioned remote from each other and respectively within and adjacent the inner surfaces of said coils, each of said members having a transverse cross-sectional area which is only a fractional part of the cross-sectional area within the corresponding coil; and relatively high-loss ferromagnetic cores movable in and relatively to said coils and to said members, for increasing the total effective inductance of said winding beyond the increased value resulting from said members, to values adequate to tune said circuit over said range of frequencies, and for simultaneously so increasing the total effective resistance of said winding as to maintain said inductance-to-resistance ratio substantially at its said increased value resulting from said members, said cores being shaped to occupy substantially the entire remaining space within said coils when fully inserted therein.

3. A high-frequency variable inductance device for use in a resonant circuit having fixed capacitance and for tuning said circuit over a required range of frequencies, including in combination, a winding having two series-aidingly connected coils supported in closely adjacent binocular relation; means for materially increasing the inductance-to-resistance ratio of said winding comprising two bar-shaped low-loss ferromagnetic members longitudinally positioned remote from each other and respectively within and adjacent the inner surfaces of said coils, each of said members having a transverse cross-sectional area which is only a fractional part of the cross-sectional area within the corresponding coil; and two relatively high-loss ferromagnetic cores oppositely movable in and relatively to said coils and to said members from opposite ends of said coils, for increasing the total effective inductance of said winding beyond the increased value resulting from said members, to values adequate to tune said circuit over said range of frequencies, and for simultaneously so increasing the total effective resistance of said winding as to maintain said inductance-to-resistance ratio substantially at its said increased value resulting from said members, said cores being shaped to occupy substantially the entire remaining space within said coils when fully inserted.

4. A high-frequency variable inductance device for use in a resonant circuit having fixed capacitance and for tuning said circuit over a required range of frequencies, including in combination, a winding having two series-aidingly connected coils supported in closely adjacent binocular relation; means for materially increasing the inductance-to-resistance ratio of said winding comprising two bar-shaped low-

loss ferromagnetic members longitudinally positioned remote from each other and respectively within and adjacent the inner surfaces of said coils, each of said members having a transverse cross-sectional area which is only a fractional part of the cross-sectional area within the corresponding coil; and two relatively high-loss ferromagnetic cores oppositely movable in and relatively to said coils and to said members from opposite ends of said coils, for increasing the the total effective inductance of said winding beyond the increased value resulting from said members, to values adequate to tune said circuit over said range of frequencies, and for simultaneously so increasing the total effective resistance of said winding as to maintain said inductance-to-resistance ratio substantially at its said increased value resulting from said members, said cores each having two cylindrical portions and a yoke portion connecting said cylindrical portions, said cylindrical portions being shaped to occupy substantially the entire remaining space within said coils when fully inserted therein.

5. A high-frequency variable inductance device for use in a resonant circuit having fixed capacitance and for tuning said circuit over a required range of frequencies, including in combination, a winding having two series-aidingly connected coils supported in closely adjacent binocular relation; means for materially increasing the inductance-to-resistance ratio of said winding comprising two bar-shaped low-loss ferromagnetic members longitudinally positioned remote from each other and respectively within and adjacent the inner surfaces of said coils, each of said members having a transverse cross-sectional area which is only a fractional part of the cross-sectional area within the corresponding coil; and two relatively high-loss ferromagnetic cores oppositely movable in and relatively to said coils and to said members from opposite ends of said coils, for increasing the total effective inductance of said winding beyond the increased value resulting from said members, to values adequate to tune said circuit over said range of frequencies, and for simultaneously so increasing the total effective resistance of said winding as to maintain said inductance-to-resistance ratio substantially at its said increased value resulting from said members, said cores each having two cylindrical portions and a yoke portion connecting said cylindrical portions, said cylindrical portions each having a keyway to admit one of said members, and said cylindrical portions being shaped to occupy substantially the entire remaining space within said coils when fully inserted therein.

6. A high-frequency variable inductance device for use in a resonant circuit having fixed capacitance and for tuning said circuit over a required range of frequencies, including in combination, a winding having two series-aidingly connected coils supported in closely adjacent binocular relation; means for materially increasing the inductance-to-resistance ratio of said winding comprising two bar-shaped low-loss ferromagnetic members longitudinally positioned remote from each other and respectively within and adjacent the inner surfaces of said coils, each of said members having a transverse cross-sectional area which is only a fractional part of the cross-sectional area within the corresponding coil; relatively high-loss ferromagnetic cores relatively movable in said coils, for

increasing the total effective inductance of said winding beyond the increased value resulting from said members, to values adequate to tune said circuit over said range of frequencies, and for simultaneously so increasing the total effective resistance of said winding as to maintain said inductance-to-resistance ratio substantially at its said increased value resulting from said members, said cores being shaped to occupy substantially the entire remaining space within said coils when fully inserted therein; and means for producing aligned axial motion of said cores relative to said coils and to said members.

7. A high-frequency variable inductance device for use in a resonant circuit having fixed capacitance and for tuning said circuit over a required range of frequencies, including in combination, a winding having two series-aidingly connected coils supported in closely adjacent binocular relation; means for materially increasing the inductance-to-resistance ratio of said winding comprising two bar-shaped low-loss ferromagnetic members longitudinally positioned remote from each other and respectively within and adjacent the inner surfaces of said coils, each of said members having a transverse cross-sectional area which is only a fractional part of the cross-sectional area within the corresponding coil; relatively high-loss ferromagnetic cores relatively movable in said coils, for increasing the total effective inductance of said winding beyond the increased value resulting from said members, to values adequate to tune said circuit over said range of frequencies, and for simultaneously so increasing the total effective resistance of said winding as to maintain said inductance-to-resistance ratio substantially at its said increased value resulting from said members, said cores being shaped to occupy substantially the entire remaining space within said coils when fully inserted therein; and means for producing simultaneous opposite aligned axial motion of said cores in opposite ends of said coils.

8. A high-frequency variable inductance device for tuning purposes, comprising in combination an inductance coil; a bar-shaped low-loss ferromagnetic member longitudinally positioned within and adjacent said coil, and angularly covering only a part of the inner surface of the coil, the material of said member substantially increasing the inductance-to-resistance ratio of said coil; and a relatively high-loss ferromagnetic core adjustably movable in said coil, for further increasing the inductance of said coil to values adequate to tune a resonant circuit including said coil over a desired range of frequencies, and for simultaneously further so increasing the effective resistance of said coil as to maintain said increased inductance-to-resistance ratio substantially constant.

9. A high-frequency variable inductance device for use in a resonant circuit having fixed capacitance and for tuning said circuit over a required range of frequencies, including in combination, a winding having two series-aidingly connected coils supported in closely adjacent binocular relation; means for materially increasing the inductance-to-resistance ratio of said winding comprising two bar-shaped low-loss ferromagnetic members longitudinally positioned respectively within and adjacent the inner surfaces of said coils, each of said members extending angularly around but a part of the inner surface of the corresponding

coil; and relatively high-loss ferromagnetic cores movable in said coils relatively to said coils and to said members, for increasing the total effective inductance of said winding beyond the increased value resulting from said members, to values adequate to tune said circuit over said range of frequencies, and for simultaneously so increasing the total effective resistance of said winding as to maintain said inductance-to-resistance ratio substantially at its said increased value resulting from said members.

10 10. A high-frequency variable inductance device for tuning purposes, comprising in combination an inductance coil; a bar-shaped low-loss ferromagnetic member longitudinally and fixedly positioned within and adjacent said coil, and extending angularly around but a part of the inner surface of the coil, the material of said member substantially increasing the inductance-to-resistance ratio of said coil; and a ferromagnetic core of material of higher loss and higher permeability than the material of said member adjustably movable in said coil, for further increasing the inductance of said coil to values adequate to tune a resonant circuit including said coil over a desired range of frequencies.

11. A high-frequency variable inductance device for use in a resonant circuit having fixed capacitance and for tuning said circuit over a required range of frequencies, including in combination, a winding having two series-aidingly connected coils supported in closely adjacent binocular relation; means for materially increasing the inductance-to-resistance ratio of said winding comprising two bar-shaped low-loss ferromagnetic members longitudinally positioned remote from each other and respectively within and adjacent the inner surfaces of said coils, each of said members having a transverse cross-sectional area which is only a fractional part angularly of the cross-sectional area within the corresponding coil; and ferromagnetic cores of material of higher loss than the material of said members, and movable in said coils relatively to said coils and to said members, for increasing the total effective inductance of said winding beyond the value to tune said circuit over said range of frequencies, said cores being shaped to occupy substantially the entire remaining space within said coils when fully inserted therein.

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