July 15, 1947. R. B. BEETHAM 2,423,824

INDUCTIVE TUNING

Filed April 10, 1943 3 Sheets-Sheet 1

Fig. 1.

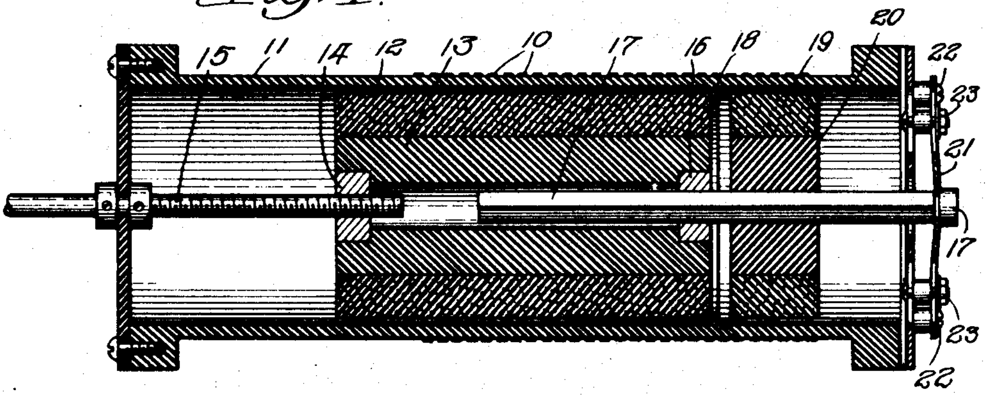


Fig. 2.

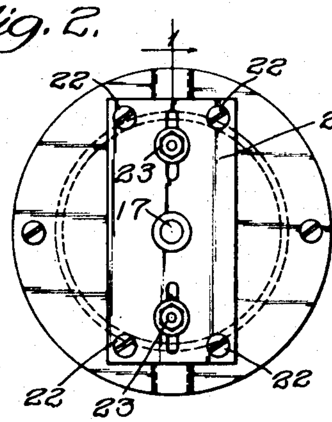


Fig. 4.

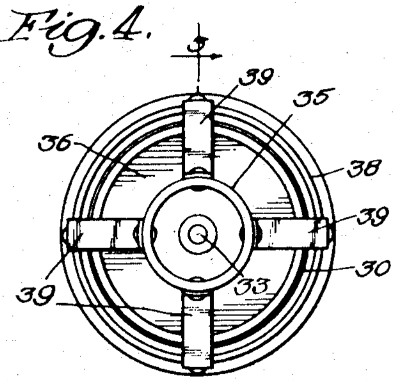
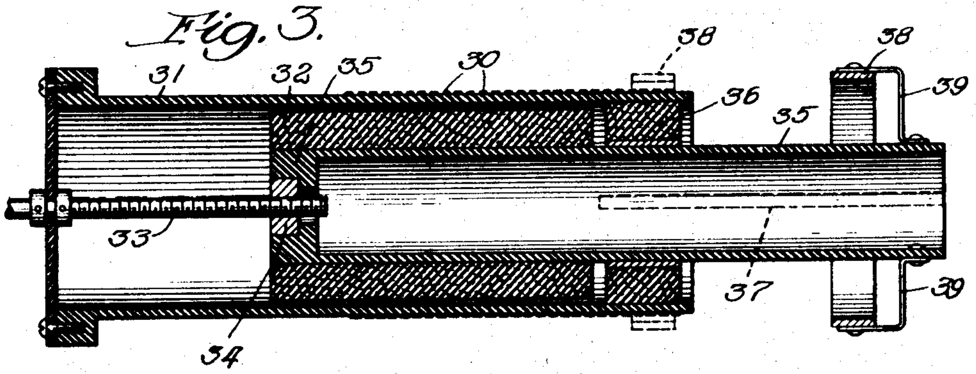


Fig. 3.



Inventor:
Robert B. Beetham,
By Chritton, Wiles, Davies, Hirschl, Schroeder & Merriam, Att'ys.

July 15, 1947. R. B. BEETHAM 2,423,824

INDUCTIVE TUNING

Filed April 10, 1943 3 Sheets-Sheet 2

Fig. 5.

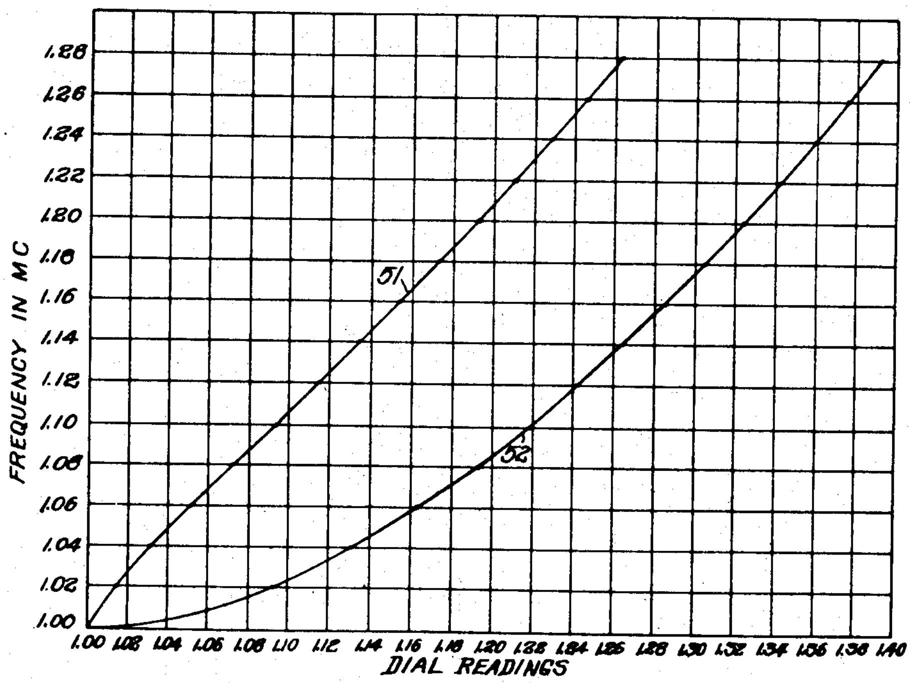
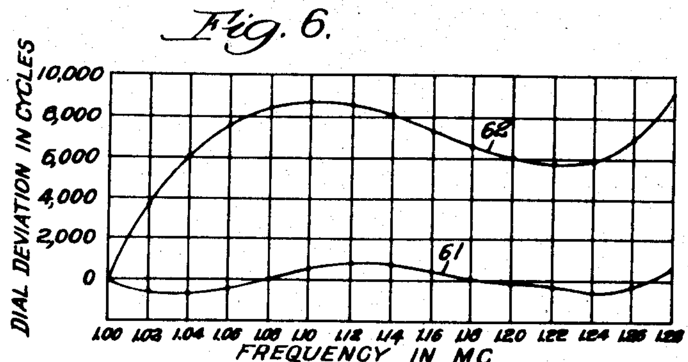


Fig. 6.



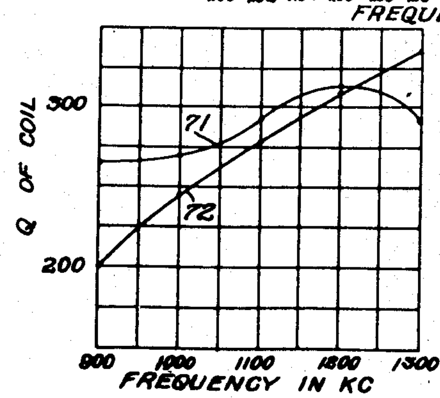


Fig. 7.

Inventor:
Robert B. Beetham,
By Chritton, Wiles, Davies, Hirschl, Schroeder, Merriam, Attys.

July 15, 1947.

R. B. BEETHAM

2,423,824

INDUCTIVE TUNING

Filed April 10, 1943

3 Sheets-Sheet 3

Fig. 8.

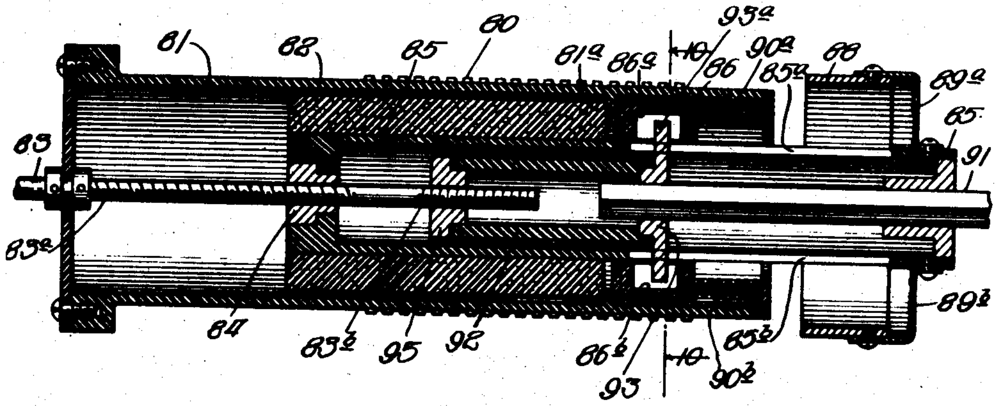


Fig. 9.

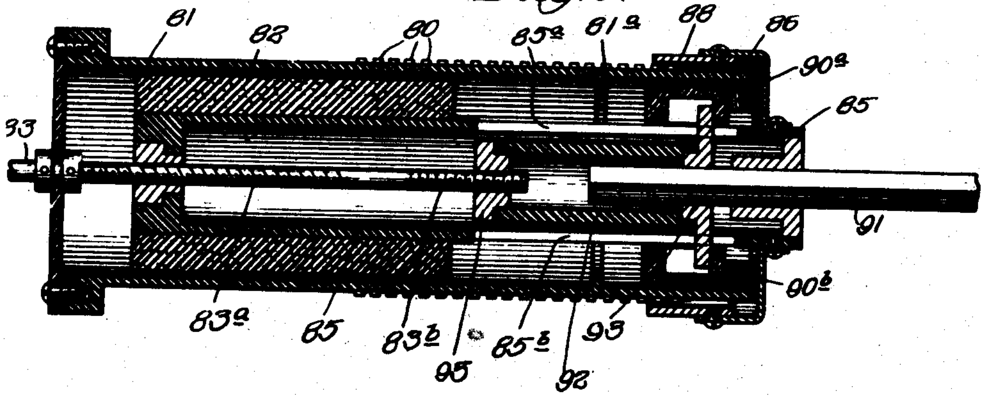
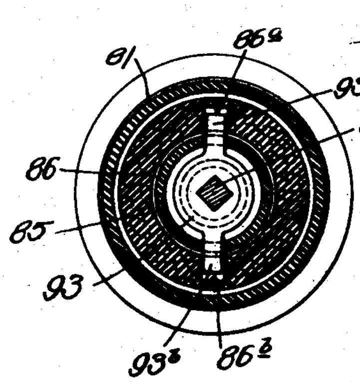


Fig. 10.



Inventor:
Robert B. Beetham,
By Chritton, Wiles, Davies, Hirschl, Schroeder, Merriam, Attys.

Patented July 15, 1947

2,423,824

UNITED STATES PATENT OFFICE

2,423,824

INDUCTIVE TUNING

Robert B. Beetham, Cedar Rapids, Iowa, assignor to Collins Radio Company, a corporation of Iowa

Application April 10, 1943, Serial No. 482,661

9 Claims. (Cl. 171—242)

1

This invention relates to inductive tuning, and more particularly to an improved arrangement for permeability tuning.

One feature of this invention is that, in combination with a cylindrical, uniformly wound coil tuned by an axially movable permeability core, it causes the frequency-movement responsive curve to closely approximate the desired straight line over a longer tuning range; another feature of this invention is that it so greatly reduces the deviation from a straight line that the tuning characteristics are even better than those of variable pitch and tapered coils, and this is achieved with cylindrical coils and cores which can be accurately reproduced in quantity as a commercial production proposition; still another feature of this invention is that it considerably increases the range of inductance variation over which the frequency-movement response curve is a straight line; yet another feature of this invention is that it is adapted to be combined with an eddy current ring to still further lengthen the straight line tuning range; a further feature of this invention is that it greatly improves the Q (the reactance-resistance ratio) of the coil at maximum inductance, and reduces the variation in Q over the tuning range, a highly desirable feature in that it avoids undue variation in the selectivity characteristics; and still further a feature is that a permeability tuning arrangement embodying this invention provides convenient means for effecting trimming and temperature compensation adjustments of the inductance, automatic or otherwise. Other features and advantages of this invention will be apparent from the following specification and the drawings, in which:

Figure 1 is a longitudinal sectional view of one embodiment of this invention; Figure 2 is an end view of the device shown in Figure 1, looking from the right of such figure; Figure 3 is a longitudinal sectional view of another embodiment of this invention; Figure 4 is an end view of the device shown in Figure 3, looking from the right of such figure; Figure 5 is a view showing comparative tuning curves of two permeability tuned oscillators, one embodying this invention and the other following conventional practice; Figure 6 is a view of two comparative deviation curves, deviation of actual tuned circuit resonance frequency from indicated frequencies being plotted against dial readings, one being in connection with a tuning arrangement embodying this invention and the other being in connection with a conventional tuning arrangement; Figure 7 is a view of two curves indicating the Q of two coils with permeability tuning, one embodying this invention and the other not; Figure 8 is a longitudinal sectional view of still another embodiment of this invention; Figure 9 is a view similar to that of Figure 8, but with the parts in another position; and Figure 10 is a transverse sectional view along the line 10—10 of Figure 8.

2

Permeability tuning of a tuned radio circuit, particularly at high frequencies, has certain advantages over tuning by a variable condenser, but has always presented the disadvantage of not providing a straight line tuning curve, or of doing so only over a limited range of inductance variation. Previous attempts to overcome this difficulty have involved the use of coils wound with variable pitch, or of coils wound on a tapered form in combination with a tapered tuning core, or both of these expedients. These methods of straightening the tuning curve, however, are in themselves open to certain objections, particularly in that they are not adapted to commercial production, it being practically impossible to accurately reproduce the desired inductance and tuning range within reasonable manufacturing tolerances.

The present invention enables a cylindrical, uniformly wound coil and a cylindrical permeability tuning core to be used, yet it provides a tuning curve of a straightness and range even better than that usually found with a tapered or variable pitch coil. This is accomplished by placing a relatively short fixed permeability core in operative association with one end of the coil and moving a longer tuning core in and out of the other end of the coil, the two cores being separated by a definite air space in their closest position. This arrangement straightens the frequency-movement response curve, and lengthens the straight portion of such curve at the low frequency (high inductance) end. Moreover, the arrangement is such that a movable eddy current ring may be used to still further lengthen the straight portion of the tuning curve at the high frequency (low inductance) end of the tuning range. In addition, the short core provides an element which may be used for trimming or similar small variations of the inductance of the coil, and for temperature compensation purposes.

In the particular embodiment of this invention illustrated in Figures 1 and 2, a coil 10 is illustrated as uniformly and regularly wound on a cylindrical coil form 11. This coil, of course, may form the inductive portion of any tuned high frequency circuit, as the oscillator tank circuit of a radio transmitter. Axially movable within the coil 10 is a core 12, movement of this core affecting the inductance of the coil 10, movement being sufficient to enable tuning of the circuit in which the coil is an element over a substantial frequency range. The core should be of a diameter approaching that of the coil, and of a length of the same order, the core being of finely divided metal, as powdered iron, in a binder of insulating material. Such cores are well known and may be purchased on the open market, so no further description is made here.

The permeability core 12 is a cylinder, being here shown as cemented on a supporting member 13 of ceramic or other appropriate non-magnetic material. A nut 14 is provided at one end of this supporting member, this nut having an internally threaded cylindrical hole receiving a threaded shaft 15; and a nut 16 at the other end of the supporting member is provided with a square opening slidably receiving the square guide shaft 17. Since the core and its supporting member are prevented from rotating by the cooperation between the nut 16 and guide bar 17, rotation of the threaded shaft 15, as by a tuning dial or any other means, effects axial movement of the core. Any appropriate means, here illustrated as an annular ridge 18 within the coil form, limits the movement of the core to the right, into the coil; and movement of the core to the left, out of the coil, may be limited by the length of the threaded shaft 15, or by means associated with the tuning means for rotating this shaft.

A much shorter core 19, also of a diameter approaching that of the coil, lies within one end of the coil and affects its inductance, acting to concentrate the lines of flux through this end of the core and giving an effect analogous to that of "bunch winding." This core is also mounted on an insulated supporting member, here identified as 20, rigidly mounted on the shaft 17.

This relatively small core should have a length only a fraction of that of the tuning core 12, preferably being of the same diameter and of a length of from one-eighth to one-third of the coil. In its farthest in or maximum inductance position the tuning core 12 should be spaced from the smaller fixed core a distance of approximately one-quarter of the length of this smaller core.

In one commercial embodiment of this invention wherein the coil forms part of an oscillator tank circuit, very satisfactory results have been obtained with a 27 turn coil four and three-sixteenths inches long and two and three-quarters inches inside diameter; with the cores having an outside diameter of two and three-eighths inches and an inside diameter of one and one-half inch, the tuning core being four inches long and the shorter core one inch long. A range of movement of two inches was used for the tuning core, and it was spaced one-quarter inch from the fixed core at its closest position. There must always be enough space, at this closest position, that most of the flux in each core passes up through the turns of the coil rather than over and through the other core. If the cores are brought too closely together, the tuning curve breaks or curves sharply at its low frequency end. It has been found preferable to have the inner end of the tuning core extend in half of the tuning range beyond the center of the coil in the maximum inductance position, one inch beyond the center of the core in the above-mentioned specific case. The optimum placement of the shorter core in the coil is determined by measuring the inductance of the coil with the shorter core removed and the longer core centered therein; moving the longer or tuning core until its inner end extends half of the tuning range beyond the center of the coil, as mentioned above; and then moving the shorter core into the end of the coil until the inductance of the coil is the same as that previously measured, this giving the best position for the shorter core.

If the shorter core is too thin or too small and does not affect the inductance of its end of the coil sufficiently, there is not enough straightening of the lower end of the tuning curve. On the other hand, too long a fixed core causes the upper (high frequency) end of the tuning curve to bend over too quickly, too much fixed inductance pulling the whole frequency-movement response curve down in the frequency range.

This invention has been found to work best in regular coils with a coil factor greater than one (where the length is greater than the diameter), and in such cases the proper length for the fixed core (assuming a diameter approaching that of the coil) increases directly with the increase in coil length, and as the square of the coil diameter. I have found that, where the core is a hollow cylinder of a diameter approaching that of the cylindrical coil with a coil factor greater than one, the optimum length of the fixed core can be determined by the formula

$$l=\frac{S\times D^2}{K}$$

where l is the length of the fixed core, S is the length of the coil and D its diameter in inches, and K is an arbitrary constant having a value between 15 and 60, preferably about 30. At its closest position, the tuning core should be spaced from the fixed core a distance on the order of one-quarter of the length of this latter core.

While the core 19 is spoken of as a "fixed" core, it is fixed only in the sense that it is not moved during tuning; but it is adapted to be given slight axial movement for purposes of trimming adjustment, or temperature compensation. In the embodiment of this invention illustrated in Figure 1 the shaft 17 is shown as mounted in the center of and carried by a bi-metal strip 21. This strip is bolted or otherwise rigidly fastened to the coil form at its four corners as by the studs 22; and bolts 23, slidable toward and away from the shaft 17 in appropriate slots, provide adjustable means for immobilizing a desired portion of each end of the thermal plate, so that the effective or movable center portion can be regulated as to length. Variations in temperature cause variations in the curvature in the movable portion of the thermal strip, this in turn effecting minute axial movement of the core 19 to provide automatic compensation for inductance variation in the coil as a result of temperature changes. In fact, this method of compensation can be used to compensate for the condenser and for variations of all of the elements of the tuned circuit. This portion of the apparatus is not being more fully described nor claimed here, since it is the subject matter of a copending application by one Theodore A. Hunter, application Ser. No. 474,371, filed Feb. 1, 1943.

Another embodiment of my invention, utilizing an eddy current ring to provide an even longer straight line tuning range by straightening the upper portion of the tuning curve also, is shown in Figures 3 and 4. In this form of the invention the coil 30 is again regularly wound on a cylindrical form 31. A movable tuning permeability core 32 is axially movable within the coil form again comprising a hollow cylinder having a diameter approaching that of the coil and a length of that same order of appropriate material and improving the permeability without introducing undue losses at high frequencies. Axial movement of the core is effected by rotation of a tuning shaft 33, which is threaded and received by a nut 34 in a cylindrical supporting member 35, the construction in this regard being similar to that described in connection with the first form of this invention. In the present instance, however, the cylindrical supporting member 35 extends out of the back of the coil (as it is here being termed) a substantial distance.

As in the earlier described form of my invention, a short or "fixed" core 36 of permeable material lies within and is adapted to affect the inductance of one end of the coil 30. In this particular modification the core is shown as cemented or otherwise permanently fastened in place within the coil form, although it could equally well be so mounted as to permit minute movements for trimming or temperature compensation, as illustrated earlier; and its size, spacing from the movable core 32, and location within the coil are determined as previously described. Movement of the tuning core 32 may be effected by manual rotation of the shaft 33, or by rotation of this shaft by automatic means—in which case appropriate stop means not shown here are associated with the shaft rotating and positioning apparatus, as disclosed in the co-pending application of Arthur A. Collins, Serial No. 472,717, filed January 18, 1943. The supporting member 35 is permitted axial movement upon rotation of the shaft but can be prevented from rotational movement as by cooperation of a slot 37 therein with a ridge or shoulder fixed to the inside of the shorter core 36.

The outer or righthand end of the supporting member 35 carries an eddy current ring 38 of copper or other appropriate material, this ring being concentric with the supporting member and supported in desired fixed relation thereto by the brackets 39. The parts are shown in solid lines in Figure 3 in their low frequency or maximum inductance position. It will be obvious that movement of the tuning core 32 to the high frequency or maximum inductance position not only withdraws this core from the coil but also, since the eddy current ring 38 is movable with it on the same supporting member, causes the eddy current ring to finally go to the dotted line position illustrated, where it affects the same end of the coil as the fixed core 36. In the position shown in dotted lines, and positions closely approaching this, the eddy current ring reduces the affect of the internal fixed core 36, thus straightening out the tuning curve and lengthening it at the upper or high frequency end. That is, the effects of the permeability core 36 and the eddy current ring 38 upon the inductance of the end of the coil with which it cooperates are opposite, so that if the eddy current ring comes into operation at the high frequency end of the tuning range it neutralizes, to a large extent, the effect of the fixed core 36.

Referring now more particularly to the illustrative views, Figure 5 shows the curve of two comparative tuning arrangements, one embodying this invention and the other without. In both cases the coil used was the tuning coil of an oscillator tank circuit, the particular coil of which the dimensions were previously given; and hollow cylindrical permeability cores having the internal and external diameter previously mentioned were used with it. In the case of the curve here identified as 51, the arrangement embodied the invention disclosed here, the movable core being four inches in length and being used in association with a fixed core of one inch length. In the case of the curve here indicated as 52, a five inch movable core was used, being centered on the coil at the start of its motion. The better shape of the tuning curve 51 and its closer conformance of actual frequency to dial readings is obvious.

The same advantage is illustrated in a somewhat different way in Figure 6. Again, the coil had the number of turns and dimensions previously specified, and the permeability cores were made from the same cylinders. In the case illustrated here, the curve indicated as 61 was made in connection with a four inch moving core and a one inch fixed core; and the curve indicated as 62 was made only with a four inch moving core. In this chart actual frequency in megacycles in the circuit thus tuned are plotted against deviations (in cycles) of the dial reading from the true frequency. The way in which the actual frequency of the tuning oscillator tank circuit deviates only slightly from the straight line dial readings, when my invention is used, is illustrated by the curve 61; and this is to be contrasted with the substantial deviation indicated by the curve 62.

The advantages of this invention in maintaining a more uniform reactance-resistance ratio of the coil, its Q, are illustrated in Figure 7. Here frequency in kilocycles are plotted against the Q of the coil. Again the same coil and the same core material was used, curve 71 being made with a four inch moving core and a one inch fixed core, curve 72 being made only with a four inch moving core. In the case of previous conventional practice, curve 72 shows that the Q of the coil varies from 200 to about 330 in the frequency range of from 900 to 1300 kilocycles, resulting in a considerable variation in the selectivity characteristics of the circuit, an undesirable feature. On the other hand, curve 71 illustrates that permeability tuning over the same frequency range with the present invention causes a variation in Q between a minimum of about 270 and a maximum of about 312. That is, by the use of this invention the Q of the coil at the low frequency end of the tuning range was substantially increased, and its over-all variation substantially reduced, both highly desirable characteristics. Some embodiments of this invention have resulted in an increase of over 50% in the Q of the coil at the low frequency end of the tuning range as compared with previous conventional permeability tuning.

Still another embodiment of this invention is illustrated in Figures 8, 9 and 10. The tuning device shown in these views also employs a regularly wound cylindrical coil and regular cores, but it provides an even longer straight-line tuning range than the form illustrated in Figures 3 and 4. This is accomplished by moving the shorter core out of the end of the coil with which it cooperates as the eddy current ring becomes more effective. In order to get the best tuning characteristic curve it is necessary to delay the movement of the shorter core until the longer tuning core has moved for a certain distance; and then to move it at a lesser rate than the tuning coil.

Referring now to the specific form shown in these last figures, it will be seen that the coil 80 is regularly wound on a cylindrical insulating form 81. A permeability tuning core 82 of cylindrical form having a diameter approaching that of the coil and a length of the same order is axially movable. Axial movement is effected by rotation of a tuning shaft 83, the threaded portion 83*a* cooperating with a nut 84 rigidly mounted in one end of a cylindrical supporting member 85. The supporting member is prevented from rotation by means which will be hereafter more fully described analogous to that of the earlier described modifications, so that rotation of the tuning shaft effects axial movement of the main tuning core 82 at a rate depending upon the pitch of the threads on the portion 83*a*.

The shorter core 86 of permeable material cooperates with the right-hand end of the coil (speaking with respect to the position of the parts as shown) and is adapted to affect the inductance of the coil, particularly at this end. This core is axially movable, its movement to the left being limited by the internal annular stop shoulder 81*a* toward which it is urged by springs 90. The size of this shorter cylindrical permeability core, its spacing from the main tuning core 82, and the other factors of design and location are determined exactly as described in connection with the shorter cores of the previously described modifications of my invention.

The outer or right-hand end of the supporting member 85 is slidably but non-rotatably splined upon a polygonal shaft 91, here shown as square. It is this splined arrangement which permits longitudinal but prevents rotational movement of the main tuning core. This end of the supporting member carries an eddy current ring 88 of copper or similar highly conducting material, this last being concentric with the coil and supported in desired relation to the supporting member 85 by brackets 89. Since this eddy current ring is mounted on the same supporting member as the main tuning core 82, its movement is in the same direction and at the same rate as that of the tuning core.

An additional moving member is provided in the form of the cylinder 92 of insulating material, this cylinder carrying at one end a nut 95 which cooperates with the threaded portion 83*b* of the tuning shaft. The threads on this portion are of lesser pitch than those on the portion 83*a* so that the movable member 92 moves at a rate which is only a fraction of that of the supporting member 85 upon rotation of the tuning shaft 83; and the threads are formed in the opposite direction, so that the member 92 moves to the right while the tuning core is moving to the left. At the right-hand end the moving member 92 carries an end member 93 with projecting pins 93*a* and 93*b* received in and cooperating with slots 86*a* and 86*b* in the shorter core. These pins project through appropriate slots 85*a* and 85*b* in the supporting member 85.

The operation of the device upon rotation of the tuning shaft 83 can be best understood from a comparison of the positions of the parts in Figures 8 and 9. The parts are shown in Figure 8 in the position of maximum inductance, at the low frequency end of the tuning range; and in Figure 9 in the position of minimum inductance, at the high frequency end of the tuning range. Referring to the position of the parts as shown in Figure 8, it will be apparent that rotation of the tuning shaft 83 effects movement of the tuning core 82 out of the coil, to the left; and effects movement of the member 92 in the opposite direction at a reduced rate. The shorter core 86 does not move, however, until the pins 93*a* and 93*b* have reached the end of the slots in the shorter core. Thereupon, however, the shorter core moves out of that end of the coil, to the right, at a rate which is a fraction of the movement of the coil 82, compressing the springs 90 as it does so. At the same time the eddy current ring 88 is approaching the end of the coil and exerting its effect upon the inductance of the coil. Thus the inductance of the coil is reduced not only by movement of the main tuning core but also by outward movement of the shorter core; and, at the same time its inductance is still further reduced by the effect of the eddy current ring. Proportioning of these movements, in the manner illustrated in Figures 8 and 9, provides a considerable extension of the upper or high frequency end of the tuning characteristic curve, maintaining this straight over a further range by appropriate outward movement of the shorter permeability core as the eddy current ring becomes effective.

While I have shown and described certain embodiments of my invention, it is to be understood that it is capable of many modifications. Changes, therefore in the construction and arrangement may be made without departing from the spirit and scope of the invention as disclosed in the appended claims.

I claim:

1. A tuning arrangement of the character described, including: a coil; a core axially movable in the coil for tuning, the movement of this core effecting a substantial variation in the inductance of the coil; a second shorter core operatively associated with one end of the coil, this core also being axially movable in the coil; and tuning means operatively connected to both of said cores to effect the desired movements thereof.

2. Apparatus of the character claimed in claim 1, wherein the connections are so arranged that the shorter core is moved at a lesser rate than the first mentioned core.

3. A tuning arrangement of the character described, including: a coil; a permeability core axially movable in the coil for tuning, the movement of this core effecting a substantial variation in the inductance of the coil; a second shorter permeability core operatively associated with one end of the coil, this core also being axially movable in the coil; an eddy current ring movable toward and away from said end of the coil; and tuning means operatively connected to both of said cores and to said ring to effect the desired movements thereof.

4. Apparatus of the character claimed in claim 3, wherein the connections are so arranged that the first mentioned core and the ring move in the same direction and at the same rate, and movement of the shorter core is initiated later than that of the other parts and is at a lesser rate.

5. A permeability tuning arrangement of the character described, including: a cylindrical, uniformly wound coil having a length greater than its diameter; a cylindrical core of a diameter approaching that of the coil and axially movable

therein through a substantial distance for tuning, this core having a length greater than half that of the coil; and a second cylindrical core operatively associated with only one end of the coil, this core having a diameter slightly less than but approaching that of the coil, having a length between one-eighth and one-third of that of the coil, and lying at least partly within one end of the coil.

6. Apparatus of the character claimed in claim 5, wherein the movement of the first-mentioned core is limited so that, in its closest position to the second core, it is spaced therefrom a distance of the order of one-twentieth of the length of the coil.

7. A permeability tuning arrangement of the character described, including: a cylindrical, uniformly wound coil having a length greater than its diameter; a cylindrical core of a diameter approaching that of the coil and axially movable therein through a substantial distance for tuning, this core having a length greater than half that of the coil; and a second cylindrical core operatively associated with only one end of the coil, this core having a diameter slightly less than but approaching that of the coil, lying at least partly within one end of the coil, and having a length determined by the formula

$$l=\frac{S\times D^2}{K}$$

where l is the length of the second core, S is the length of the coil, and D is its diameter, all such dimensions being in inches, and K is an arbitrary constant having a value between 15 and 60, the movement of the first mentioned core being limited so that, in its closest position to the second core, it is spaced therefrom a distance of the order of

$$\frac{l}{4}$$

8. Apparatus of the character claimed in claim 7, where the arbitrary constant K has a value of about 30.

9. A permeability tuning arrangement of the character described, including: a cylindrical, uniformly wound coil having a length greater than its diameter; a cylindrical core of a diameter approaching that of the coil and axially movable therein through a substantial distance for tuning, this core having a length greater than half that of the coil; a second cylindrical core operatively associated with only one end of the coil, this core having a diameter slightly less than but approaching that of the coil, having a length substantially less than half that of the coil, and lying at least partly within one end of the coil; and an eddy current ring operatively associated with said one end of the coil and connected to the first-mentioned core for movement therewith, the ring moving toward said one end of the coil as the first-mentioned core moves away from the second core.

ROBERT B. BEETHAM.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,168,351	La Rue et al.	Aug. 8, 1939
2,180,175	Sivertsen	Nov. 14, 1939

FOREIGN PATENTS

Number	Country	Date
441,982	Great Britain	Jan. 30, 1936
298,990	Great Britain	Aug. 22, 1929