May 23, 1933. F. B. LLEWELLYN 1,910,957

REACTIVE ELEMENT HAVING STABLE TEMPERATURE REACTANCE CHARACTERISTICS

Filed Jan. 13, 1932 2 Sheets-Sheet 1

FIG. 1

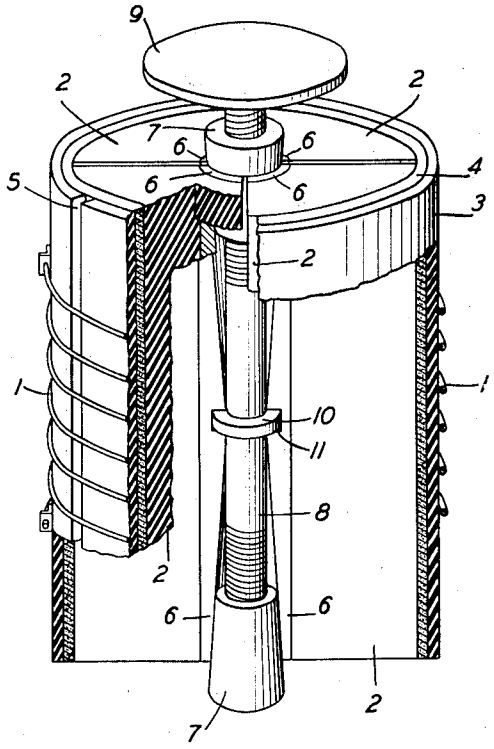

FIG. 2

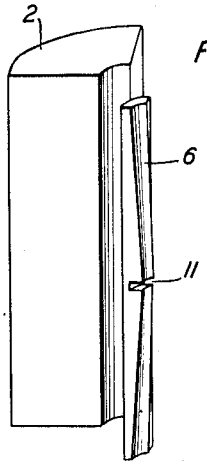

FIG. 3

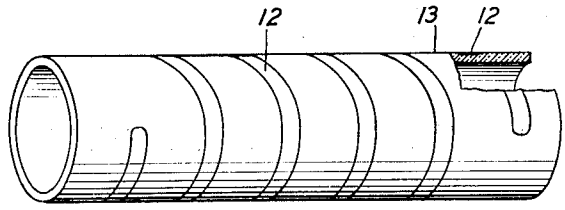

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FIG. 4

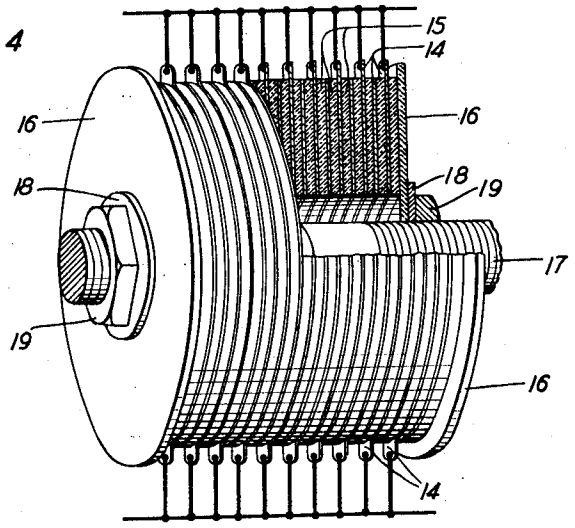


FIG. 5

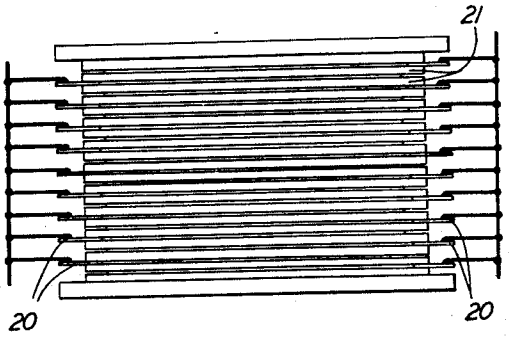
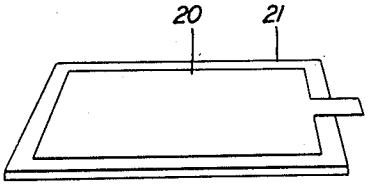


FIG. 6



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Patented May 23, 1933 1,910,957

UNITED STATES PATENT OFFICE

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REACTIVE ELEMENT HAVING STABLE TEMPERATURE-REACTANCE CHARACTERISTICS

Application filed January 13, 1932. Serial No. 586,266.

This invention relates to reactive circuit elements and particularly to means for predetermining the effect of variation of temperature on the reactances of such elements.

It is an object of the invention to stabilize the reactive properties of such elements under conditions of temperature change, that is, to insure that their variations of reactance with temperature change will proceed in accordance with a desired definite and normal physical law. In practical embodiments of the invention, the temperature coefficient of reactance may be either substantially zero or have a definite finite value.

It is another object of the invention to achieve adjustment of the temperature coefficient of such reactances by means which are simple, systematic, capable of uniform and gradual variation, and which have a minimum effect on other characteristics of the reactive elements.

In the cases of both inductors and condensers of conventional types the reactance varies in one direction with a change in an axial dimension and in the other direction by a change in a transverse dimension. In an inductor, these dimensions are respectively the length and radius of the inductance coil, or more specifically, the length and cross-section of the coil. In a condenser, these dimensions are respectively the interelectrode spacings and the radii or areas of the electrodes.

Consistently with this physical law, the invention is expressible in two generic forms, each of which may, in turn, be divided according as the principle is to be applied to an inductor or to a condenser.

In one form, the variations of the two dimensions with changes in temperature are caused, by simple mechanical means, to mutually compensate to any reasonable degree so as to result in a desired overall temperature coefficient of reactance.

In the other form, the reactances are made stable by insuring either a relative invariability of the dimensions affecting the reactance or a definite predeterminable variation of such dimensions, under variable conditions of temperature, as by integrally securing the coil or electrodes to a support which has a substantially zero coefficient of expansion with change of temperature, or which has a definite coefficient of expansion with change of temperature. The use of fused quartz has been found to be particularly effective, especially when the coil or electrode is in the form of a thin conductive coating secured to the quartz with an intimacy such as would result, for example, from the use of a cementing or a "sputtering", process.

For a better understanding of the invention, reference is made to the following detailed description taken in connection with the accompanying drawings in which:

Figs. 1 and 2 illustrate, respectively by a broken perspective and by a detail of one element, an inductance so mounted as to have a temperature-reactance characteristic which may be easily varied as desired;

Fig. 3 illustrates an inductance coil which is so mounted as to be invariable in the dimensions which affect its reactance so that the coil is immune from the effect of reactance variations due to temperature;

Fig. 4 illustrates a condenser whose parts are so mounted relatively to each other and made of such material that its temperature-reactance characteristics may be changed at will within a reasonable degree; and

Figs. 5 and 6 illustrate a condenser, and an element thereof, respectively, so mounted as to be invariable with respect to dimensions which affect its reactance so as to be substantially immune from the effects of temperature variations on its reactance.

The structural form of the inductance coil organization illustrated by Figs. 1 and 2, whereby the variations of the two signifi-

cant dimensions with changes in temperature are caused to mutually compensate to any reasonable degree, is predicated on the following formula expressing the law of variation of the inductance of a single layer solenoid coil in terms of such variations of dimension.

$$\frac{\Delta L}{L}=2\frac{\Delta a}{a}-\frac{\Delta b}{b}+\frac{\Delta K}{K}$$

where:

a=the radius of the coil

b=the length of the coil

K is what is known as Nagaoka's coefficient.

It happens that Nagaoka's coefficient may, for practical purposes, be considered as a constant, its variations with temperature being of negligible importance as compared with the similar variations of the dimensions identified in the formula.

From this formula it is apparent that the effect of temperature may be such as to either increase or to decrease the inductance, according as to whether the radius or the length term exerts a preponderating effect. For instance, if the ends of the coil were held a fixed distance apart it is apparent from the formula that the coefficient of inductance of the solenoid coil would be approximately twice the linear coefficient of expansion of the conductor constituting the coil since the $\frac{\Delta K}{K}$ term is small and since the variation in the radius of the coil is of course a direct function of the change in linear length of the conductor making up the coil.

Now, imagine that instead of being fixed the two ends of the coil are fastened to a form which has a coefficient of expansion equal to twice that of the conductor. With this arrangement, the overall coefficient of the coil will consist only of the coefficient corresponding to the small correction factor K since the remaining two terms completely mutually compensate for each other. Therefore, a suitable selection of the material of the form, as determined by its temperature coefficient of expansion, will yield a coil whose overall coefficient is zero. Analogously the coefficient may be, within reason, somewhat greater than zero in either direction.

Now, consistently with the disclosure in Figs. 1 and 2, imagine the form on which the conductor is wound to consist of a cylinder cut into four quadrants or the like so arranged with expansion bushings that they may be moved radially to press against the helix formed by the conductor wire. When the form exerts no pressure on the helix, which may be substantially realized by interposing a thin sheet of sponge rubber or the like between the form and the wire, there is the condition that the coefficient corresponding to the first term of the formula at the right of the equal sign, is a function of the linear coefficient of the conductor while the coefficient corresponding to the second term of the formula at the right of the equal sign is a function of that of the form. If the coefficient for the form is large it is thus quite possible to secure an overall coefficient which is negative.

Now let it be imagined that the bushings are actuated so as to move the quadrants outwardly until the form presses tightly against the helix. If the coefficient of the form is larger than the coefficient of the conductor, a condition which is easily realizable in practice, the dimensions of the coil will be strictly a function of the dimensions of the form as effected by its coefficient of expansion, the conductor being stretched an amount governed by the increase in dimensions of such form. Under these conditions, consistently with the relations given in the formula, the overall coefficient may be expected to be positive.

Adjustment of the bushings for pressures between these two limiting conditions will correspondingly adjust the overall temperature coefficient over the range including both negative and positive values. In an experimental coil it was found that the coefficient of inductance could be varied between +60 parts in a million and −30 parts in a million per degree centigrade. The experimental coil was placed in an oscillation circuit with a condenser which had a negative coefficient of about 50 parts in a million. Without great difficulty it was found possible to obtain an overall coefficient for the oscillator whose frequency was determined by the natural frequency of said oscillation circuit which was very small.

An inductance coil organization as last described is illustrated in Figs. 1 and 2. The coil is represented by reference numeral 1, which coil is wound on a form which is comprised principally by the four quadrantal masses (herein to be called quadrants) indicated by reference numeral 2. Since these quadrants are adaptable for movement relatively to the coil, the coil is separated therefrom by a tubing, made of hard rubber or the like, 3, on which the coil is immediately wound and which therefore separates the quadrants from the coil and insures that their movements do not result in abrasion thereof. Between the quadrants and the tube 3 is a layer of sponge rubber or the like 4 through which pressure may be transmitted from the quadrants to the inside surface of the hard rubber tubing and thence to the coil itself. In order that the dimensions of the hard rubber tube 3 may accurately reflect the movements of the quadrant in a radial direction, and therefore to insure that

it functions only as a "wear" member for the coil, said tube is slotted at 5.

The quadrants are actuated in a radial direction by correspondingly shaped cam members 6 which in turn are responsive to the screw-fed movement of frustum members 7, which are constrained to both move simultaneously toward or away from the center of the form by screw 8, which is oppositely threaded at the respective extremities to insure this relative movement. The screw is propelled by knurled head or the like 9. The cam members are constrained to a fixed axial position by engagement of a lug 10 at the mid-section of the screw member in slot 11 of such cam members. Fig. 2 illustrates better than the broken perspective of Fig. 1 the relation of the quadrants and their actuating cam members.

It is evident that the screw, frustums and cam members cooperate effectively as an expansible bushing organization. The mass of the quadrants may be made large as compared with that of all of the other elements taken together and therefore to be more significant in respect to the effect of temperature-responsive expansions of the form as a whole. It is presumed that the movement of the quadrants is small and that the elastic reaction of the coil itself with that of the sponge rubber and hard rubber tube is sufficient to restore the quadrants to such a position as to accommodate them to the positions of the frustums when propelled outwardly, that is, when moved so as to relieve the coil of stress.

Fig. 3 illustrates the alternative type of temperature-stable inductance which is distinguished from the one disclosed in Figs. 1 and 2 by the fact that the dimensions of the inductance coil are made invariable with changes in temperature. Of course, in the instance of this alternative type the temperature-reactance coefficient, for a given frequency, is substantially zero rather than being adjustable to a desired value.

The invention disclosed in Fig. 3 depends for its efficacy on the fact that fused quartz has a temperature coefficient which equals substantially zero, specifically 0.5 part in a million per degree centigrade. The inductance coil 12 is in the form of a very thin conducting strip so attached to the fused quartz tube 13 as to partake of its changes of dimensions or figure to the exclusion of any change in dimension of the conductor individual to itself. Experiments have indicated that it is quite possible to attach conducting material (specifically copper) to a fused quartz form by the sputtering process so that the resultant conductor is thin enough to exert no appreciable force on the quartz. An inductance coil so mounted would satisfy the above conditions and therefore would have closely the temperature coefficient of the fused quartz form. Obviously, the form may have embodiments alternative to that disclosed. For example, it could be constituted by a solid fused quartz cylinder. The conductor could even be fastened to the surface of a fused quartz plate in the form of a spiral.

The sputtering process, which is one process by which a conductor may be so intimately associated with the quartz form as to satisfy the conditions, is old and well known in the art. Instances of patent disclosures in the prior art of this or related processes are Burtis 1,692,074, January 20, 1928; Hitchcock 1,790,148, January 27, 1931 and Hartley 1,565,566, December 15, 1925. Similar disclosure of the process may be found in the Journal of the Franklin Institute, vol. 196, 1923, page 751, and in the Journal of the Society of Scientific Instruments for June 1930, page 193. Alternatively to the use of the sputtering process or other analogous processes of metal deposition, an electroplating process may be used with like effect, this, of course, necessitating initially providing a conducting course of some kind as by one of the deposition processes.

Fig. 4 discloses a condenser having a stable temperature-reactance coefficient and one which may easily be varied between reasonably spaced limits of opposite sign. The coefficient may be adjusted as in accordance with a method somewhat analogous to that described in connection with Figs. 1 and 2.

In U. S. patent to Gabriel and Thurston 1,722,083, granted July 23, 1929, there is disclosed a relation involving the dimensions of the significant elements of a fixed air condenser and its temperature coefficient so as to enable one, knowing the temperature coefficient of the respective materials used, to closely predetermine the temperature coefficient of the condenser as a whole. In such relation the temperature coefficient of the material of the spacers is a significant item. The condenser disclosed in Fig. 4 may be considered, according to one aspect, as a condenser of the Gabriel-Thurston type provided with a convenient means for varying at will the temperature coefficient of the aggregate of spacers. The condenser is constituted by condenser plates 14 alternating with separating insulating members 15, the whole being confined between end plates 16 by bolt 17, washer 18 and nuts 19. The condenser assembly is, therefore, basically the same, as so far described, as conventional forms of drystack condensers.

An important feature of the invention is the bi-metallic nature of the bolt 17. If the two portions, which are axially aligned, are of materials having different tempera-

ture coefficients of expansion, perhaps one being of one sign and the other of the opposite sign, the assembly is such as to permit this holding bolt to be adjusted, by backing off one nut 19 and turning up the other, relatively to the condenser plate so as to interpose in expansion-significant relation to said condenser plates the desired relative portions of the bolt. In this way, the temperature coefficient of expansion of the bolt, so far as concerns the condenser plates, may be adjusted between the two limits corresponding to the temperature coefficients of the respective portions of the bolt.

As simulating the Gabriel-Thurston condenser, the invention provides a means for effecting a temperature coefficient adjustment that could be effected in the Gabriel-Thurston condenser only by choice of spacer material. However, regardless of the temperature coefficient of the other parts of the condenser, the bi-metallic bolt does at least enable an adjustment of a condenser element which has significance as to the temperature coefficient of the combination as a whole, and, in this aspect, the invention may be used more generally than in the Gabriel-Thurston organization.

It is a condition necessary to the effective functioning of the bi-metallic bolt that the elasticity of the combination of plates and spacers be small enough so that the change in axial dimension of the condenser is governed substantially entirely by the change in length of the bolt. This condition may most easily be satisfied if the condenser plates and spacers are put under considerable compression by nuts 19 and washers 18. This perhaps is the principal reason for the extension of the spacers 15 nearly to the edges of the condenser plates.

Figs. 5 and 6 illustrate a substantially zero temperature coefficient condenser of a type analogous to the zero temperature coefficient inductance coil illustrated in Fig. 3. That is, the condenser plates or electrodes are constituted by thin metallic coatings on fused quartz plates, the coatings being so intimately associated with the plates as to insure that the coating has no variation of dimension specific to itself but partakes wholly of the characteristics of the plate on which it is mounted as to change in dimension. A condenser so constituted therefore has the same temperature coefficient as that of the plate.

The coating may be united with the plate by any of the methods described in connection with Fig. 3, the sputtering process perhaps being of most general availability.

Fig. 5 illustrates the organization of a plurality of units, each unit being illustrated in Fig. 6 in which the reference numeral 20 indicates the coating and reference numeral 21 indicates the plate, the corresponding element in Fig. 5 being similarly numbered. The various units are shown as build-up into the resultant multi-unit condenser much after the manner of conventional drystack condensers, and somewhat after the manner of the condenser of Fig. 4. As being subject to physical variation to adapt it to special environments in ways not significant for the present purpose, the multi-plate condenser as a whole is shown devoid of much of the detail that might otherwise be illustrated. It is noted, however, that the unit illustrated by Fig. 6 does not constitute a complete condenser, being rather a constructional unit. Rather, each quartz plate with its own coating and the coating of the next adjacent plate constitutes a condenser unit. As illustrated in Fig. 5 (and analogously in Fig. 4) the condenser as a whole is adapted to be connected into its associated circuit by electrically connecting alternate sets of electrodes together, each set effectively constituting the corresponding electrodes of a like number of parallel unitary condensers, each electrode therefore functioning with respect to two such unit condensers.

What is claimed is:

1. A reactance element comprising electrical structure, a support therefor, and means attaching said electrical structure to said support so as to tend to cause it to change all of its electrically significant dimensions in accordance with the temperature-responsive changes in dimensions of the support, the relative elasticities of said structure and said support being such that the structure is readily coerced by the support.

2. In a reactor, in combination, mounting means whereby a given dimension of the reactor varies with temperature, and means associated with the first mentioned means whereby a dimension transverse with respect to the first dimension varies with temperature, said two means having such relative variation characteristics as to mutually compensate said changes of dimension to a desired degree depending on the desired overall temperature coefficient of reactance for a given frequency.

3. A reactance element comprising electrical structure, a support therefor, said support having a fixed and known temperature coefficient of expansion, and means integrally attaching said electrical structure to said support.

4. The combination specified in claim 2 in which said reactor is a helical inductance coil.

5. The combination specified in claim 2 in which said reactor is a condenser.

6. A temperature-reactance stable inductor comprising a linear conductor, a sup-

port therefor having a fixed and known temperature coefficient of expansion, and means unitarily attaching said conductor throughout its linear extent to said support, the relative elasticities of the conductor and support being such that the dimensions of the conductor in a plane parallel to the surface of the support are responsive substantially wholly to the temperature-dimensional changes in the support.

7. A temperature-reactance stable condenser comprising electrodes, a support for each said electrodes having a fixed and known temperature coefficient of expansion, and means unitarily attaching each said electrode at every portion of at least one of its principal surfaces to its support, the relative elasticities of each electrode and its support being such that the dimensions of each said electrode in a plane parallel to the surface of the support is responsive substantially wholly to the temperature-dimensional changes in the support.

8. The structure specified in claim 3 in which the support principally comprises a mass of fused quartz.

9. The structure specified in claim 6 in which the support comprises a mass of fused quartz.

10. The structure specified in claim 7 in which the support principally comprises a mass of fused quartz.

In witness whereof, I hereunto subscribe my name this 12th day of January, 1932.

FREDERICK B. LLEWELLYN.