

May 5, 1964

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ALTERNATING CURRENT SYSTEM FOR NEGATIVE RESISTANCE LOADS

Filed May 23, 1960

2 Sheets-Sheet 1

Fig. 1

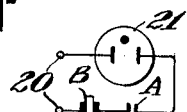
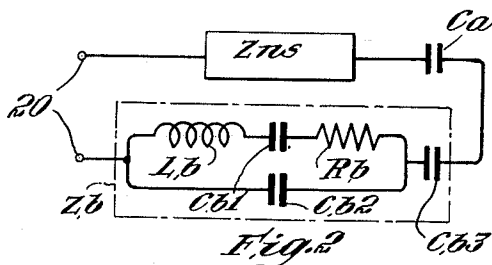
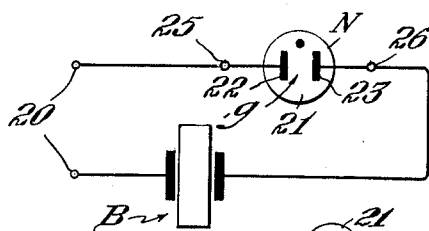


Fig. 1a

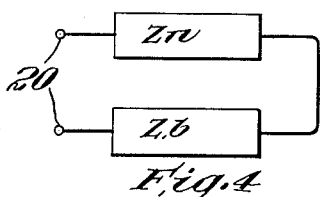
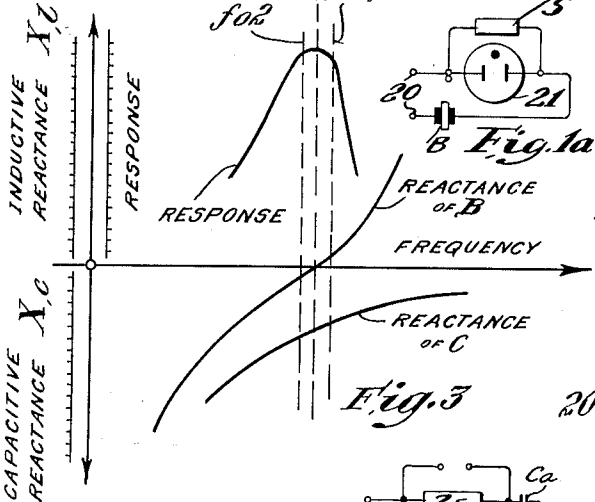
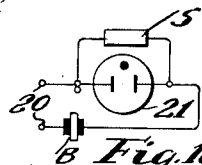


Fig. 4

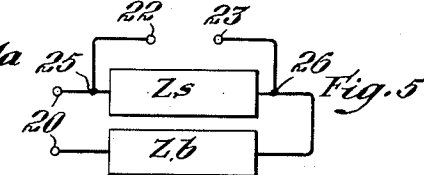


Fig. 5

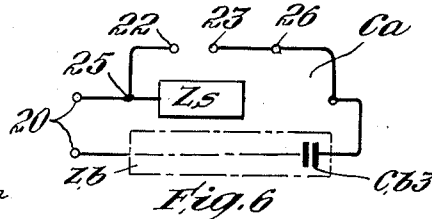


Fig. 6

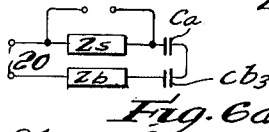


Fig. 6a

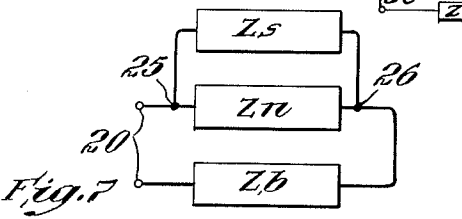


Fig. 7

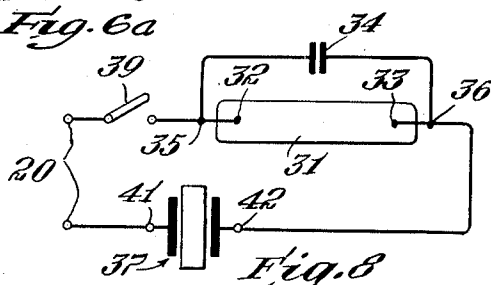


Fig. 8

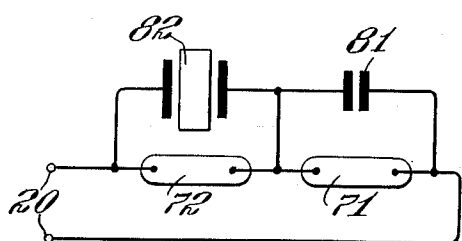


Fig. 15

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ALTERNATING CURRENT SYSTEM FOR NEGATIVE RESISTANCE LOADS

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2 Sheets-Sheet 2

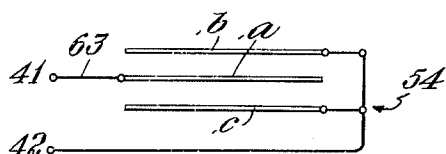


Fig. 12

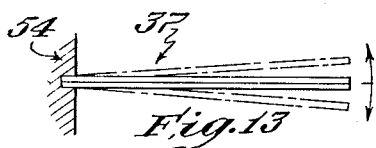
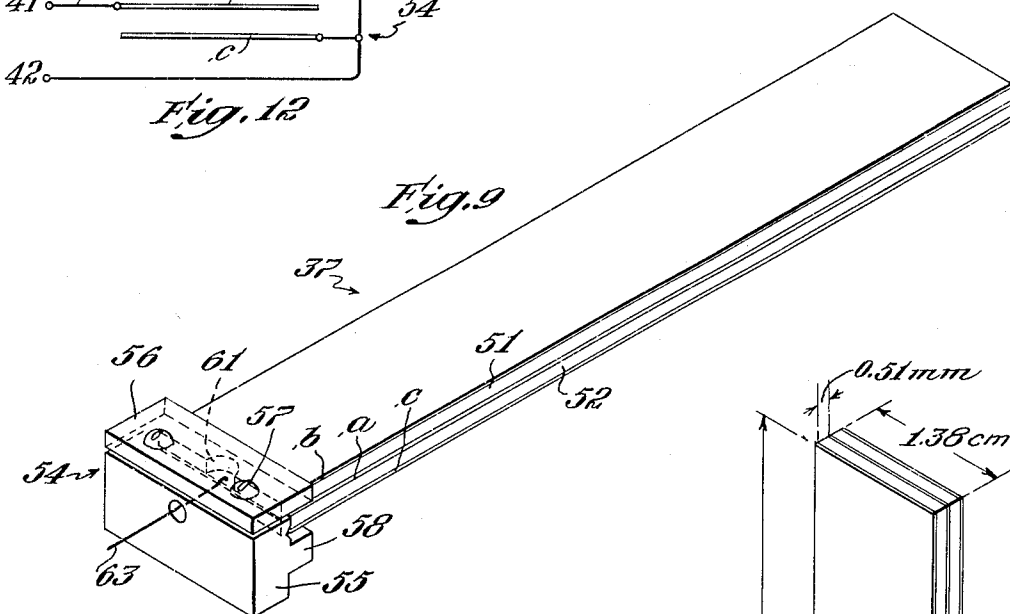


Fig. 13

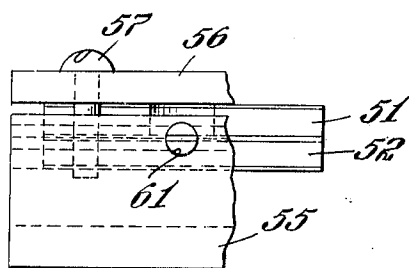


Fig. 10

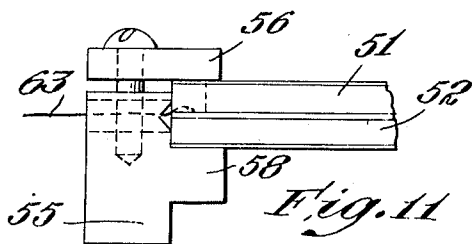


Fig. 11

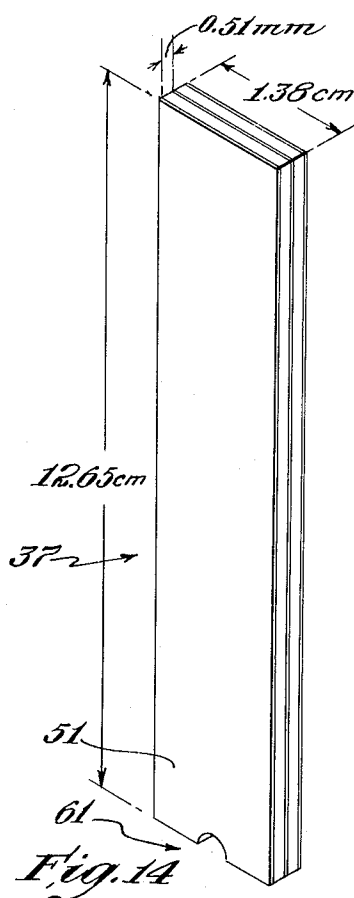


Fig. 14

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ALTERNATING CURRENT SYSTEM FOR NEGATIVE RESISTANCE LOADS

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22 Claims. (Cl. 315-284)

The present invention relates to a system, including a method and apparatus for carrying out that method, of utilizing alternating current operated loads with negative resistance. It includes apparatus peculiarly suited for purposes of providing ballast or starting impedances in accordance with the invention and, as particularly practical embodiments, it embraces circuits and devices for the starting, and stable operation of gaseous discharge apparatus such as fluorescent lamps.

It is well known that the operation of loads which have negative resistance over at least part of their operating range (such as arc discharge devices including solid electrode arcs and gaseous discharge apparatus) requires stabilizing series impedances or ballasts, compare for example C. D. Child, "Electric Arcs."

At the present time conventional reactive impedances are used for the purpose of operating such loads with alternating current, including transformers and inductors which are quite cumbersome and expensive and the supply of which is critical since they involve comparatively large iron cores with heavy copper windings.

It is one object of the present invention to provide a system for safely operating with alternating current negative resistance loads, with comparatively simple, inexpensive and light ballast devices which can be easily set or adjusted to any operating frequency, which involve a minimum amount of metal and similar critical materials, and which fully replace the heretofore employed devices of undesirable size and weight requiring large amounts of copper, iron, wax and other critical materials.

Certain loads, including many of the above-mentioned negative resistance loads, present in inoperative condition very high resistances and require provisions for starting them by bridging in some manner the gap of practically infinite resistance prior to normal operation. One such starting expedient, especially useful in the case of gaseous discharge devices, is the application of a high starting voltage.

It is another object of the invention to provide a system which automatically provides, with a minimum of bulk and critical materials, for the reliable application of wholly adequate starting voltages which can easily be made to exceed those heretofore attained with conventional means.

The above-mentioned ballast or starting system according to the invention can be used in combination with conventional starting or ballast devices respectively, or both starting and stable operation can be secured according to the invention by peculiar organization thereof without essential addition or complication of arrangements such as would be used only for normal operation or starting, respectively.

Particularly important and now frequently employed examples of negative resistance loads are gaseous discharge tubes such as fluorescent lamps and neon signs. In common with all negative resistance loads, such gaseous discharge tubes have characteristics of decreasing impedance with increasing current, within the current and voltage ranges ordinarily employed. They also require starting voltages which exceed in value the voltages which are sufficient to maintain normal current. More or less complicated starting devices for this purpose have been proposed, and these are in many instances separate from or at least add considerably to the bulk and expense of

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the ballast devices. It is the usual practice of operating such lamps from constant voltage alternating current lines to employ a reactive impedance as device for providing a proper starting voltage and also as the current limiting device in the steady state condition. The ballast element in series with the discharge device is most commonly an inductor but may be a resistor or capacitor or some combination thereof. To obtain an adequate starting voltage and to gain flexibility in design of the ballast, a high reactance autotransformer is commonly employed.

For the purpose of eliminating the need for such undesirable conventional circuit components, further objects of the invention are to provide improved starting means for overcoming the large initial impedance of nonconductive gas discharge tubes, to provide novel limiting reactor means for dampening and quieting the operating current of such loads, and to provide a system for starting and operating gaseous discharge tubes which completely dispenses with conventional ballast reactors or transformers and which if desired also assumes the function of the expensive and bulky high voltage capacitors which are often used for purposes of proper current phasing.

It is often considered desirable to reduce the so-called stroboscopic effect of gaseous discharge lamps by means of so-called lead lag arrangements for two or more lamps, although it has been found that simple series ballast arrangements are in many instances sufficient, particularly also due to the more recently developed phosphorus with considerable luminescence lag.

It is an additional object of the invention to provide lead lag installations practically without additional cost, by way of a peculiar utilization of ballast or starting arrangements according to the invention.

A further object of the invention is adaptability to the problem of starting the so-called hot cathode discharge devices whose electrodes are preheated prior to applying the main discharge voltage as well as the so-called cold cathode lamps which do not require such preheating; the present invention is applicable, with the above-mentioned advantages, to either type of gas discharge devices.

A still further object of the invention is to provide a starting system for gaseous discharge tubes which rapidly applies one of the requisites, namely a voltage that is considerably higher than that heretofore found practical in view of the economically possible conventional starting devices, thus shortening the starting period and prolonging the life of the lamps, for well-known reasons inherent in the nature of electron emitting materials used for cathodes of such devices. In accordance with the present invention, it becomes economically feasible to provide starting voltages higher than those heretofore thought feasible so that there is no longer any practical limitation on the magnitude of the starting voltage, up to values of the order of thirty times the line voltage. Accordingly, the starting period can be reduced to a few cycles of the power supply frequency which results in increased tube life since a prolonged starting period is one of the factors that reduce the life of cathodes.

Mechanically strained impedance devices such as potential (electric field) responsive piezoelectric bodies or current (magnet field) responsive magnetostrictive bodies define reactance values which are functions of the mechanically adjustable inherent resonance frequency of such bodies and the supply or operating frequency. For a given operating frequency, these reactance values can be selected by mechanical dimensioning or adjustment of the said bodies as incorporated in a given circuit, from practically appreciable inductive values through zero (with only the ohmic resistance remaining) to practically appreciable capacitive values. The present invention is

based on the recognition that the above facts can be utilized for accomplishing various practical objects, including those above mentioned, in the following manner.

A device according to one of the aspects of the invention, for stably operating loads of negative resistance with alternating current of a given operating frequency, has in series connection with such load a mechanically vibrating impedance device which is tuned to resonate at a frequency that differs from the operating frequency thus constituting at the operating frequency a dampening ballast reactance; the vibrating impedance device can be tuned to resonate at a frequency below or above the operating frequency range such as to constitute a capacitive or inductive ballast reactance, respectively.

A device according to another aspect of the invention for initiating conductivity at given operating frequency and voltage, of a normally substantially nonconductive load which tends to become conductive at a starting voltage higher than such operating voltage, has a reactive starting impedance means connected in parallel to the load, and in series connection with such load and starting impedance means a mechanically vibrating impedance device which is tuned to a frequency within an essentially resonant frequency range including the operating frequency; although the frequency to which the vibrating impedance device is tuned is not necessarily the operating frequency, this vibrating impedance device can be tuned to said operating frequency and at that frequency have a reactance which essentially cancels the reactance of the parallel connected starting impedance means.

In a further aspect of the invention, apparatus for starting as well as operating negative resistance loads comprises means for supplying alternating current of given operating frequency and operating voltage, a normally nonconductive negative resistance load which tends to become conductive at a voltage higher than the operating voltage, a mechanically vibrating impedance device connected with the load in series to the current supply means, provisions for tuning the vibrating impedance device to a resonant frequency other than the operating frequency, and a reactive starting impedance means which is connected in parallel to the load and is dimensioned relatively to the vibrating device to constitute therewith at the operating frequency a resonant or near resonant circuit which presents at the load a terminal voltage that is appreciably higher than the operating voltage, so that the load becomes conductive and the vibrating device constitutes a dampening resistance during normal operation at the operating frequency and voltage.

In an additional aspect, the invention embraces a method of stably operating with alternating current of a given frequency loads of negative resistance connected in series with a mechanically vibrating impedance device, which method includes the step of tuning the device to resonate at a frequency which differs a given amount from the operating frequency or is essentially equal thereto, by adjusting mechanical dimensions of the mechanically vibrating device.

Other objects, aspects and features will appear, in addition to those contained in the above statement of the nature and substance including some of the objects of the invention, from the herein presented outline of its theoretical basis, and from the following description of typical practical embodiments thereof illustrating its novel characteristics. This outline and description refer to drawings in which

FIG. 1 is a diagram illustrating the principal features of method and apparatus according to the invention;

FIG. 1a is a diagram similar to FIG. 1 illustrating the use of an auxiliary impedance device;

FIG. 1b is a diagram similar to FIG. 1 illustrating the use of an auxiliary capacitor;

FIG. 2 is a circuit diagram similar to FIG. 1, indicating the equivalent circuit of the mechanically vibrating impedance device;

FIGS. 3 to 7 and 15 are diagrams of several embodiments of the invention, namely arrangements for stabilizing, starting with several possibilities of incorporating a starting reactance, starting as well as stabilizing, and series operation of two loads;

FIG. 8 is a diagram of a fluorescent lamp installation according to the invention;

FIG. 9 is an axonometric view of a piezoelectric device for use in the installation according to FIG. 8;

FIGS. 10 and 11 are front and side elevations respectively of the device according to FIG. 9;

FIG. 12 is a diagram illustrating the connection of the device according to FIGS. 9 to 11 in an installation according to FIG. 8;

FIG. 13 illustrates the mode of vibration of a device according to FIG. 9; and

FIG. 14 indicates the dimensions of a device according to FIG. 9, for purposes of the installation according to FIG. 8.

FIG. 1 is a diagram of a system according to the present invention, for operating or starting or both, a negative resistance load of the above defined type. In this figure electrical supply leads indicated at 20 furnish alternating current for example of 60 or 400 cycles per second. The negative resistance load N is connected to the supply leads 20 in series with a mechanically vibrating impedance device B. If it is desired in accordance with one of the aspects of the invention to apply to the load N a comparatively high starting voltage, an impedance device S can be connected across N as shown in FIG. 1a. An auxiliary capacitor A can be connected in series with B as shown in FIG. 1b, for purposes explained below. It is expressly understood that elements S and A are tentatively employed, as indicated by the dot and dash lines showing them.

The device B comprises, in accordance with the invention, a strain oriented body which vibrates mechanically under the influence of an oscillating field applied thereto, such as a piezoelectric crystal or magnetostrictive core. Practical embodiments of mechanically vibrating strain elements of types found especially suitable for purposes of the present invention will be described in detail hereinafter.

The negative resistance load N may for example consist of an arc device comprising a gas filled vessel 21 having two electrodes 22, 23. This device can be rendered conductive in some manner such as by liberating electrons from the electrodes or by otherwise ionizing the electrode gap g.

The impedance S, if such is used, is connected to the terminals 25, 26 of the load N. In a preferred embodiment, a capacitor is used for this purpose but it is understood that other impedance means can be used at this point. It is further understood that this component can be omitted if the load is rendered conductive in some other way, in which case the device B has only the purpose of providing suitable running conditions.

The element B is designed to resonate mechanically at a frequency f_r which is near or for some uses equal to the operating frequency f_o of the power supply 20. Mechanically vibrating circuit elements are commonly used in oscillatory circuit, at or near one or more of their resonant frequencies to take advantage of the electric properties they exhibit upon dimensional variation. These fundamental properties of piezoelectric substances such as quartz, barium titanate and Rochelle salt, or of magnetostrictive structures are now well known and described in the technical literature. Generally speaking, such a strain plate or core, associated with a field applying device, can be introduced into an electrical circuit as required, with a frequency of the circuit at or near one of its resonant frequencies, at which frequency it vibrates mechanically and has electrical properties which for example simulate in the case of piezoelectric plate a series resonant circuit of very high Q in parallel with its dielectric capacitance.

This electrically equivalent network is illustrated in FIG. 2 where box Z_N s represents the negative resistance load N with or without shunting impedance S . The equivalent circuit within box Z_b represents the element B and comprises an inductance L_b , a capacitance C_{b1} and a resistance R_b , which represent the so-called motional impedance of the mechanically vibrating element. The equivalent circuit has further a capacitance C_{b2} in parallel with the motional impedance, which represents the dielectric capacitance of element B . A capacitance C_{b3} represents the air gap capacitance of the element B in series with motional and dielectric impedances. It will be evident that the above-mentioned auxiliary capacitor A having a capacitance C_a can be considered to be included in or used to augment or adjust the capacitance C_{b3} . The above equivalent circuit is at length discussed in the literature, for example in "Radio Engineering" by F. E. Terman, 3rd Edition, McGraw-Hill, 1947, pages 762 and 428, in "Piezo Electric Crystals and Their Application to Ultrasonics" by Warren Mason, Van Nostrand, 1950, pages 67 et seq., and in "Piezo Electricity" by Walter G. Cady, McGraw-Hill, 1946, page 335 et seq.

Circuit components of this type have, apart from the air gap capacitance C_{b3} , the response and reactance versus frequency characteristics indicated in FIG. 3. It will be seen that at resonant frequency f_r the response is greatest, indicating a series resonant phenomenon at which the component Z_b exhibits zero reactance. The reactance curve crosses the zero axis at frequency f_r . Thus if the operating frequency f_{o1} is greater than the resonant frequency f_r of Z_b the latter constitutes at that operating frequency an inductive reactance X_l ; when the operating frequency f_{o2} is less than the resonant frequency f_r , it constitutes the capacitive reactance X_c . FIG. 3 also indicates the general reactance characteristic of capacitances such as C_{b3} and C_a in the present instance.

As mentioned above and as discussed at length in the literature such as the above indicated text books, by selection of the dimensions, material, shape, and mode of vibration of the dimensionally vibrating element B , it is possible to predetermine by conventional means, over wide ranges, any desired value of its various electrical characteristics such as resonant frequency f_r , resistance R_b , inductance L_b , series capacitance C_{b1} and parallel capacitance C_{b2} .

Referring to the shunting reactance S used in an important embodiment of the present invention in the form of a capacitor in parallel with the negative resistance load, this capacitor can be considered in such a circuit, so long as the load has infinite resistance, as the equivalent air gap capacitance C_{b3} or that air gap capacitance in combination with other capacitances such as C_a added to provide optimal operating conditions. The precise mathematical value of these capacitances is of necessity adjusted to the constants of the negative resistance load N , and to the constants of the mechanically vibrating device B .

For purposes of the following explanation of the specific construction and operation of apparatus according to the invention, it should be kept in mind that these systems are designed for a given operating frequency or frequency range such as the conventional power line frequency of 60 cycles per second with its practically tolerated variations. Needless to say, other frequencies such as the now utilized frequency of 400 cycles per second can be selected for determining the operating characteristics of such systems.

With reference to FIG. 4, a device according to the invention intended for stable normal operation of a negative resistance load will first be described. FIG. 4 indicates at Z_b the reactance of a ballast element B of the nature discussed with reference to FIG. 2, and at Z_N the reactance of the load N . Having in mind the frequency, response, and reactance relations illustrated in FIG. 3, it will be evident that the elements of B can be so dimensioned that it has a resonant frequency f_r which

differs from the operating frequency f_o to such an extent that Z_b constitutes a definite reactive impedance means such as to offer the proper series reactance which in this circuit fixes and limits the current as to both magnitude and phase angle for normal operation. As pointed out above, this dimensioning of the device B which is in this instance principally a ballast, is accomplished by applying the theory of the network equivalent Z_b (FIG. 2) for selecting a proper material size and shape of the mechanically vibrating element with suitable air gap and electrode size to give the electrical constants desired. A practical example illustrating how this can be accomplished will be given hereinbelow.

With reference to FIG. 5 the use of the present invention for the rendering conductive of loads of certain types will now be described. As well known, loads which have negative resistance, commonly referred to as arcs not only require a steadying or ballast series impedance if they are supplied from a constant potential circuit, but they also require special starting provisions, because normal operating conditions do not provide energy in a form or mode of application such that it can be expended for initiating starting conditions such as a stream of incandescent vapor forming a current bridge. Therefore such arcs cannot start spontaneously and special expedients have to be resorted such as separation of initially contacted electrodes, or a subsidiary arc furnishing the initial vapor bridge, or stressing the dielectric between the initially separated conductors by over voltage until it breaks down electrically and becomes conducting. The present invention is especially suited for the starting of arcs by the last mentioned method, with means which at the same time provide, if desired, an especially advantageous ballast reactance.

FIG. 5 illustrates the circuit of FIG. 1 with initially nonconducting load, therefore showing only impedances Z_b and Z_s , in series on alternating current terminals 20. It should be kept in mind that shunting impedance Z_s is provided for the purpose of starting a load in accordance with the invention, which impedance Z_s is not necessary for purposes of providing a ballast reactance in accordance with the invention, if the negative resistance load is initially rendered conductive in some other manner. The negative resistance load N is not indicated in FIG. 5 since, so far as the load is concerned, this is a completely open circuit prior to starting.

As set forth above, by choosing its individual resonant frequency in relation to the operating frequency, the element B can be made to represent any desired reactance either capacitive or conductive. Thus, the element B can be designed to exhibit an inductive reactance Z_b in a series circuit containing a capacitive reactance Z_s , or vice versa so that at or near resonance of this series circuit a voltage will be developed across Z_s , at 25 and 26, which greatly exceeds the line voltage at 20.

Near resonance, where the inductive reactance of one is practically balanced by the capacitive reactance of the other element so that essentially only the ohmic resistance R_b remains in the circuit, the voltage across the load on 25, 26 can easily reach a value which exceeds the line voltage up to 30 times. This effect is not essentially affected by the series capacitances C_a and C_{b3} which are usually negligible as compared to Z_s , or can be taken into consideration upon dimensioning the circuit as a whole. It is theoretically possible, but in most instances impractical, to utilize the gap capacitance C_{b3} with or without C_a as starting reactance, in which case the load is connected across a capacitance represented by B , or by B in series with A , so that C_{b3} takes the place of S as shown in FIG. 6a, or C_{b3} with C_a takes the place of S as shown in FIG. 6a. These alternatives are indicated in FIG. 6, wherein the dot and dash lines represent the respective connections of terminal 26.

In some instances it is desirable and quite practical to add to predominantly capacitive ballasts which are

feasible according to the invention, inductive reactances such as chokes, analogously to the above mentioned additional capacitors in circuit with inductive reactances according to the invention.

It will now be understood that by suitably selecting the gap impedance prior to starting, namely Z_s , and the impedance Z_b , any desired gap voltage can be obtained up to the maximum value at resonance. However only in the ideal case where the mechanically vibrating device B is not used as a ballast can its resonant frequency be made equal to the operating frequency in which instance the entire circuit across the terminals 20 will be a series resonant circuit in which the inductive reactance of B is balanced by the capacitive reactance of S, leaving the ohmic resistance of the circuit as the sole impedance therein. It is further understood that, since pure ohmic resistances are satisfactory ballasts, the mechanically vibrating element will also qualify as ballast if operated at resonance. As will appear hereinbelow, this condition cannot be obtained if the element B is also used as a ballast, but it is nevertheless quite easy to obtain also in that instance gap voltages which considerably exceed those available by means of conventional starting and ballast means.

It should be kept in mind that normal stabilized operation according to the invention can take place regardless of the manner in which the negative resistance load has been rendered conductive although, as will be presently seen, the invention lends itself very well to the starting as well as the normal operation of such loads.

It will now be evident that an important feature of the present invention is the utilization of the voltage magnification across a starting reactance in series with a mechanically vibrating reactance, as applied to gas discharge lamps parallel with such starting reactances.

It is a well known characteristic of gas discharge lamps that they require a considerably higher starting voltage than the operating voltage. In the case of a conventional 40 watt fluorescent tube designed for 120 volts operation, the normal operating voltage is of the order of 108 volts, while the minimum starting voltage V_s may be of the order of 475 volts. However a higher voltage of optimum value is preferable, since the magnitude of the starting voltage used has a distinct influence on the life of the tube, for the well-known reasons involving the cathode coatings at either end of the tube which essentially determine the life of the cathodes in conjunction with an optimum number of cycles prior to starting. Generally speaking, application of a starting voltage considerably higher than the minimum required by a particular tube reduces the number of cycles of starting voltage applied prior to initiation of the discharge. In the past, to obtain a higher starting voltage, it was necessary to have larger, heavier and more expensive ballasts. In accordance with the present invention, starting voltages as high as thirty times the line voltage can be readily obtained, merely by suitable choice of the available operating characteristics of the piezo-electric unit, so that optimum starting voltages can be economically obtained.

Referring to FIG. 7, the application of the principles according to the invention to starting as well as running of a general negative resistance load will now be described. It will now be evident that, in FIG. 7, Z_s represents the starting or gap impedance, Z_n the load impedance, and Z_b the ballast impedance.

Prior to starting, resistance Z_n is infinitely large, and upon connection of the circuit to the alternating current source 20 the circuit, although not resonating with peak response, will be close enough to resonance to carry a current which effects a voltage drop across the terminals of Z_s which is sufficiently high to render the load B conductive so that impedance Z_b is now in parallel with Z_n . With the mechanically vibrating element B being dimensioned not only to resonate at a frequency f_r sufficiently close to the operating frequency f_o to furnish the start-

ing voltage, but also to constitute at f_o a ballast reactance, the circuit provides favorable starting as well as running conditions. Thus, this embodiment requires that the mechanically vibrating element is dimensioned to resonate at frequency f_r which is not only sufficiently close to the operating frequency f_o to provide an adequate starting voltage, but which frequency f_r is also sufficiently different from f_o to provide an adequate ballast reactance. As the example given hereinbelow will demonstrate, both conditions can be fulfilled. It will be noted that, although the vibrating element could be tuned to resonate at operating frequency if it served only as a starter, it must in this instance be tuned to resonate off the operating frequency, since it could otherwise not supply a ballast reactance during normal operation.

As mentioned above Z_s alone is in series with Z_b upon starting (FIG. 5) whereas during normal operation Z_n is in parallel with Z_s (FIG. 7), and this fact is taken into account upon dimensioning the circuit elements for the purpose of starting as well as stabilizing the negative resistance load.

A simple practical embodiment of the invention, embodying both starting and stabilizing features, will now be described with reference to FIG. 8. In this figure, 20 are again the terminals of an alternating current supply system. A fluorescent lamp 31 with electrodes 32, 33 is connected between terminals 20. The lamp tube is in conventional manner filled with gas at a predetermined pressure and coated with a conventional phosphor. A capacitor 34 is connected across lamp terminals 35, 36. In series with the lamp circuit is a mechanically vibrating impedance element, in this instance a piezoelectric device 37. A conventional switch is indicated at 39.

The ratings of the conventional elements of the circuit are as follows:

Fluorescent lamp N-----	"Low Brightness" lamp, 40 watt 256 ohm at 106 volt and .415 amp.
Starting capacitor 34-----	12 mf.

A starting and ballast crystal 37 suitable for purposes of the above embodiment is shown in FIGS. 9 to 14 and has the following structural and dimensional characteristics.

The electro mechanically effective elements of the crystal are two plates 51, 52 made of barium titanate ceramic. These are molded from the powdered material, baked and activated in a field of about 50 volt per mil. An admixture of approximately 5 percent lead titanate to the barium titanate powder was found advantageous. Permanent electric polarization sets in below a given temperature (such as at normal ambient temperature below the baking temperature) probably resulting largely from the actual displacement of certain ions in the crystal. This polarization is often best obtained with the above-mentioned polarizing electric field, by running the crystal through and above the Curie point. In accordance with recent very accurate measurements, the stable state of these crystals is believed to be one in which the ions are displaced to slightly unsymmetrical positions, though raising the temperature makes the ions take up symmetrical positions of slightly higher energy which do not involve electric moments. Plates of this type become mechanically vibrating under the influence of alternating potential differences of electrodes applied thereto.

Three electrodes a , b , c are applied to the plates 51 and 52 in the form of silver paint baked to the large faces of the plates. Upon assembly, electrode layer a is between plates 51 and 52, and electrodes b and c are on the outside of plates 51 and 52 respectively. The plates are mounted in any convenient way, for example in a clamp 54 (FIGS. 9, 10, 11) consisting of a block 55 and a plate 56 screwed thereto as indicated at 57. It will be evident that the plates can thus be firmly held between a ridge 58 of block 55 and the clamp plate 56. One of the plates for example 51 has a semi-circular notch

61 permitting easy access to electrode layers *a* by way of a hole 61 of block 55 which accommodates a conductor 63 that is soldered or otherwise fastened to layers *a* within the notch 61, as shown in FIG. 11. The clamp 54 serves as the other terminal. The electrical connections are shown in FIG. 12 where terminals 41 and 42 correspond to those similarly indicated in FIG. 8.

Crystals mounted in this manner vibrate in the so-called first mode of flexural vibration in fixed-free state, that is they swing together in the manner of a reed as indicated in FIG. 13.

A crystal constructed as above described and having the dimensions indicated in FIG. 14 (12.65 cm. long, 1.38 cm. wide and 0.508 mm. or 20 mils thick) will resonate near the power line frequency of 60 cycle per second and, in a circuit according to FIG. 8, produce an abundantly sufficient starting voltage as well as provide satisfactorily stable operation of the lamp.

In the above example, the crystal 37 defines during starting an inductive reactance of approximately $X=277$ ohms and a resistance of 10 ohms which values effect across capacitor 34 of the above rating a starting voltage of 700 volts.

Corresponding to the above given values of the starting reactance of the crystal namely $X=277$ ohms, of the minimum starting voltage $V_s=475$ volts, and of the standard line voltage $V=115$ volts, the starting capacitor reactance is in this example $X_c=X[1\pm(V/V_s)]=220$ ohms. With a standard frequency of $f=60$ c.p.s., the above value agrees with the stated starting capacitor rating $C=12$ mf. in accordance with the relation $X_c=1/fC$.

These crystals can be exactly tuned in several ways such as by varying the mechanical impedance with an adjustable weight at the free tip of the crystal, or by varying the free vibrating length of the crystal by moving it within the clamp, or by changing the stiffness (the reciprocal of the elastic constant) by recessing one or more of the crystal faces.

In this manner an appropriate resonant frequency of the crystal can be obtained, either essentially equal to the operating frequency if the crystal serves for starting only, or somewhat off the operating frequency if the crystal is used as a ballast or for starting as well as stabilizing, in the above described manner.

Regarding gaseous discharge lamps for which the present invention is particularly well suited, it will be remembered that these lamps are either operated with cold or hot cathodes. The cold cathode devices use transformers or auto-transformers to obtain the requisite high starting voltage. The hot cathode devices use a ballast reactor or auto-transformer in combination with a starter unit which initially connects the heaters in the tube in series while permitting the cathodes to heat up in order to start ignition, whereupon the starter opens its circuit effecting an inductive kick from the ballast unit which starts the lamp. The present invention is suitable for operation of gaseous discharge devices of either type, replacing the transformer, auto-transformer, and ballast reactor, but not the starting unit.

If desired, the power factor of a circuit of this type can be improved by either applying a shunt capacitance across the terminals *a*, *c* or a series capacitance, in conventional manner.

As an example of the adaptability of the general concept of the invention a so-called "two in series, instant start lamp circuit" incorporating the invention will now be described with reference to FIG. 15.

In FIG. 15, two fluorescent lamps 71, 72 are connected to line terminals 20. The lamp 71 is bridged by a capacitor 81 whereas the lamp 72 is bridged by a piezoelectric device 82 according to the invention. The lamp 71 has preferably the usual double terminal socket contacts so that if the lamp is removed the circuit is left open at this point. The capacitor 81 corresponds to the

above referred to capacitance C_a , whereas device 82 has a capacitance C_{b3} , so that it can be said that capacitances C_a and C_{b3} are connected in series to the line terminals 20 with one lamp each shunting a respective capacitance.

Upon starting, a very large voltage is obtained across capacitor 81 in a starting circuit according to FIG. 5, with 81 representing Z_s and 82 representing Z_b . The components are so dimensioned that the voltage across 82 is about twenty-nine times the voltage applied at terminals 20, if the starting voltage across 81 is about thirty times the terminal voltage. These voltages across 81, 82 respectively must be nearly 180° out of phase in order to add vectorially to the line voltage.

The lamps start easily due to the high voltage applied thereto as above indicated, and are during operation stabilized by the reactances which are effective in series thereto.

It should be understood that the present disclosure is for the purpose of illustration only and that this invention includes all modifications and equivalents which fall within the scope of the appended claims.

I claim:

1. A device for stably operating loads of negative resistance with alternating current of a given operating frequency which comprises in series connection with such load a mechanically vibrating impedance device which is tuned to resonate at a frequency different from said operating frequency thus constituting at the operating frequency a dampening ballast reactance.
2. Device according to claim 1 wherein said vibrating device is tuned to resonate at a frequency below said operating frequency such as to constitute an inductive ballast reactance.
3. Device according to claim 1 wherein said vibrating device is tuned to resonate at a frequency above said operating frequency such as to constitute a capacitive ballast reactance.
4. Device according to claim 1 wherein said vibrating device is tuned to resonate substantially at said operating frequency such as to constitute an essentially ohmic resistance.
5. A device for stably operating loads of negative resistance with alternating current within an operating frequency range, which comprises in series connection with such load a mechanically vibrating impedance device which is tuned to resonate at a frequency within a range which is larger than and includes said operating frequency range, the vibrating device thus constituting a dampening ballast reactance at a resonant frequency which is different from the concomitant operating frequency.
6. A device for initiating conductivity, at given operating frequency and voltage, of a normally substantially non-conductive load which tends to become conductive at a starting voltage higher than said operating voltage, which device comprises a reactive impedance means connected in parallel to said load, and in series connection with such load and impedance means a mechanically vibrating impedance device which is tuned to a frequency within an essentially resonant frequency range including said operating frequency.
7. Device according to claim 6 wherein said vibrating device is tuned to said operating frequency and has at said frequency a reactance which essentially cancels the reactance of said impedance means.
8. Device according to claim 6 wherein said vibrating device is tuned to resonate at a frequency that defines at said impedance means at said operating frequency, a voltage which appreciably exceeds said operating voltage.
9. Device according to claim 8 wherein said vibrating device is tuned to a frequency near, but different from, said operating frequency.
10. Electrical apparatus comprising means for supplying alternating current of given operating frequency and operating voltage, a negative resistance load, a mechani-

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cally vibrating reactive impedance device, means connecting said load and said vibrating device in series to said current supply means, and means for tuning said vibrating device to a resonant frequency outside said operating frequency, whereby said vibrating device constitutes at said operating frequency a dampening reactance.

11. Apparatus according to claim 10 wherein said vibrating device is tuned to resonate below said operating frequency range thus constituting at said operating frequency an inductive reactance.

12. Apparatus according to claim 10 wherein said vibrating device is tuned to resonate above said operating frequency range thus constituting at said operating frequency a capacitive reactance.

13. Apparatus according to claim 10 wherein said load is a gas discharge device.

14. Apparatus according to claim 10 wherein said impedance device includes a piezo electrical crystal whose mechanical dimensions are adjusted for maximum response to said resonant frequency.

15. Electrical apparatus comprising means for supplying alternating current of given operating frequency and operating voltage, a negative resistance load which represents in non-conducting condition an essentially infinite resistance, a mechanically vibrating reactive impedance device, means connecting said load and said vibrating device in series to said current supply means, reactance means connected in parallel to said load, and means for maintaining said vibrating device tuned to a resonant frequency near said operating frequency, whereby said reactance means provides at said reactance means, while the load presents a substantially infinite resistance, a terminal voltage which exceeds said operating voltage.

16. Apparatus according to claim 15 wherein said vibrating device is tuned to resonate below an operating frequency range thus constituting an inductive reactance while the operating frequency is within said range.

17. Apparatus according to claim 15 wherein said vibrating device is tuned to resonate above said operating frequency range thus constituting a capacitive reactance while the operating frequency is within said range.

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18. Apparatus according to claim 15 wherein said parallel reactance means is dimensioned to establish with said impedance device, within said range, an approximately resonant circuit as the load approaches infinite resistance.

19. Apparatus according to claim 15 wherein said vibrating device and said reactance means are dimensioned relatively to each other such as to make said terminal voltage appreciably higher than said operating voltage.

20. Apparatus according to claim 15 wherein said load is a gas discharge device of negative resistance characteristic.

21. Electrical apparatus comprising means for supplying alternating current of given operating frequency and operating voltage, a negative resistance load, a mechanically vibrating reactive impedance device, means connecting said load and said vibrating device in series to said current supply means, means for tuning said vibrating device to a resonant frequency outside said operating frequency, and reactance means which is connected in parallel to said load and is dimensioned relatively to said vibrating device to constitute with said vibrating device while said resistance is essentially infinite, a resonant circuit which presents at the load a terminal voltage which is appreciably higher than said operating voltage, whereby said load becomes conductive and said vibrating device constitutes at said operating frequency a dampening resistance.

22. Apparatus according to claim 21 wherein said reactance means is a capacitor connected in parallel to said load and has a capacitance which defines with said load a reactance smaller than said capacitance and is approximately equal to the dampening reactance represented by said impedance device.

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