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A. H. M. HIJMANS

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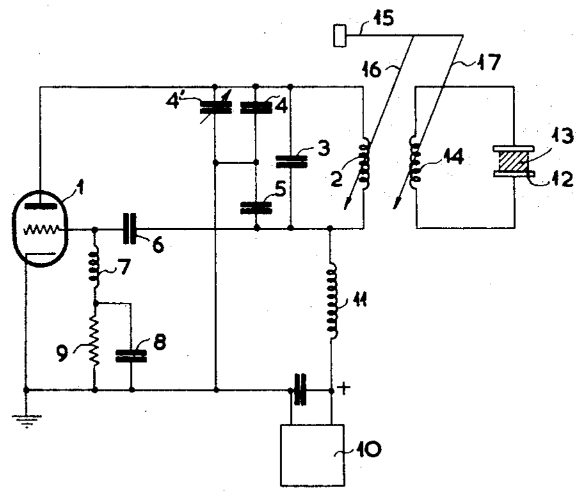


FIG. 1

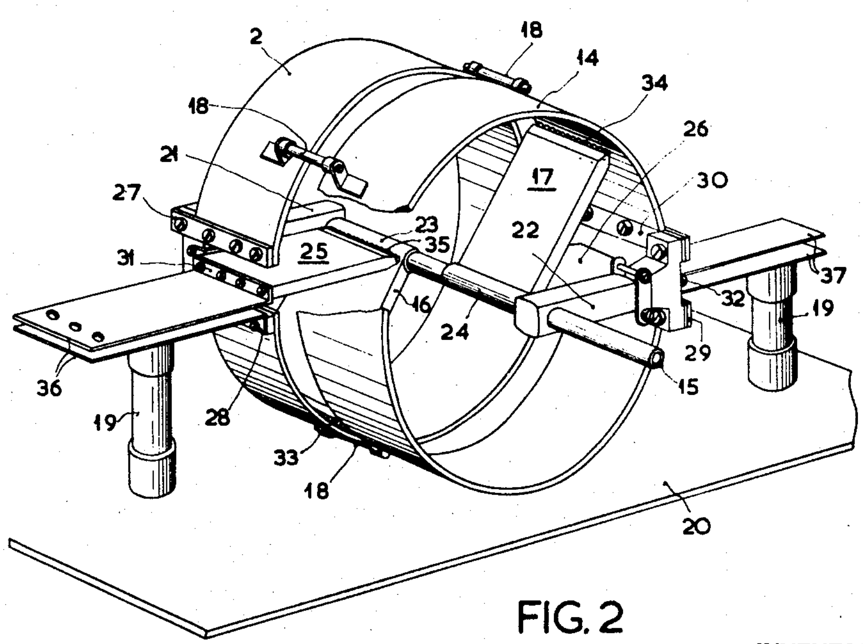


FIG. 2

INVENTOR
ANTONIUS HENRICUS MARIA HIJMANS

BY
Frank R. Jeifari
AGENT

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# HIGH-FREQUENCY DIELECTRIC-HEATING FURNACE

Antonius Henricus Maria Hijmans, Emmasingel, Eindhoven, Netherlands, assignor to North American Philips Company, Inc., New York, N.Y., a corporation of Delaware

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The invention relates to a high-frequency, dielectric-heating furnace circuit arrangement comprising a fed-back electron-tube oscillator having a resonant circuit included in its anode circuit. The circuit arrangement further comprises a load circuit including a charging capacitor. The anode-circuit coil is coupled inductively with the load-circuit coil. The high-frequency furnace according to the invention is particularly important for high power performances, for example of 1 kw. and more at very high frequencies, for example in the frequency range from 40 to 200 mc./s.

The invention has for its object to provide a high-frequency furnace of the aforesaid kind, which is particularly advantageous in practice and in which, in a simple manner, an adaptation of the load to the oscillator tube is obtained over a very wide range, which is desired, for example, with dielectric heating of work pieces of highly different kind and size.

The high-frequency furnace according to the invention has the feature that the relatively stationary anode-circuit coil and load-circuit coil, which are structurally integral with each other, are continuously variable to ensure adaptation to load. Furthermore, each of these variable coils is provided with adjusting means which are rigidly secured to a common control-member. When the common control-member is actuated, vary simultaneously the values of the inductance of the anode-circuit coil and of the load-circuit coil in opposite senses.

According to a further aspect of the invention the anode-circuit coil and the load-circuit coil each consist of a cylindrically curved, flat strip of conductive material. The strips are arranged side by side in an axial direction and fixed in place, the common control-member shaped in the form of a rotatable shaft being arranged in the axial direction of the strips. Each of the coil adjusting means seated rigidly on the control-shaft is formed by a contact arm, which moves, upon rotation of the common control-shaft, along the inner wall of each of the anode-circuit coil and the load circuit coil cylindrically curved strip.

Apart from the rugged mechanical structure, the embodiment described above for high power processes at high frequencies has important advantages. In the first place, owing to the large outer surface of the coils constructed in the form described skin effect cannot adversely affect the output. Furthermore, due to the large cooling surface of these coils forced water- or air-cooling can be dispensed with.

The invention and its advantages will now be described with reference to the figures.

Fig. 1 shows the principal diagram of a high-frequency furnace according to the invention and

Fig. 2 is a perspective view of the mechanical structure of an anode circuit coil and load circuit coil to be used in the high-frequency furnace according to the invention.

With the high-frequency furnace for dielectric heating, shown in Fig. 1 and suitable for a performance of 4 kw. at frequencies of more than 40 mc./s., the high-frequency energy required for heating is derived from a triode oscillator, having a triode **1**. The anode circuit of the oscillator, constructed in the form of a Colpitts oscillator, includes a circuit coil **2**, a circuit capacitor **3** and a capacitative potentiometer included between the anode and the control-grid. The potentiometer is formed by the anode-connected parallel combination of a stationary capacitor **4** and an adjustable capacitor **4'**, connected in series with a fixed capacitor **5**. The tapping point of the potentiometer formed by the capacitors **4**, **4'**, **5** is connected to the grounded cathode of the tube **1**. The end of the potentiometer capacitor **5**, remote from the tapping is connected via a grid capacitor **6** to the control-grid of the tube **1**. The control grid of the tube **1** is connected to the cathode via the series combination of a high-frequency choke **7** and a resistor **9**, shunted by a capacitor **8**. The supply voltage of the triode **1** is obtained from a direct voltage source **10**, which is connected via a supply choke **11** and the anode circuit coil **2** to the anode of the triode **1**.

In the high-frequency furnace for very high frequencies, as shown, the capacitors **3**, **4**, **5** are formed by the tube capacities and the additional stray capacities of the arrangement.

The high-frequency energy produced during the oscillation of the arrangement is supplied to a load circuit, constituted by a charging capacitor **12**, which includes a work piece **13**, and a load circuit coil **14**. The load circuit coil **14** is coupled inductively with the anode circuit coil **2**.

In order to adapted the load to the generator under varying operational circumstances it is required with the high-frequency furnace shown, having a tuned load circuit **12**, **14** and a tuned anode circuit, consisting of the circuit coil **2** and the total circuit capacity formed by the capacitors **3**, **4**, **4'**, **5**, that the frequencies of the anode circuit **2**, **3**, **4**, **4'**, **5** and of the load circuit **12**, **14** should be adjusted relatively to each other. This is due to the fact that in accordance with the kind and size of the work piece **13** to be heated the tuning frequency of the load circuit **12**, **14** may deviate strongly from the tuning frequency of the anode circuit **2**, **3**, **4**, **4'**, **5** and hence from the oscillations produced by the high-frequency furnace circuit arrangement. This may result in an inadequate energy transfer to the work piece **13**, to be heated. Thus, for example, when heating a rod-shaped work piece, the distance between the plates of the charging capacitor **12** is large, so that the capacity of the charging capacitor **12** is large, so that the capacity of the charging capacitor **12** is small and the tuning frequency of the load circuit **12**, **14** will be comparatively high. If a flat work piece is heated, however, the distance between the plates of the charging capacitor **12** is small, so that the capacity of said charging capacitor is large and the tuning frequency of the load circuit **12**, **14** has a low value.

In order to obtain a simple adaptation control in a large range of adaptations, the relatively stationary anode circuit coil **2** and load circuit coil **14** are continuously variable. Each of the variable coils **2**, **14** are provided with adjusting means **16** and **17** respectively secured rigidly to a common control-member **15**. The adjusting means **16** and **17** vary in opposite senses simultaneously the values of the inductances of the anode circuit coil **2** and the load circuit coil **14**, when the common control-member **15** is actuated. The relatively fixed anode circuit coil **2** and the load circuit coil **14** are structurally integral with each other.

The adaptation control, which includes the relative frequency adjustment of the anode circuit **2**, **3**, **4**, **4'**, **5** and the load circuit **12**, **14** is obtained in the high-frequency furnace shown by means of the common control-member **15**, which varies in opposite senses the values of the inductances of the anode circuit **2** and the load circuit **14**. If it is assumed that by introducing a work piece **13** into the charging capacitor **12** the tuning frequency of the load circuit **12, 14** is materially higher than that of the anode circuit **2, 3, 4, 4′, 5**. Then, the tuning frequency of the anode circuit **2, 3, 4, 4′, 5** and that of the load circuit **12, 14** are raised and reduced respectively to obtain a relative frequency adjustment of these circuits. This is achieved by reducing simultaneously the value of the inductance of the anode circuit coil **2** and increasing that of the load circuit coil **14** with the aid of the common control-member **15**. Conversely, if the tuning frequency of the load circuit **12, 14** is lower by the introduction of a work piece into the charging capacitor **12**, than that of the anode circuit **2, 3, 4, 4′, 5**, the tuning frequency of the anode circuit **2, 3, 4, 4′, 5** will be reduced and that of the load circuit **12, 14** will be increased with the aid of the common control-member **15**.

An accurate load adaptation of the work piece **13** to the high-frequency furnace is obtained by detuning the anode circuit **2, 3, 4, 4′, 5** and the load circuit **12, 14** relatively to each other to some extent with the aid of the common control-member **15** in accordance with the value of the load. This is due to the fact that the value of the load formed by the work piece **13**, viewed from the oscillator tube **1**, varies with the relative detuning between the load circuit **12, 14** and the anode circuit **2, 3, 4, 4′, 5**. Thus, with the aid of the common control-member **15** opposite variations of the anode circuit coil **2** and the load circuit coil **14** bring about the adaptation of the work piece **13** to the generator.

The adaptation range of the high-frequency furnace as shown is very large, as will be explained more fully hereinafter. It is assumed that the minimum and the maximum inductances of the anode circuit coil **2** are L and $p$L and the minimum and the maximum inductances of the load circuit coil **14** are also L and $p$L and the value of the total anode circuit capacity **3, 4, 4′, 5** is $C_0$. If, in this device, the anode circuit coil **2** has its minimum value L, the load circuit coil **14** has its maximum value $p$L and the charging capacitor **12** has a value of $1/p.C_0$, in order to ensure equal tuning frequencies of the load circuit **12, 14** and of the anode circuit **2, 3, 4, 4′, 5**. Conversely, with a maximum value $p$L of the anode circuit coil **2** and a minimum value of L of the load circuit coil **14**, the charging capacitor **12** has a value of $pC_0$.

In accordance with the size of the work piece **13** to be heated, the charging capacitor **12** may be varied between $1/p.C_0$ and $pC_0$, i.e. the adaptation range is proportional to the square of the ratio $p$ between the maximum and the minimum inductances of the coils **2** or **14**. Thus, in the high-frequency furnace shown, a very large adaptation range is obtained, for example, the charging capacitor **12** may be varied in the ratio of 1:30. Thus, the high-frequency furnace circuit arrangement described is particularly suitable for high-frequency heating of work pieces of widely different kinds and sizes.

The use of the high-frequency furnace described above for high power processes at very high frequencies, for example more than 40 mc./s. has, apart from the simple adaptation control and the very large adaptation range, the important advantage that an optimum transfer of energy to the work piece is obtained throughout the adaptation range. The applicant has found, in practice, that in the most highly differing operational conditions there is no adverse effect on the working efficiency owing to the coupling frequencies of the coupled circuits **2, 3, 4, 4′, 5** and **12, 14**. Nor is there an abrupt leap of the oscillator frequency to a parasitic frequency, which phenomenon is due to the inductance of the supply conductors and further parasitic impedances in the arrangement. It is these factors which can no longer be neglected in the case of high frequencies.

It is advantageous in this respect that the adaptation control described does not require additional elements and that a separation capacitor to obtain direct-current separation of the anode circuit and the load circuit may be dispensed with. Such a separation capacitor, together with the parasitic impedances in the arrangement, appears to give rise to parasitic oscillations affecting adversely the efficiency under highly differing operational conditions.



Fig. 2 is a perspective view of a structural embodiment of the anode circuit coil **2** and the load circuit coil **14**, constructed as a mechanical unit. Corresponding elements of Figs. 1 and 2 are designated by the same reference numerals.

In the mechanical structure shown the anode circuit coil and the load circuit coil are constituted by cylindrically curved copper tapes **2** and **14** respectively, which are stationary in an axial direction side by side. In order to illustrate the construction employed, part of the coil **14** of cylindrical tape is shown broken away, for the sake of clarity.

The two coils **2** and **14** are relatively secured in place via insulators **18** and secured rigidly to a frame **20** with the aid of insulators **19**. It is evident from the figure that the anode circuit coil **2** and the load circuit coil **14**, constituted by cylindrically curved tapes, have a large outer surface, so that the efficiency is not affected by skin effect. The large cooling surfaces of the coils **2** and **14** thus formed renders unnecessary forced air- or water-cooling, even in the case of high power processes.

The common control member is provided in the axial direction of the cylindrically curved tapes **2** and **14** in the form of a rotatable shaft **15** of insulating material, which can be rotated for adaptation control with the aid of a hand wheel (not shown in the figure). On either side of the cylindrically curved, flat tapes **2** and **14** the rotatable shaft **15** is journalled in mounting pieces **21** and **22** of insulating material, each of which is secured rigidly with the aid of screws, to the two ends **27, 28** and **29, 30** respectively of the cylindrically curved, flat tapes **2** and **14** respectively.

On the control-shaft **15** are seated, as adjusting members of the coils **2** and **14**, two plate-shaped copper contact arms **16** and **17**, which extend in a radial direction of the anode circuit coil **2** and the load circuit coil **14**. The contact arms **16** and **17** are seated rigidly on the control-shaft **15** with the aid of cylindrical fastening sleeves **23** and **24**. The fastening sleeves **23** and **24** of the contact arms **16** and **17** respectively constitute contact paths for stationary, plate-shaped, copper contact arms **25** and **26**, secured to the mounting pieces **21** and **22**. The contact arms **25** and **26** extend in a radial direction of the anode circuit coil **2** and the load circuit coil **14**. The connecting terminals of the anode circuit coil **2** are constituted by the end **31** of the stationary contact plate **25**, secured to the mounting piece **21** and by the end **28** of the cylindrical tape. The ends **31** and **28** are secured via plate-shaped conductors **36** to the anode and the control-grid of the tube **1**. The charging capacitor **12** is positioned and connected between the end **32** of the stationary contact plate **26**, secured to the mounting piece **22**, and the end **29** of the load circuit coil **14**, via plate-shaped conductors **37**.

In order to obtain an excellent electrical contact the movable contact plates **16, 17** establish a contact substantially throughout the width along a generatrix of the inner walls of the anode circuit coil **2** and the load circuit coil **14** by means of contact pins **33** and **34** respectively, subjected to spring-pressure. The stationary contact plates **5** and **26** establish a contact throughout the width along a generatrix of the contact paths **23** and **24** respectively with the aid of contact pins subjected to spring pressure. The contact pins associated with the stationary contact plate **25** are designated by **35** and the contact pins associated with the stationary contact plate **26** are not shown in the figure.

If in the construction described above the common shaft **15** is rotated, the movable contact arms **16** and **17** move along the inner walls of the anode circuit coil **2** and the load circuit coil **14**, so that, as is evident from figure, simultaneously the values of the inductances of the anode circuit coil **2** and the load circuit coil **14** are varied in opposite sense. In the extreme positions of the contact arms **16** and **17** the minimum inductances of the anode circuit coil **2** and of the load circuit coil **14** are reduced in the construction shown to a very low value, which is essential to otbain a large adaptation range. This is due to the fact, indicated above, that the adaptation range is proportional to the square of the ratio between the minimum and the maximum inductances of the anode circuit coil **2** and the load circuit coil **14**.

By using the arrangement shown in a mechanically simple and rugged construction of the high-frequency furnace, the control and the electrical properties thereof are particularly advantageous for high power processes at very high frequencies.

By way of example, data is indicated below for a practical embodiment of a high-frequency furnace as described above, suitable for powers of 4 kw. in the frequency range between 40 and 200 ms./s.

The triode **1** is of the type TBL 6/6000.

The diameter of each of the cylindrically curved tapes **2** and **14** is 220 millimeters.

The width of each of the tapes **2**, **14**, measured in an axial direction, is 80 mms.

Relative distance between the tapes **2**, **14**: 20 mms.

Ratio between minimum value and maximum value of the charging capacitor **12**: about 1:30.

In the embodiments of the anode circuit coil **2** and the load circuit coil **14** shown in Fig. 2 these coils are of identical structure, which has the mechanical advantage that a minimum of different parts will be sufficient. However, this is not an imperative requirement; in certain conditions it may, for example, be advantageous to vary the size of the load circuit coil **14** from that of the anode circuit coil **2**.

It should finally be noted that, with respect to the simple adjusting possibility in the high-frequency furnace shown, this furnace is particularly suitable for automatic control.

What is claimed is:

1. A high frequency furnace circuit arrangement comprising an oscillator circuit including an electron tube having an output electrode and a resonant circuit having a first inductive coil connected to said output electrode, a load circuit comprising heating means and a second inductive coil connected to said heating means, said second coil being inductively coupled to said first coil, said first and second coils being structurally integral with each other, and adjusting means for continuously simultaneously varying the inductance of each of said first and second coils in a sense opposite to that of the other.

2. A high frequency furnace circuit arrangement comprising an oscillator circuit including an electron tube having an output electrode and a resonant circuit having a first inductive coil connected to said output electrode, said first coil comprising a substantially cylindrically curved flat strip of electrically conductive material, a load circuit comprising heating means and a second inductive coil connected to said heating means, said second coil comprising a substantially cylindrically curved flat strip of electrically conductive material positioned coaxially with and adjacent to said first tape and being inductively coupled to the said first coil, said first and second coils being structurally integral with each other, and adjusting means for continuously simultaneously varying the inductance of each of said first and second coils in a sense opposite to that of the other.

3. A high frequency furnace circuit arrangement comprising an oscillator circuit including an electron tube having an output electrode and a resonant circuit having a first inductive coil connected to said output electrode, said first coil comprising a substantially cylindrically curved flat strip of electrically conductive material, a load circuit comprising heating means and a second inductive coil connected to said heating means, said second coil comprising a substantially cylindrically curved flat strip of electrically conductive material positioned coaxially with and adjacent to said first tape and being inductively coupled to the said first coil, said first and second coils being structurally integral with each other, and adjusting means for continuously simultaneously varying the inductance of each of said first and second coils in a sense opposite to that of the other, said adjusting means comprising a common control member adapted to actuate the said adjusting means upon actuation thereof.

4. A high frequency furnace circuit arrangement comprising an oscillator circuit including an electron tube having an output electrode and a resonant circuit having a first inductive coil connected to said output electrode, said first coil comprising a substantially cylindrically curved flat strip of electrically conductive material, a load circuit comprising heating means and a second inductive coil connected to said heating means, said second coil comprising a substantially cylindrically curved flat strip of electrically conductive material positioned coaxially with and adjacent to said first tape and being inductively coupled to the said first coil, said first and second coils being structurally integral with each other, and adjusting means for continuously simultaneously varying the inductance of each of said first and second coils in a sense opposite to that of the other, said adjusting means comprising a common control shaft rotatably mounted on the axis of said coils and means for varying the inductance of each of said first and second coils in a sense opposite to that of the other rigidly affixed to said shaft in a manner whereby said inductance varying means rotate with the said shaft and said inductance is so varied upon rotation of the said shaft.

5. A high frequency furnace circuit arrangement comprising an oscillator circuit including an electron tube having an output electrode and a resonant circuit having a first inductive coil connected to said output electrode, said first coil comprising a substantially cylindrically curved flat strip of electrically conductive material, a load circuit comprising heating means and a second inductive coil connected to said heating means, said second coil comprising a substantially cylindrically curved flat strip of electrically conductive material positioned coaxially with and adjacent to said first tape and being inductively coupled to the said first coil, said first and second coils being structurally integral with each other, and adjusting means for continuously simultaneously varying the inductance of each of said first and second coils in a sense opposite to that of the other, said adjusting means comprising a common control shaft rotatably mounted on the axis of said coils and contact arms contacting at one end thereof the inner surface of each of said coils and rigidly affixed at the other end thereof to said shaft in a manner whereby said contact arms rotate with the said shaft and the inductance of each of said first and second coils is varied in a sense opposite to that of the other upon rotation of the said shaft.

6. A high frequency furnace circuit arrangement comprising an oscillator circuit including an electron tube having an output electrode and a resonant circuit having a first inductive coil connected to said output electrode, said first coil comprising a substantially cylindrically curved flat strip of electrically conductive material, a load circuit comprising heating means and a second inductive coil connected to said heating means, said second coil comprising a substantially cylindrically curved flat strip of electrically conductive material positioned coaxially with and adjacent to said first tape and being inductively coupled to the said first coil, said first and second coils being structurally integral with each other, and adjusting means for continuously simultaneously varying the inductance of each of said first and second

coils in a sense opposite to that of the other, said adjusting means comprising a common control shaft rotatably mounted on the axis of said coils and a pair of contact arms, each of said contact arms comprising an electrically conductive plate contacting at one end thereof the inner surface of one of said coils and rigidly affixed at the other end thereof to said shaft in a radially extending manner whereby said contact arms rotate with the said shaft and the inductance of each of said first and second coils is varied in a sense opposite to that of the other upon rotation of the said shaft.

7. A high frequency furnace circuit arrangement comprising an oscillator circuit including an electron tube having an output electrode and a resonant circuit having a first inductive coil connected to said output electrode, said first coil comprising a substantially cylindrically curved flat strip of electrically conductive material, a load circuit comprising heating means and a second inductive coil connected to said heating means, said second coil comprising a substantially cylindrically curved flat strip of electrically conductive material positioned coaxially with and adjacent to said first tape and being inductively coupled to the said first coil, said first and second coils being structurally integral with each other, and adjusting means for continuously simultaneously varying the inductance of each of said first and second coils in a sense opposite to that of the other, said adjusting means comprising a common control shaft rotatably mounted on the axis of said coils, first and second contact arms each comprising an electrically conductive plate contacting at one end thereof the inner surface of one of said coils and rigidly affixed by a cylindrical fastening sleeve at the other end thereof to said shaft in a radially extending manner, and first and second stationary contact arms each comprising an electrically conductive plate contacting at one end thereof a terminal edge of one of said coils and contacting at the other end thereof the fastening sleeve of one of said coils in a manner whereby said first-mentioned contact arms rotate with the said shaft and the inductance of each of said first and second coils is varied in a sense opposite to that of the other upon rotation of the said shaft.



8. A high frequency furnace circuit arrangement comprising an oscillator circuit including an electron tube having an output electrode and a resonant circuit having a first inductive coil connected to said output electrode, said first coil comprising a substantially cylindrically curved flat strip of electrically conductive material, a load circuit comprising heating means and a second inductive coil connected to said heating means, said second coil comprising a susbtantially cylindrically curved flat strip of electrically conductive material positioned coaxially with and adjacent to said first tape and being inductively coupled to the said first coil, said first and second coils being structurally integral with each other, and adjusting means for continuously simultaneously varying the inductance of each of said first and second coils in a sense opposite to that of the other, said adjusting means comprising a common control shaft rotatably mounted on the axis of said coils, first and second contact arms each comprising an electrically conductive plate contacting at one end thereof the inner surface of one of said coils and rigidly affixed by a cylindrical fastening sleeve at the other end thereof to said shaft in a radially extending manner, contacting means at said one end of each said first and second contact arms comprising a plurality of contact pins and spring means applying pressure to said contact pins, first and second stationary contact arms each comprising an electrically conductive plate contacting at one end thereof a terminal edge of one of said coils and contacting at the other end thereof the fastening sleeve of one of said coils in a manner whereby said first-mentioned contact arms rotate with the said shaft and the inductance of each of said first and second coils is varied in a sense opposite to that of the other upon rotation of the said shaft, and contacting means at said other end of each of said first and second stationary contact arms comprising a plurality of contact pins and spring means applying pressure to said contact pins.

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