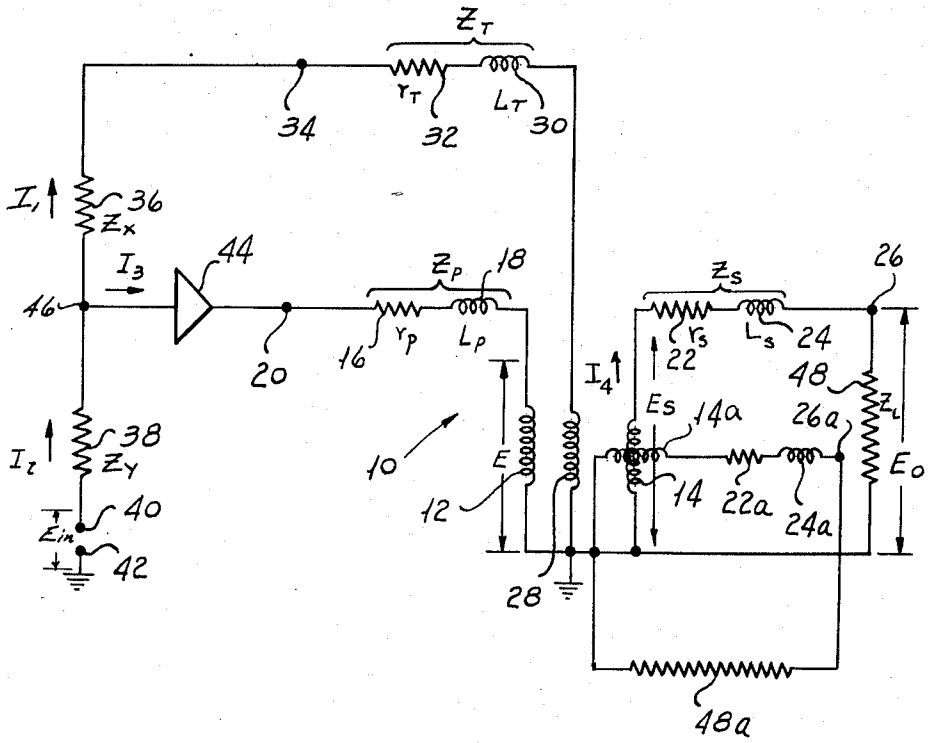
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WINDING COMPENSATING DEVICE

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WINDING COMPENSATING DEVICE

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My invention relates to a method of reducing temperature variation errors in winding compensated devices and more particularly to an improved method in which the device is compensated for errors which otherwise would be introduced owing to variation in the secondary winding resistance.

In rotating devices of the prior art having inductively coupled primary and secondary windings, it has been suggested that a tertiary winding be provided to compensate for the undesirable effect of temperature change on the device. This tertiary winding affords a measure of the mutual flux linking both the primary and secondary windings. When a change in temperature occurs, the mutual flux changes and thus the tertiary winding voltage changes. This tertiary winding voltage is fed back to the input terminal of the device to drive the input voltage to such value as will cause the mutual flux, and thus the winding voltages, to return to the values from which they deviated as a result of the temperature change.

The system described above functions satisfactorily in compensating for temperature variation as long as the secondary winding is not loaded. As soon, however, as the secondary winding is loaded, there occurs a voltage drop in the secondary winding which causes the output terminal voltage to drop. In response to temperature changes the impedance of the secondary winding varies with the result that the output voltage of the device varies.

I have invented a method of reducing temperature variation errors in winding compensated devices to overcome the defect of prior art systems described above. My method compensates for errors which otherwise would be introduced in a winding compensated device as a result of the effect of the temperature variation on the secondary winding impedance. My method causes the output terminal voltage of a winding compensated device to remain substantially constant over a wide range of temperatures.

One object of my invention is to provide a method of reducing temperature variation error in a winding compensated device.

Another object of my invention is to provide a method of reducing temperature variation errors in a winding compensated device which overcomes the defects of systems of the prior art.

A further object of my invention is to provide a method of reducing temperature variation errors in a winding compensated device which otherwise would occur as a result of secondary winding impedance variation.

Still another object of my invention is to provide a winding compensated device, the output voltage of which remains substantially constant over a wide range of temperatures.

Other and further objects of my invention will appear from the following description.

In general my invention contemplates the provision of a method of reducing temperature variation errors in compensating windings in which I replace the very high impedance in the feedback circuit of a winding compensated device with an impedance having a value such that the ratio of the overall output winding circuit impedance to the overall feed-back circut impedance is equal to the square of the ratio of output winding turns to feedback winding turns.

In the accompanying drawing which forms part of the

instant specification and which is to be read in conjunction therewith:

The figure is a schematic view of the equivalent circuit of a winding compensated device which is compensated for errors which otherwise would be introduced as a result of temperature variation.

Referring now to the figure, there is shown a winding compensated device indicated generally by the reference character **10** having a primary winding **12** and second windings **14** and **14***a* which in the form of my invention shown in the figure are disposed at right angles to each other. The winding **12** may, for example, be a primary winding while the windings **14** and **14***a* are secondary windings. As will be explained in detail hereinafter, my invention has its special utility in a device having a number of output phases to which the same loads are applied. In the figure I have represented the impedance Z_p of the winding **12** by a resistor **16** having a value r_p and an inductor **18** having a value L_p connected in series between the primary winding input terminal **20** and the winding **12**. Similarly, I have shown the impedance Z_S of the secondary winding **14** as a resistor **22** having a value r_s and an inductor **24** having a value L_S connected in series between the winding **14** and the secondary winding or output terminal **26** of the device **10**.

The device **10** includes a tertiary winding **28** having an impedance Z_T indicated by the inductor **30** having a value L_T and a resistor **32** having a value r_T connected in series between the winding **28** and the tertiary winding terminal **34**. The winding **28** may, for example, be wound in the same slots as is the winding **12** in order to ensure that the tertiary winding **28** have very nearly the same characteristics as does the winding **12**. In the form of my invention shown in the figure I connect respective voltage dividing impedances such as resistors **36** and **38** in series between the tertiary winding terminal **34** and one input terminal **40** of a pair of input terminals **40** and **42**, the terminal **42** of which is connected to ground. I connect an amplifier **44** between the common terminal **46** of resistors **36** and **38** and the input terminal **20** of the primary winding **12**. In winding compensated devices of the prior art the impedances **36** and **38** are selected to have very high values and a high gain amplifier **44** is employed.

In normal operation of the device according to the prior art, negligible current flows through the impedances **36** and **38** and the voltage induced in the tertiary winding **28** bucks out the input voltage to the terminals **40** and **42** with the result that the common terminal **46** of the impedances **36** and **38** is a virtual ground. Under these conditions, when a temperature change occurs, the value of the resistance r_p changes so that the voltage E of the primary winding **12** changes and the induced voltage in the tertiary winding **28** also changes. When this occurs, the voltage E_{in} no longer is equal to the feedback potential at terminal **34** and a signal is applied at terminal **46**, which signal is amplified by the amplifier **44** to restore the voltage E to that value from which it departed in response to the temperature change.

As is explained hereinabove, the system of the prior art employing the winding **28** operates satisfactorily to compensate for errors which otherwise would occur as a result of temperature change so long as no current flows in the circuits of the secondary windings **14** and **14***a*. When a current does flow through a load impedance **48** connected to the output terminal **26**, there results a voltage drop in the resistor **22** and the inductor **24**. As a result of this voltage drop, the output voltage at terminal **26** varies. Not only is this true but when the resistance of the resistor **22** changes as a result of a temperature change, then the voltage drop produced by the load cur-

rent flowing through the resistance **22** changes to produce a further change in the output voltage at terminal **26**.

My method provides a solution to the problem outlined above to maintain the output voltage at terminal **26** substantially constant. In accordance with my invention I replace the very high impedance **36** with an impedance Z_X having a value such that the ratio of the load impedance Z_L plus output winding impedance Z_S to the impedance Z_X plus the feedback winding impedance Z_T is equal to the square of the ratio of the turns of winding **14** to the turns of winding **28**. For impedance **38** I select a value Z_Y which in relation to E_{in} produces the desired output voltage value E_O. It will be understood that the impedance (Z_X+Z_T) should have the same phase angle as the impedance (Z_L+Z_S). This is the salient feature of the invention. Of course, if $Z_T=Z_S$ upon a unity-turns-ratio basis, as in the usual case, then the requirement of equal phase angle will be satisfied by impedance matching. With this arrangement changes in temperature and varying saturation of magnetic circuits do not appreciably affect the output voltage of my device even where the secondary windings are loaded. This fact can readily be demonstrated analytically. For purposes of simplicity and to avoid an unnecessarily involved analysis of my device, I will assume that all the windings **12**, **14** and **28** are identical and that the relative angular displacement of the primary and secondary of my device is such that the winding **14** is parallel to the winding **12** thus to have the maximum voltage induced therein while the winding **14***a* is at right angles to the winding **12** so that the voltage induced in this winding is substantially zero.

Let us assume that the current I_3 flowing in the direction indicated in the figure is substantially zero. Under this condition I_1 equals I_2 and we can write the expressions:

$$(1) \qquad I_1=\frac{E}{Z_T+Z_X}=I_2=\frac{E_{in}}{Z_Y}$$

and

$$(2) \qquad I_4=\frac{E_s}{Z_S+Z_L}$$

With a unity turns ratio:

$$(3) \qquad E=E_S=E_T$$

and

$$(4) \qquad Z_S=Z_T$$

Substituting Z_T for Z_S in Equation 2, we obtain:

$$(5) \qquad I_4=\frac{E_s}{Z_T+Z_L}$$

If now we make the impedance of each of the resistors **36** and **38** equal to the load impedance Z_L, we see that:

$$(6) \qquad I_1=\frac{E}{Z_T+Z_L}=I_2=I_4$$

From Equation 6 it will be apparent that since the same current flows through all windings, the same voltage drops will be produced in the winding impedances. Further, when the impedance of any winding changes in response to a temperature variation, then the impedances of all windings change by the same amount with the result that the output voltage at terminal **26** remains substantially constant. That is, if the ratio of the rotor winding resistance r_S to the rotor winding load impedance Z_L is the same as the ratio of the tertiary or compensating winding resistance to the load Z_X then the variation in compensator winding voltage just offsets the variation in rotor winding voltage owing to the effect of a temperature change.

In operation of a winding compensated device to which I apply my method of reducing temperature variation errors, assuming unity turns ratio, the impedance **36** is made equal in value to the load impedance applied to each of the secondary or rotor windings. Under these

conditions the current I_3 is substantially zero and equal currents flow through the impedances **36** and **38** and through the load impedance **48**. If now a temperature change occurs to cause a change in the resistance r_p of the winding **12**, then the voltage E in this winding changes and also the feedback voltage at terminal **34** changes. As a result of the change in the feedback voltage, a signal appears at terminal **46** which is amplified by the amplifier **44** to restore the voltage E and the feedback voltage at terminal **34** to that value from which they departed in response to the temperature change. In the same manner the secondary winding voltage E_s is maintained at its value. Since the temperature variation produces the same change in the impedance of all three windings and since equal currents flow through the three windings then the output voltage E_O at terminal **26** remains substantially constant. It will be appreciated that in order for my method to achieve the result outlined above in all relative positions of the rotor and stator, it is necessary that a balanced load be applied to the secondary winding so that the same effective load impedance is reflected back to the primary winding in all relative positions of the rotor and stator.

It will readily be understood that the ratio of feedback winding turns to secondary winding turns of my device may be other than unity. In this case in the manufacture of the device the impedances of the secondary and feedback windings could be so regulated in manufacture as to have the proper relationship. If the ratio of feedback winding turns to secondary winding turns were two, for example, then the impedance **36** would have a value four times that of impedance **48** and could have the same phase angle. If this were done and a ratio of E_O to E_{in} of one to four were desired then the impedance **38** would be one which had twice the value of impedance **36**.

It can also be demonstrated that the same impedance is reflected from the output circuit of my device into the feedback circuit irrespective of angular displacement of the rotor with respect to the stator. Clearly the voltage induced in the winding **14** may be a cosine function while the voltage induced in the winding **14***a* is a sine function. The reflected voltage will be a sum of the squares of a sine and a cosine function so that it is apparent that the relative angular position of the rotor does not affect the impedance reflected to the feedback winding.

It will be seen that I have accomplished the objects of my invention. I have provided a method for reducing temperature variation errors in winding compensated devices. My method maintains the output voltage of the device substantially constant even in the case where the secondary winding is loaded. My method overcomes the defects of methods of the priod art which compensate for the effect of temperature change in the absence of a load applied to the rotor of the device.

It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of my claims. It is further obvious that various changes may be made in details within the scope of my claims without departing from the spirit of my invention. It is, therefore, to be understood that my invention is not to be limited to the specific details shown and described.

Having thus described my invention, what I claim is:

1. A winding compensating device including in combination an input winding, an output winding inductively coupled to said input winding, a feedback winding inductively coupled to said input winding, a load impedance having a predetermined value, means connecting said load impedance across said output winding, means comprising a feedback impedance distinct from the impedance of said feedback winding for coupling said feedback winding to said input winding, said feedback impedance having a

value such that the ratio of said load impedance to said feedback impedance is substantially equal to the square of the ratio of the output winding turns to the feedback winding turns.

2. A winding compensating device including incombination a primary winding, a secondary winding having an impedance, a load impedance, means connecting said load impedance across said secondary winding, a compensating winding having an impedance, means comprising a feedback impedance distinct from the impedance of said compensating winding having a value such that the sum of said secondary winding and load impedances has the same angle as that of the sum of said compensating winding and feedback impedances.

3. A winding compensating device including in combination a primary winding, polyphase secondary windings, balanced load impedances, means for connecting said load impedances respectively to said secondary windings, a feedback winding, and means comprising a feedback impedance distinct from the impedance of said feedback winding matched to said load impedances for connecting said feedback winding to said input winding.

4. A winding compensating device including in combination a primary winding, a secondary winding, a tertiary winding, the three windings being inductively coupled, a load imepdance, means connecting the load impedance across the secondary winding, a high-gain amplifier, means for impressing the output of the amplifier upon the primary winding, means including a feedback impedance distinct from the impedance of said tertiary winding for coupling the tertiary winding to the input of the amplifier, a source of input excitation voltage, means including an input impedance for coupling the source to the input of the amplifier, the feedback impedance having a value such that the sum of the tertiary winding and feedback impedances is equal in phase angle to that of the sum of the secondary winding and load impedances.

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