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INTERPOLATING ARRANGEMENT FOR A PRECISION TRANSDUCER

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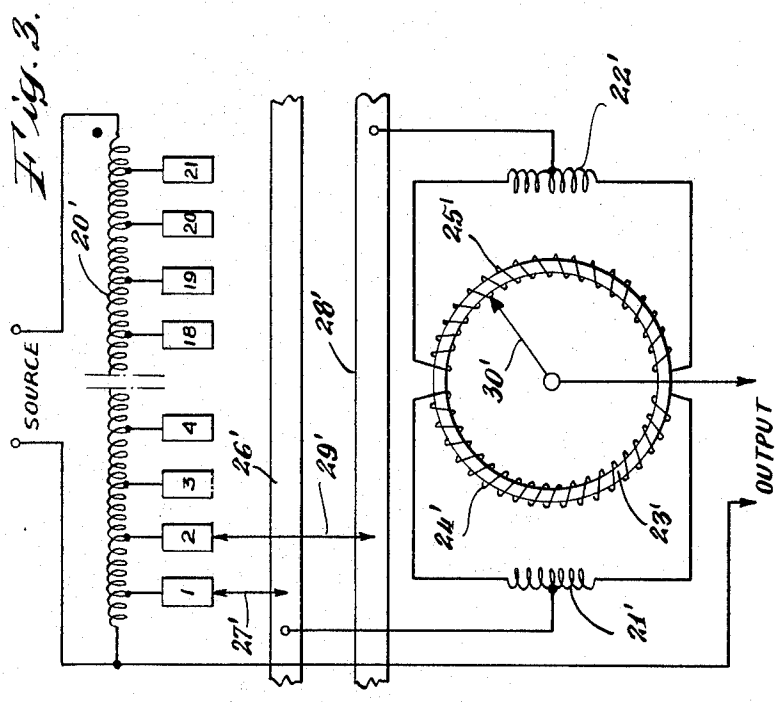


Fig. 3.

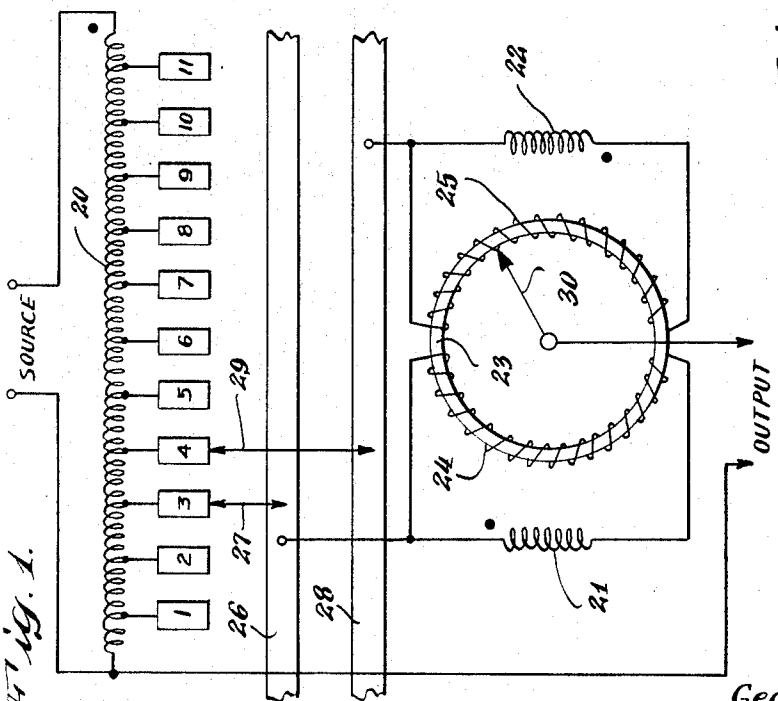


Fig. 1.

	1 REV.			2 REV.			3 REV.			4 REV.			5 REV.			6,7,8,9 REV.			10 REV.		
A	0	90	180	270	0	90	180	270	0	90	180	270	0	90	180	270	0	90	180	270	0	90	180	270
B	1	1	1	–	2	2	2	–	3	3	3	–	4	4	4	–	5	5	5	–	10	10	10	–
C	1	–	2	2	2	–	3	3	3	–	4	4	4	–	5	5	5	–	6	6	10	–	11	11

(ETC)

Fig. 2.

INVENTOR.
George H. Keats

BY
Andrew L. Ney
ATTORNEY.

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INTERPOLATING ARRANGEMENT FOR A PRECISION TRANSDUCER

George H. Keats, Stamford, Conn., assignor to The Perkin-Elmer Corporation, Norwalk, Conn., a corporation of New York

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ABSTRACT OF THE DISCLOSURE

A precision A.C. transducer includes an autotransformer winding having a plurality of accurately positioned taps. A first pair of inductive elements is arranged in magnetic flux linkage with the autotransformer winding. Each of these elements develops equal voltages which are equal to one-half of the voltage existing between adjacent taps. Switching means are provided for connecting one point on each of said inductive elements to adjacent autotransformer taps progressively along the series. A second pair of inductive elements is wound on an annular mandrel of magnetic material and each of these elements is coupled across a different inductive element of said first pair. Moveable contact means for movement along and contact with said second pair of inductive elements are provided for selectively tapping any portion of the voltages developed by said first pair of inductive elements. The movement of the contact means is synchronized with the operation of said switching means for providing that said contact means is operative at all times on an inductive means of said second pair.

General

The present invention relates to precision transducers for use in electrical apparatus and is particularly concerned with a novel precision transducing device by means of which any selected intermediate voltage may be derived from an input voltage. This device possesses highly desirable input and output impedence characteristics as well as extraordinary linearity and precision of the output voltage with respect to its analog input.

There is described in U.S. Patent 3,027,510 Precision A.C. Transducer to Larkin B. Scott a device which is generally similar in construction and operation to the present invention. The transducer described in this patent develops a plurality of intermediate voltages from an input signal and various interpolating techniques are shown for effecting smooth and continuous variations not only from one intermediate voltage to the next, but also from one end of the range to the other. One interpolating technique described in the patent employs two inductive elements which are in magnetic flux linkage with the autotransformer which develops the intermediate voltages. The inductive elements are switched progressively from one autotransformer tap to another and a contact or wiper arm moves in synchronism with such progressive switching to develop the interpolated voltages.

The second interpolating technique described in the patent employs resistive elements which are connected across the previously described inductive elements. As is explained in the patent, in order to provide a device capable of supplying large load currents without significantly sacrificing the high precision and linearity of its output with respect to its input, it is desirable that the inductive elements be conductors of large cross-section so as to minimize ohmic resistance. Such heavy conductors, if wound on a toroidal form, will necessarily have relatively few turns as compared to a fine wire potentiometer. While it is desirable to form the inductive elements of heavy

conductors, one result of that choice is that the maximum resolution obtainable between adjacent turns of the inductive elements may be considerably less than would be possible with a fine wire resistive element. By connecting resistive elements across the inductive elements in the manner shown in the patent, the highly desirable characteristics and features of the transducer of that patent are preserved without the sacrifice of resolution.

In order to achieve these results and to minimize the possibilities of nonlinear output, it is necessary that the fine wire resistive element be wound with great care and accuracy. The greater the required linearity, the more care needed in winding the resistive wire. Those skilled in the art will appreciate the difficulties involved in precisely winding resistive fine wire elements in order to achieve extreme linearity.

Accordingly, it is an object of the present invention to provide a new and improved precision transducer.

It is another object of the present invention to provide a new and improved precision transducer having improved linearity between the output voltage and its analog input.

It is a further object of the present invention to provide a new and improved precision transducer capable of providing high linearity between its output voltage and analog input and not requiring extremely precise winding of its interpolating member.

It is still another object of the present invention to provide a new and improved precision transducer which is simple in construction.

A precision transducer constructed in accordance with the present invention includes an autotransformer having a series of taps for developing equal increments of voltage and a first pair of conductive elements disposed in magnetic flux linkage with the autotransformer for developing two equal induced voltages. The precision transducer of the invention additionally includes a soft magnetic material mandrel and a second pair of inductive elements wound on the mandrel. Each of the inductive elements of the second pair are connected across a different inductive element of the first pair. The invention further includes switch means for connecting one point on each of the inductive elements of the first pair to adjacent autotransformer taps progressively along the series, and a contact moveable along the second pair of inductive elements to selectively tap any portion of the voltages developed by the first pair of inductive elements. The movement of the contact is so synchronized with the operation of the switch means that the contact is operative at all times on an inductive element of the second pair connected to an inductive element of the first pair energized by conductive connection with the autotransformer in addition to magnetic flux linkage therewith.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description, taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

Referring to the drawings:

FIGURE 1 shows one embodiment of a precision transducer constructed in accordance with the present invention;

FIGURE 2 is a table of the switching sequences performed during the operation of the FIGURE 1 embodiment through its range; and

FIGURE 3 shows a second embodiment of a precision transducer constructed in accordance with the present invention.

Description and operation of FIGURE 1 precision transducer

Referring to FIGURE 1, a precision transducer according to the present invention includes an autotransformer

20 having a series of taps for developing equal increments of voltage. The taps numbered 1–11 are located at equally spaced points along the autotransformer winding. The autotransformer is energized by an alternating current source (not shown).

The precision transducer of the invention also includes a first pair of inductive elements 21 and 22 disposed in magnetic flux linkage with the autotransformer 20. Although FIGURE 1 shows the autotransformer windings and inductive elements 21, 22 separately, this is done for purposes of explanation only and in the interest of clarity. The number of turns of each of the inductive elements 21 and 22 with respect to each other is such that each of these inductive elements develop equal voltages. The number of turns of the inductive elements 21 and 22 with respect to the number of turns between autotransformer taps is, for the FIGURE 1 embodiment, such that each of these inductive elements develop an induced voltage equal to one-half the voltage increment between adjacent autotransformer taps. The dots adjacent inductive elements 21 and 22 are conventional polarity symbols.

The precision transducer of the invention further includes a soft magnetic material mandrel 23. This mandrel is preferably in the form of a closed ring.

The invention further includes a second pair of inductive elements 24 and 25 wound on the mandrel 23. Each of the inductive elements of the second pair is connected across a different inductive element of the first pair. In particular, inductive element 24 is connected across inductive element 21, while inductive element 25 is connected across inductive element 22.

The precision transducer according to the invention additionally includes switch means for connecting one point on each of the inductive elements of the first pair to adjacent transformer taps progressively along the series. In particular, for the embodiment of FIGURE 1, one end of inductive element 21 is electrically connected to the autotransformer taps through a slip ring 26 and a connector 27 while a corresponding point on inductive element 22, namely, one of the ends of this inductive element, is connected to the autotransformer taps, through a slip ring 28 and a connector 29. The switching operations are accomplished by movement of the connectors 27 and 29, each having one end in electrical connection with its associated slip ring, while the other end is connected progressively to autotransformer taps along the series.

The precision transducer of the invention further includes a contact 30 moveable along the second pair of inductive elements to selectively tap any portion of the voltages developed by the first pair of inductive elements. Specifically, as contact 30 rotates it makes contact with the different turns of the third and fourth deductive elements 24 and 25 and in this way selectively taps any portion of the voltages developed by inductive elements 21 and 22. The movement of contact 30 is so synchronized with the operation of the switch means that the contact is operative at all times on an inductive element of the second pair which is connected to an inductive element of the first pair, the first pair being energized by conductive connection with the autotransformer 20 in addition to magnetic flux linkage with the autotransformer.

The mechanism for accomplishing the switching function of the present invention may be conveniently carried out by an internal-external gear arrangement such as that disclosed in U.S. Patent 2,843,822, Precision Transducer, to Larkin B. Scott, wherein one of the gears is disposed to be eccentrically rotated about a central rotary axis to progressively make connections between an interpolating means and the taps of the autotransformer in the proper sequence. Alternatively, an arrangement of Geneva gears or other appropriate mechanical means may be employed to accomplish the switching functions as taught by the present invention.

The interpolating contact means of the present invention may also be similar to that illustrated in U.S. Patent

2,843,822, but it is important to note that the present invention differs from the device disclosed in this patent in that the inductive elements of the present invention are separate and distinct from each other and are arranged to have only one point connected to the autotransformer taps.

The table of FIGURE 2 shows the progressive switching operations as carried out in connection with the embodiment of FIGURE 1. The data of the table shows operation of the device through ten revolutions of the interpolating contact 30, each revolution being subdivided into angular rotation expressed in degrees, as shown along line A. Line B tabulates the connection of slip ring 26 with the autotransformer taps along the series, while line C tabulates the connection of slip ring 28 with the autotransformer taps along the series.

From the table of FIGURE 2, it may be seen that when the interpolating contact 30 is initially at zero degrees, the inductive elements 21 and 22 are connected through slip rings 26 and 28 and their respective connectors 27 and 29 to tap No. 1 of the series of taps along the autotransformer 20.

Assuming that the interpolating contact 30 is rotated in a counterclockwise direction through 90 degrees, the operation of the switch means is such that the connector 27 is moved out of contact with autotransformer tap No. 1. As the interpolating contact 30 is moved to a 180-degree position, connector 29 makes connection between slip ring 28 and tap No. 2 of the autotransformer 20.

In its rotation from 180 degrees to 360 degrees, the interpolating contact 30 is operative to tap the potential developed by inductive element 21. At approximately the 270-degree point in the rotation of the interpolating contact 30, slip ring 26 is disconnected from tap No. 1 of the autotransformer 20 and is thereafter connected to tap No. 2 of the autotransformer before the interpolating contact 30 begins to rotate through the second revolution of its operation.

The present invention conceives that each of the inductive elements 21 and 22 develop an induced voltage equal to one-half the voltage increment between adjacent autotransformer taps of the autotransformer 20. Therefore, when the inductive element 22 is connected to autotransformer tap No. 1, the interpolating contact 30 may be selectively positioned to tap any desired voltage between that appearing at autotransformer tap No. 1 and one-half of the potential difference between autotransformer taps Nos. 1 and 2.

The inductive elements 21 and 22 are arranged to be so disposed and switched that the voltages induced therein may be either additive or subtractive from the voltages appearing at the autotransformer taps Nos. 1–11 along the series. Thus, in the operation just explained, the induced voltage developed by inductive element 22 is arranged to be additive to that appearing at autotransformer tap No. 1. On the other hand, the induced voltage developed by inductive element 21 is arranged to be subtractive from the voltage appearing at autotransformer tap No. 2. The interpolating contact 30 may therefore be positioned to selectively tap any desired voltage increment between adjacent autotransformer taps.

As previously stated, when using a resistive element as the interpolating element the fine wire must be wound with great care and accuracy in order to provide improved resolution without any sacrifice to the highly desirable impedance characteristics. This means that care must be taken to insure that the homogeneity of the wire remains constant at it is wrapped around the winding form. First, the wire itself must be uniform in cross section to give a constant resistance per unit length. Second, the cross section of the winding form must be held constant else a variable wire length per wire convolution will result, thus creating variable resistance per convolution. Thirdly, care must be taken to insure that the wire is not strained unevenly so as to produce a variable cross section wire

from turn to turn. The effect of the incremental resistance not being equal or uniform is to produce a voltage ratio error which is accumulative.

However, by winding the interpolating wire on a soft magnetic material mandrel the incremental voltage ratio errors due to variations in incremental resistance are minimized considerably. This result is due to the voltage induced in each wire convolution. The induced voltages are precisely equal to each other if the flux in the core uniformly cuts each turn. This is a reasonable assumption to make if the leakage flux is low and the permeability of the core is sufficiently high. Even where uniform cutting by the magnetic flux is lacking, the net current flow which is the difference between the current due to the input source and the induced current is so small that the voltage drops are small. Thus, by winding the interpolating wire on a soft magnetic material mandrel the requirement of exercising great care and accuracy as was the case for a resistive interpolating element is lessened so that the resulting device is capable of providing a more linear output along its entire range.

The ten-revolution device shown in FIGURE 1 was described for illustrative purposes only. It will be obvious to those skilled in the art that the concept of the present invention is not limited to any particular number of revolutions, and may be carried out in embodiments having any conveniently desirable number of autotransformer taps along the series, as well as being operative through any number of revolutions according to the requirements of the particular application for which the embodiment is designed.

Description and operation of FIGURE 3 precision transducer

FIGURE 3 shows a second embodiment of a precision transducer constructed in accordance with the present invention. The apparatus of FIGURE 3 is generally similar in construction and operation to the apparatus of FIGURE 1. Therefore, a detailed description of the FIGURE 3 apparatus will be omitted. Elements in FIGURE 3 corresponding to elements in FIGURE 1 have been given the same reference numerals followed by a prime symbol.

Referring to FIGURE 3, it is seen that in this embodiment the centers, rather than the ends, of inductive elements **21′** and **22′** are switched to adjacent autotransformer taps. This results from, first, an increase in the number of autotransformer taps by a factor of two and, second, from a different number of turns of the inductive elements **21′** and **22′**. Although not shown in the drawing, the number of turns of inductive elements **21′** and **22′** is such that each of these inductive elements develops an induced voltage equal to the voltage increment between adjacent autotransformer taps rather than one-half this voltage.

The particular construction of the FIGURE 3 transducer provides improved performance over the FIGURE 1 transducer when linearity errors due to transformer imperfections and loading and regulating errors arise. The FIGURE 3 transducer employs symmetrical switching so that these linearity errors are biased equally about the zero point. Thus, while the peak-to-peak error may remain the same for both embodiments, the average error for the FIGURE 3 transducer is decreased by a factor of two.

While there has been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is therefore aimed to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A precision transducer comprising:
an autotransformer having a series of taps for developing equal increments of voltage;
a first pair of inductive elements disposed in magnetic flux linkage with said autotransformer for developing two equal induced voltages;
an annular mandrel formed of a soft magnetic material;
a second pair of inductive elements wound on said mandrel, each of said inductive elements of said second pair connected across a different inductive element of said first pair;
switch means for connecting one point on each of said inductive elements of said first pair to adjacent autotransformer taps progressively along the series;
and a contact movable along said second pair of inductive elements to selectively tap any portion of the voltages developed by said first pair of inductive elements, the movement of said contact being so synchronized with the operation of said switch means that said contact is operative at all times on an inductive element of said second pair connected to an inductive element of said first pair energized by conductive connection with said autotransformer in addition to magnetic flux linkage therewith.

2. A precision transducer according to claim **1** wherein the mandrel is in the form of a closed ring.

3. A precision transducer comprising:
an autotransformer having a series of taps for developing equal increments of voltage;
a first pair of inductive elements each having a plurality of turns disposed in magnetic flux linkage with said autotransformer, each of said inductive elements of said first pair developing an induced voltage equal to the voltage increment between adjacent autotransformer taps;
an annular mandrel formed of a soft magnetic material;
a second pair of inductive elements wound on said mandrel, each of said inductive elements of said second pair connected across a different inductive element of said first pair;
said second pair of inductive elements each having a greater number of turns than said first pair and which exhibit variations of resistance between turns;
switch means for connecting one point on each of said inductive elements of said first pair to adjacent autotransformer taps progressively along the series;
and a contact movable along said second pair of inductive elements to selectively tap any portion of the voltages developed by said first pair of inductive elements, the movement of said contact being so synchronized with the operation of said switch means that said contact is operative at all times on an inductive element of said second pair, said first pair connected to an inductive element of said first pair energized by conductive connection with said autotransformer in addition to magnetic flux linkage therewith.

4. A transducer in accordance with claim **3** wherein said switch means connects a center point on each of said inductive elements of said first pair to adjacent autotransformer taps progressively along the series.

5. A transducer in accordance with claim **3** wherein said switch means connects an end thereof of each of said inductive elements of said first pair to adjacent autotransformer taps progressively along the series.

6. A precision transducer comprising:
an autotransformer having a series of taps for developing equal increments of voltage;
first and second inductive elements each having a plurality of turns disposed in magnetic flux linkage with said autotransformer for developing two equal induced voltages;
an annular mandrel formed of a soft magnetic material;
a third inductive element wound on said mandrel and connected across said first inductive element, said third element having a greater number of winding turns than said first element and which exhibits variations in resistance between turns;

a fourth inductive element wound on said mandrel and connected across said second inductive element, said fourth element having a greater number of winding turns than said first element and which exhibits variations in resistance between turns;

switch means for connecting one point on said first inductive element and a corresponding point on said second inductive element to adjacent autotransformer taps progressively along the series;

and a contact movable along said third and fourth inductive elements to selectively tap any portion of the voltages developed by said first and second inductive elements, the movement of said contact being so synchronized with the operation of said switch means that said contact is operative at all times on one of said third and fourth inductive elements which are connected to one of said first and second inductive elements respectively, and which is energized by

conductive connection with said autotransformer in addition to magnetic flux linkage therewith.

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JOHN F. COUCH, *Primary Examiner.*

A. D. PELLINEN, *Assistant Examiner.*