

Aug. 2, 1966 **J. L. WINGET** **3,264,588**
POSITION-MEASURING TRANSFORMER HAVING MEANS FOR
COMPENSATING ERRORS IN CONDUCTOR ALIGNMENT
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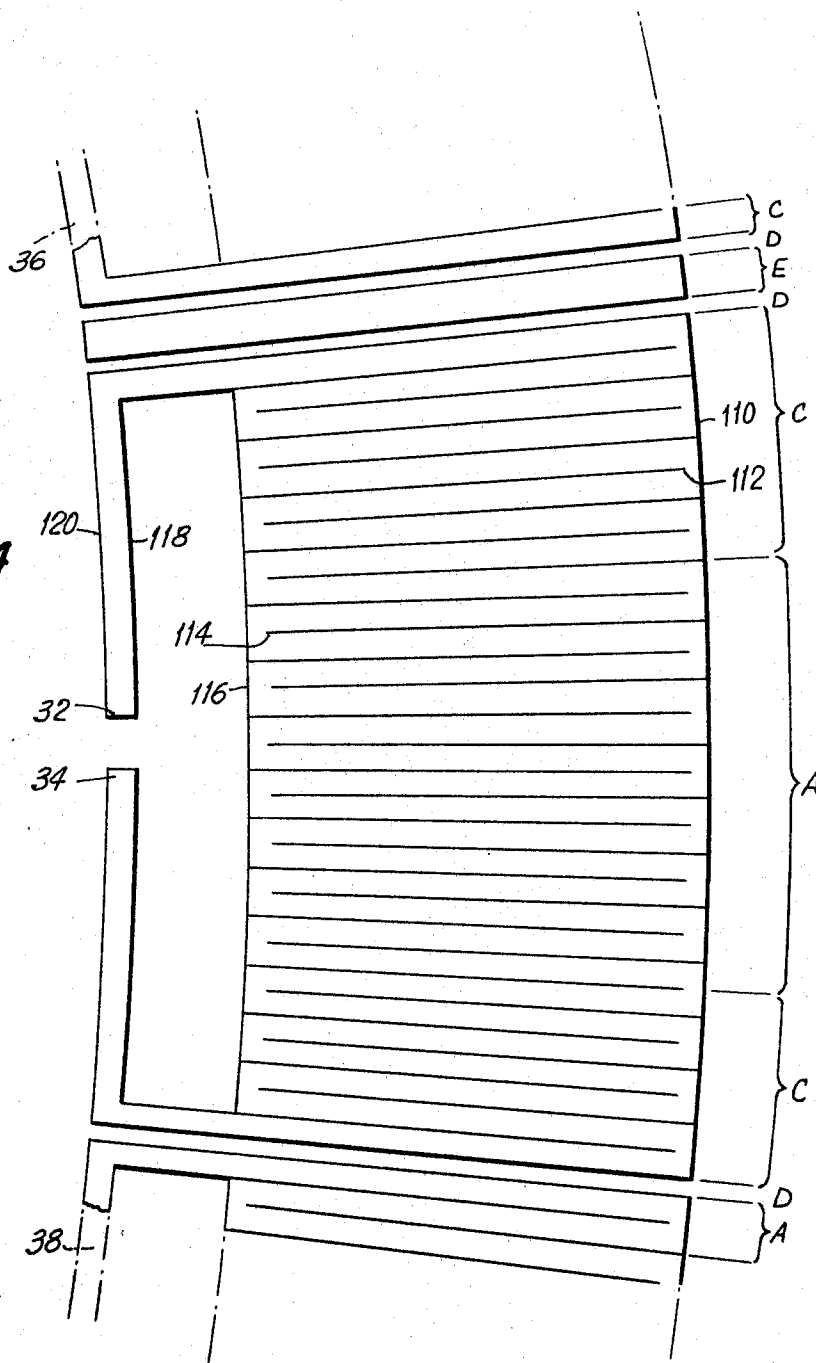
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FIG. 4



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FIG. 5

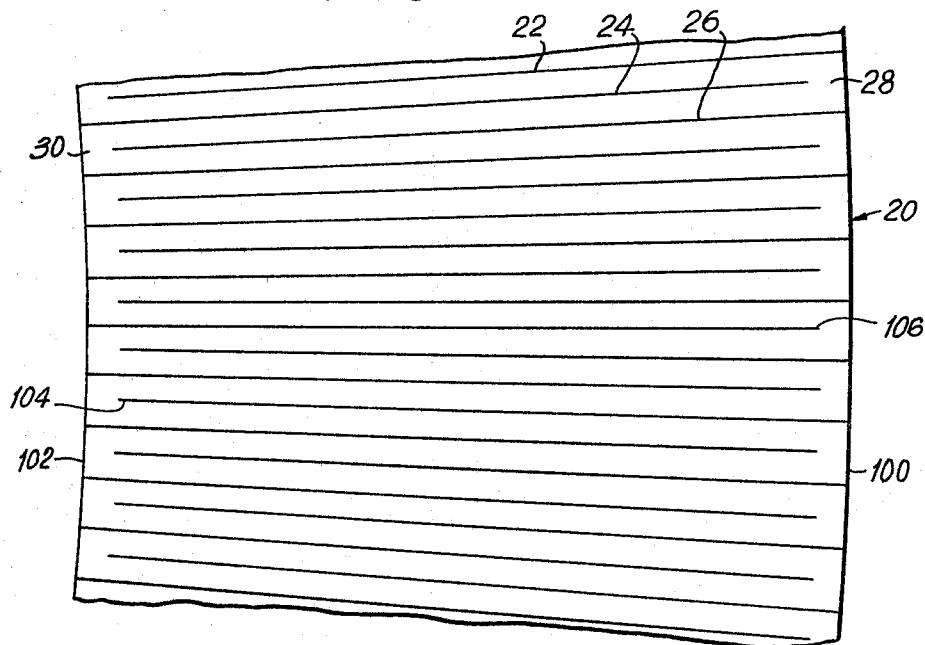


FIG. 6

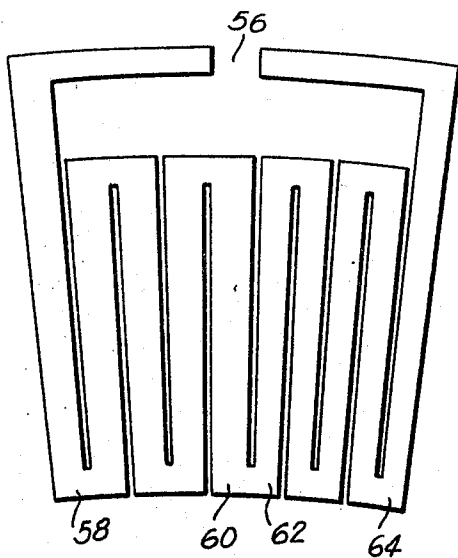
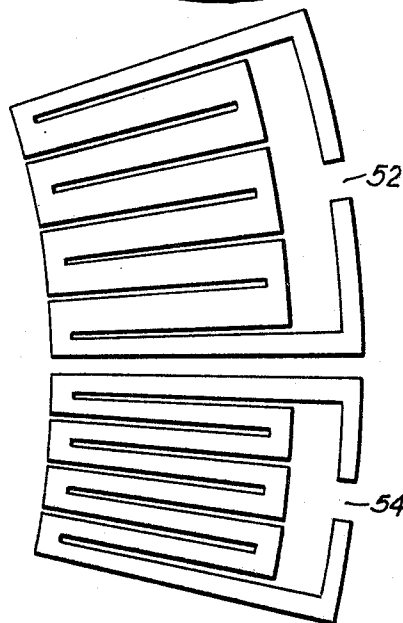


FIG. 7

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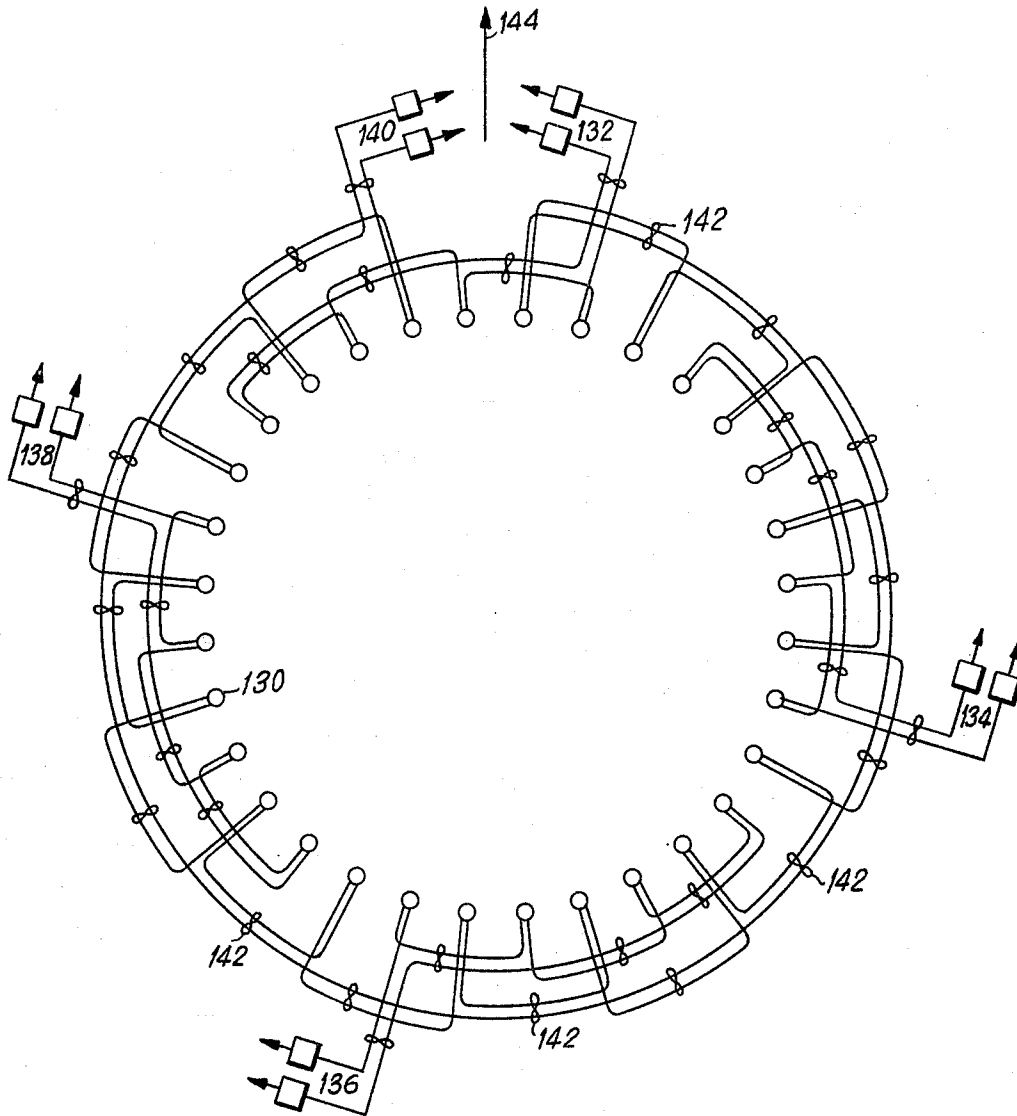


FIG. 8

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POSITION-MEASURING TRANSFORMER HAVING MEANS FOR COMPENSATING ERRORS IN CONDUCTOR ALIGNMENT

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14 Claims. (Cl. 336—30)

This invention relates to transformers, and more particularly to position-measuring transformers.

An improved position-measuring transformer comprising closely spaced relatively rotatable primary and secondary discs, each with radial conductors connected in series circumferentially, is described in United States Patent 2,799,835, issued to Robert W. Tripp and the present inventor. The general object of the present invention is to further improve the position-measuring transformers described in said patent.

In that patent, means are described whereby the spacing or pitch between the conductors of the stator sectors is made somewhat different from that on the rotor member, for the purpose of reducing or eliminating particular harmonics of the coupling wave. This feature is a very valuable one, but it has been found that it gives rise to some sensitivity to mechanical misalignments with respect to the mechanical axis of rotation. In particular it has been found that a combination of decentering and wobble produces errors having a periodicity of once per revolution.

This type of error can be explained by noting that a wobble or tilt of one plate with respect to the other (without decentering) results in a higher relative value of the electromagnetic coupling to the conductors of the stator sector which are nearer to the rotor element than the conductors at the other side of the stator sector. The overall effect of the device is the sum of the various electromagnetic couplings of the conductors involved. Since the mechanical spacing of the conductors of the stator sector are not the same as those of the rotor, the sum or total effect is as if the stator sector had been shifted in position.

Generally there will be another stator sector diametrically opposite the one described above, which experiences a similar effect but in the opposite direction in terms of angular rotation. To a first approximation, these two effects therefore cancel. However, when a combination of decentering and wobble are present, the two effects do not cancel, and there is a residual error having a period of once per revolution.

A specific object of the present invention is to overcome an error in position reading caused by a combination of wobble and relative decentering of the discs. I have found that the effect of such an error is in one direction when the conductors of the stator have a larger spacing or pitch than the corresponding conductors of the rotor, and that the effect is in the opposite direction when the conductors of the stator have a smaller spacing or pitch than that of the conductors of the rotor. I am able therefore to overcome the error by using a combination of increased pitch and of decreased pitch of the stator conductors relative to the rotor conductors, thereby avoiding sensitivity to mechanical errors, while retaining the desirable feature of reduction of harmonics.

To accomplish the foregoing objects, and other more specific objects which hereinafter appear, my invention resides in the position-measuring transformer elements and their relation one to another, as are hereinafter more particularly described in the following specification. The specification is accompanied by drawings in which:

FIG. 1 is a small partially sectioned elevation of a transformer, shown in highly schematic form;

FIG. 2 shows a group of radial conductors, some with

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smaller and some with larger spacing or pitch, arranged symmetrically in the group;

FIG. 3 shows a part of a stator disc with a series of such groups of conductors;

FIG. 4 corresponds to a part of FIG. 3 drawn to larger scale;

FIG. 5 is a fragmentary view of a part of a rotor;

FIG. 6 shows a group of conductors as in FIG. 2, but with the conductors of smaller and larger pitch arranged unsymmetrically;

FIG. 7 shows a modification in which one group has conductors of larger pitch, and an adjacent group has conductors of smaller pitch; and

FIG. 8 is explanatory of the wiring of the stator shown in FIG. 3.

Referring to the drawing, and more particularly to FIG. 1, the transformer comprises discs 10 and 12, which have plane faces adjacent one another, with a clearance 14 therebetween of only a few thousandths of an inch. Disc 10 is mounted on a shaft 16, and disc 12 is mounted on a co-axial shaft 18, the discs being perpendicular to the axis. Either disc may be rotatable relative to the other, or both may be rotatable. The discs are held against axial movement, it being understood that the showing in FIG. 1 is highly simplified and schematic, rather than structural.

The adjacent faces of the discs have an insulating surface with radial conductors printed thereon. Either disc may be considered to be a primary, and the other a secondary. Either may be considered to be a rotor, and the other a stator. These terms are used hereinafter for convenience of identification, but would be interchangeable.

In most cases one disc (the stator) is not mounted for rotation at all. Its pattern of conductors has an axis which should be coaxial with the axis of the pattern on the rotor. Decentering may result from the rotor pattern being displaced from its own shaft axis, or from the shaft axis and rotor pattern being displaced from the axis of the stator pattern. It is convenient to speak of decentering of the discs or members, but of course it is the printed pattern of radial conductors that is meant. Wobble means that a disc face and pattern thereon is not truly perpendicular to the axis of rotation.

Referring now to FIG. 5, the rotor has an annular film of metal 20 deposited thereon, this film being interrupted by radial lines 22, 24 and 26, etc., so that adjacent conductors are circumferentially connected at one end, as indicated at 28, and are progressively circumferentially connected at the other end, as indicated at 30, so that the radial conductors are connected in series. This series connection extends entirely around the disc, except at a terminal point where leads are brought through the disc from adjacent radial conductors which are not connected to one another.

Referring now to FIG. 4, the stator is divided into a series of groups of radial conductors. Such a group or sector is shown with terminal connections at 32 and 34. The terminal connection for one end of an adjacent sector is suggested at 36, and one terminal connection for an adjacent sector on the opposite side is suggested at 38. Within the group the conductors are connected in series.

Referring now to FIG. 3, such sectors or groups of conductors are shown at 40, 42, 44, 46, 48 and 50. The insulating lines separating the individual conductors are not shown, except for some in sector 48, but it will be understood that in each sector there are radial insulating lines as shown in FIG. 4. As is more fully described in the aforesaid Patent 2,799,835, some groups are connected in series for circumferential flow in one direction, and the other groups are connected in series for circumferential flow in opposite direction. The circumferential paths in each direction are preferably made substantially equal,

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thereby neutralizing the effect of circumferential flow, while retaining the effect of radial flow, as is desired for position-measurement.

The spacing or pitch of the radial conductors of the rotor, as shown in FIG. 5, has a constant or uniform value. In accordance with the teachings of said Patent 2,799,835, the spacing or pitch and also the number of conductors of the stator may differ slightly from the pitch and number of conductors of the rotor, and this difference may be so quantitatively selected as to suppress one or more undesired harmonics of the coupling wave in the transformer.

As explained above, I have found that a combination of mechanical errors, and more particularly a combination of decentering and wobble of the discs, produces an error in position-measurement having a period of once per revolution. I have further found that this error is in one direction when the stator conductors have a larger pitch than the rotor, and is in opposite direction when the stator conductors have a smaller pitch than the rotor. The error therefore may be overcome by balancing one against the other, and referring to FIG. 7, the conductors with terminals at 52 have a larger pitch than the conductors with terminals at 54. These groups are intermixed to obtain a desired averaging around the stator. The rotor has the middle or average pitch.

The conductors of larger and smaller pitch may be provided in each group, and such an arrangement is shown in FIG. 6, in which the group has terminals at 56. In this group the radial conductors from conductor 58 to conductor 60 have an increased pitch, and from radial conductor 62 to conductor 64 they have a decreased pitch. It will be noted that the conductors of larger pitch are equal in number to the conductors of smaller pitch.

In preferred form the difference in pitch is made symmetrical in each group, and referring to FIG. 2, the group has terminals at 66. The radial conductors from 68 to 70 and from 72 to 74 have decreased pitch, while the conductors from 76 to 78 have increased pitch. Here again the conductors of smaller pitch are equal in number to the conductors of larger pitch.

In FIGS. 2, 6 and 7 the width of the conductors and the insulating space between conductors has been exaggerated for clarity. A structural showing which is more nearly to scale is given in FIG. 4, in which the group has terminals 32 and 34. Another difference is that in FIG. 4 the terminals are within the groups, that is, they are at a smaller radius from the center of the disc, whereas in FIGS. 2, 6 and 7 the terminals are shown outside the groups, that is, at a larger radius. Either pattern arrangement maybe employed, depending on convenience in any particular structure. In FIG. 4 the radial conductors of reduced pitch are defined by the two end brackets C, and the middle conductors of larger pitch are defined by the bracket A. One insulating space between groups is indicated at D, at the lower part of the drawing. At the upper part of the drawing there is a wider space, part of which may be metal-coated, as indicated at E. This may be referred to as a dummy conductor. There is an insulating gap D at each side of the dummy conductor E.

The spacing between sectors is determined by the formulae given in the aforesaid Patent 2,799,835. Sometimes, for example if the rotor has 360 poles or 720 poles, the spacing between sectors comes out uniform. In other cases the formulae provide sectors with a spacing which does not come out even, and in such case the extra space is distributed around the stator disc as evenly as feasible. A wide space is given a dummy conductor to help maintain uniform eddy currents and phase shift around the transformer.

Because of the difference in spacing the overall center-to-center arcuate spacing from sector to sector differs, and this difference is indicated in FIG. 3 by the curved arrows F and G. The arcuate spacing at G is somewhat

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larger than the arcuate spacing at F because of the extra space between groups here shown at 80.

As one specific example of a transformer embodying features of the invention, I shall describe a transformer using discs about twelve inches in diameter. Referring to the rotor shown in FIG. 5 the circumference of the printed conductors, as bounded by the circular line 100, has a radius of 5.875 inches. The inner line or circle 102 has a radius of 4.725 inches. The circumferential printed connections have a width of 0.025 inch, so that the radius at the points like point 104, that is, at the inner ends of the insulating lines, comes out to be 4.750 inches. The radius at the outer ends of the division lines, that is at the points like point 106, then becomes 5.850 inches. There are 1024 lines around the disc, forming a like number of radial conductors or poles. The width of the insulating lines between conductors is 0.010 inch. The angular width of the conductors is $\frac{45}{128}$ of a degree.

Referring now to the stator shown in FIG. 3, in this case there are 960 radial conductors or poles, divided into groups or sectors, and there are 32 such sectors. The arcuate spacing G between some sectors is 11 and $\frac{109}{256}$ degrees. The arcuate spacing F between other sectors is 10 and $\frac{185}{256}$ degrees.

Referring now to FIG. 4, the radius at the outer circle 110 is 5.875 inches; the radius at the outer ends of the dividing lines, that is at points like the point 112, is 5.850 inches; the radius at the inner ends of the dividing lines, that is, at the points like point 114 is 4.750 inches; and the radius at the inner circle 116 is 4.725 inches. The radius of lines 118 is 4.510 inches, and the radius of line 120 is 4.450 inches. The pitch of the radial conductors at the bracket A is $\frac{47}{128}$ of a degree and the pitch of the radial conductors at the bracket C is $\frac{43}{128}$ of a degree. Thus the conductors are of increased width and of decreased width respectively, relative to the rotor in which the conductor width was $\frac{45}{128}$ of a degree.

The insulating gap between sectors at D is $\frac{45}{256}$ of a degree. The extra metal coated space at E is $\frac{135}{256}$ of a degree. The insulating gap at each side of the coated part E is like the gap at D, that is $\frac{45}{256}$ of a degree. The width of the insulating or dividing lines between conductors is 0.010 inch.

Separations like the separation D at the lower part of FIG. 4 occur eight times around the disc, at equal intervals of 45 degrees each. The other separations are all like that shown at D, E, D in the upper part of the drawing, there being twenty-four such separations around the disc, with twenty-four dummy conductors. These are also shown at 80 in FIG. 3.

It will be understood that the specific dimensions given above have been given solely as one specific example of the invention, and are not intended to be in limitation of the invention. These transformers may be made with discs of different diameter, and with different numbers of poles.

Referring now to FIG. 8, this shows the wiring of the stator described and shown in FIGS. 3 and 4. The inner ring of small circles 130 represents holes through the stator disc through each of which a pair of connections extend to the back of the disc from the sector terminals such as those indicated at 32, 34 in FIG. 4. The connections then are made as shown in the drawing, and terminate in five pairs of leads indicated by the five pairs of rectangles 132, 134, 136, 138, and 140. The pairs of conductors in back of the disc are twisted, and are combined to form a harness extending arcuately around the stator. The twisting of the pairs is indicated by the numerous "8" outlines on the drawing, a few of which have been marked 142. All five pairs of leads may be brought out at a single point, here indicated at 144.

The wiring need not be described in excessive detail because it may follow the principles fully described and explained in the aforesaid Patent 2,799,835. In a typical case, the stator, assuming the sectors numbered in se-

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quence from 1 to 32, the odd numbered sectors are connected in series, and in that series alternate sectors have circumferential current flow in one direction, and the intermediate sectors have circumferential current flow in opposite direction. Similarly, the even numbered sectors are connected in series, and in that series the alternate sectors have circumferential current flow in one direction, and the intermediate sectors have circumferential current flow in opposite direction.

The patterns may be ruled directly on the disc by means of a precision ruling engine.

The transformer members have been described as discs, used for measurement of a change in angular position, but as is fully described in said Patent 2,799,835, the members may be rectangular with parallel conductors, and arranged for rectilinear movement in a direction perpendicular to the conductors. The members then are sometimes referred to as a slider and a scale, instead of being referred to as a stator and a rotor. In such a transformer there may be an error in parallelism of the slider and scale. An error in the sense of a change in the spacing therebetween from one end to the other corresponds to wobble of the discs, and an error in parallelism in the planes of the members corresponds to decentering of the discs.

In the aforesaid Patent 2,799,835 the discs are described as made of non-ferromagnetic and non-conducting material such as glass. Such discs may in fact be used, but it is now preferred to employ metal discs the adjacent faces of which are coated with an insulating material before receiving the radial conductors, or more specifically, before receiving a conductive film which subsequently is etched to provide the desired pattern.

In a typical case a film of copper may be bonded to a metal disc by means of a film of insulating cement which may have a thickness of only say 0.002 to 0.004 inch. The bonding material may be one which is treated or set under heat and pressure. The discs not only may be made of a metal, which is more convenient to work with than glass, but may be made of a ferromagnetic material such as hot rolled steel, cold rolled steel, stainless steel, and so on. Thus, the discs may be magnetic or non-magnetic.

It is believed that the construction and operation of my improved position-measuring transformer, as well as the advantages thereof, will be apparent from the foregoing detailed description. It will also be apparent that while I have shown and described the invention in a preferred form, changes may be made without departing from the scope of the invention, as sought to be defined in the following claims. In the claims the reference to discs and radial conductors is not intended to exclude the equivalent use of transformer members arranged for relative rectilinear movement as described above. The terms primary, secondary, rotor, and stator are used in a relative sense, as explained above.

I claim:

1. A position-measuring transformer comprising closely spaced relatively rotatable stator and rotor transformer members in coupling relationship, each being a disc having radial conductors connected in series circumferentially, the pitch of the radial conductors of said stator differing slightly from the pitch of the radial conductors of the rotor in such amount as to suppress an undesired harmonic, the pitch of some stator conductors being greater and the pitch of other stator conductors being less than the pitch of the rotor conductors, the conductors of greater and lesser pitch being distributed around the stator disc approximately uniformly.

2. A position-measuring transformer comprising closely spaced relatively movable primary and secondary transformer members in coupling relationship, one of said members being a rotor disc having radial conductors connected in series circumferentially, the other of said members being a stator disc having its radial conductors

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divided into a plurality of concentric arcuate groups, some groups being circumferentially connected clockwise and some counterclockwise with their opposed circumferential paths being substantially equal, the pitch of the radial conductors of said stator differing slightly from the pitch of the radial conductors of the rotor in such amount as to suppress an undesired harmonic, the pitch of some stator conductors being greater and the pitch of other stator conductors being less than the pitch of the rotor conductors, the conductors of greater and lesser pitch being distributed around the stator disc approximately uniformly and serving to substantially avoid an error in position reading caused by a combination of wobble and relative decentering of a disc.

3. A position-measuring transformer comprising closely spaced relatively rotatable primary and secondary transformer members in coupling relationship, said members being adjacent coaxial discs of non-conducting non-ferromagnetic material with radial conductors connected in series so that adjacent conductors have radially opposite directions of current flow, the pitch of the radial conductors of said primary disc so differing slightly from the pitch of the radial conductors of the secondary disc as to suppress an undesired harmonic, the said different pitch being greater as to some of the radial conductors and being less as to other of the radial conductors in order to substantially avoid an error in position reading caused by a combination of wobble and relative decentering of a disc.

4. A position-measuring transformer comprising relatively rotatable primary and secondary transformer members in coupling relationship, said members being coaxial discs with radial conductors connected in series so that circumferentially adjacent conductors have opposite directions of current flow, the primary disc having groups of conductors disposed on said disc in a circular array, some groups being connected in series, and the other groups being connected in series for circumferential flow in opposite direction, the pitch of the radial conductors of said primary disc so differing slightly from the pitch of the radial conductors of the secondary disc as to suppress an undesired harmonic, the said different pitch being greater as to some of the radial conductors and being less as to other of the radial conductors.

5. A position-measuring transformer comprising closely spaced relatively rotatable primary and secondary transformer members in coupling relationship, said members being adjacent coaxial discs at least the adjacent faces of which are made of insulating material with radial conductors connected in series so that adjacent conductors have opposite directions of current flow, the primary disc having an even number of groups of conductors disposed on said disc in a circular array, circumferentially alternate groups being connected in series, and the intermediate groups being connected in series, alternate groups in each series being connected for circumferential flow in one direction and the intermediate groups in each series being connected for circumferential flow in opposite direction, the pitch of the radial conductors of said primary disc so differing slightly from the pitch of the radial conductors of the secondary disc as to suppress an undesired harmonic, the said different pitch being greater as to some of the radial conductors and being less as to other of the radial conductors in order to substantially avoid an error in position reading caused by a combination of wobble and relative decentering of a disc.

6. A position-measuring transformer as defined in claim 2 in which all of the radial conductors in some groups of radial conductors have the increased pitch and all of the radial conductors in other groups of radial conductors have the decreased pitch.

7. A position-measuring transformer as defined in claim 4 in which all of the radial conductors in some groups of radial conductors have the increased pitch and

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all of the radial conductors in other groups of radial conductors have the decreased pitch.

8. A position-measuring transformer as defined in claim 2, in which each group of radial conductors has some conductors of increased pitch and some conductors of decreased pitch.

9. A position-measuring transformer as defined in claim 4, in which each group of radial conductors has some conductors of increased pitch and some conductors of decreased pitch.

10. A position-measuring transformer as defined in claim 2, in which each group of radial conductors has some conductors of increased pitch and some conductors of decreased pitch, and in which the conductors of increased pitch and those of decreased pitch are disposed symmetrically in the group.

11. A position-measuring transformer as defined in claim 4, in which each group of radial conductors has some conductors of increased pitch and some conductors of decreased pitch, and in which the conductors of increased pitch and those of decreased pitch are disposed symmetrically in the group.

12. A position-measuring transformer as defined in claim 5, in which each group of radial conductors has

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some conductors of increased pitch and some conductors of decreased pitch, and in which the conductors of increased pitch and those of decreased pitch are disposed symmetrically in the group.

13. A position-measuring transformer as defined in claim 2 in which the discs are made of metal, and in which the conductors are bonded to the discs by means of a thin layer of non-conducting material which acts as both an insulator and a cement.

14. A position-measuring transformer as defined in claim 4 in which the discs are made of metal, and in which the conductors are bonded to the discs by means of a thin layer of non-conducting material which acts as both an insulator and a cement.

References Cited by the Examiner

UNITED STATES PATENTS

2,799,835	7/1957	Tripp et al.	336—123
3,202,948	8/1965	Farrand	336—123 X

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