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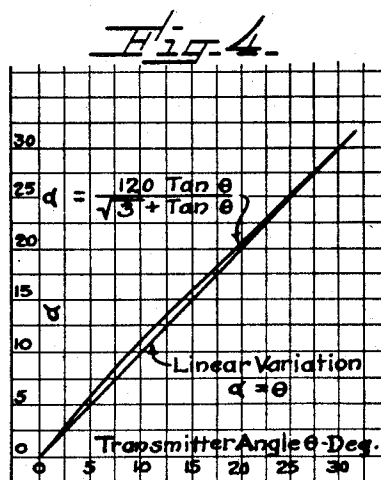
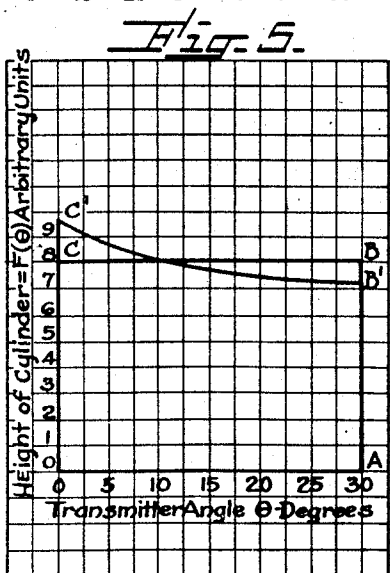
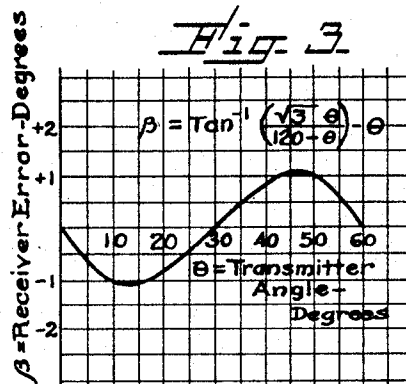
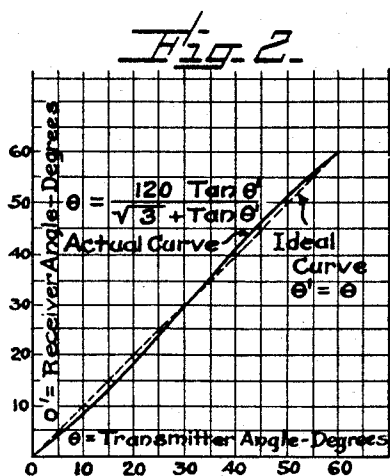
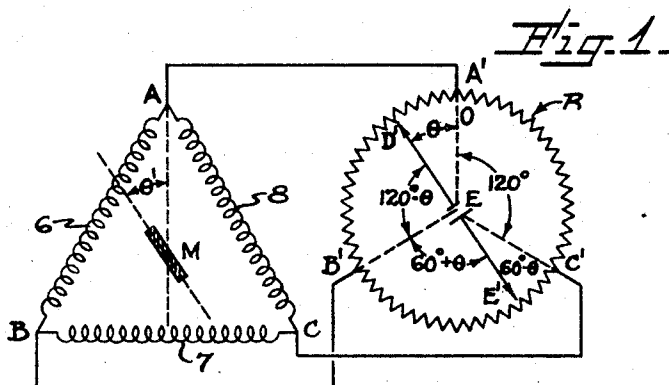
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2,432,029

CORRECTION OF SELSYN TRANSMITTER ERRORS

Filed Oct. 5, 1945

3 Sheets-Sheet 1



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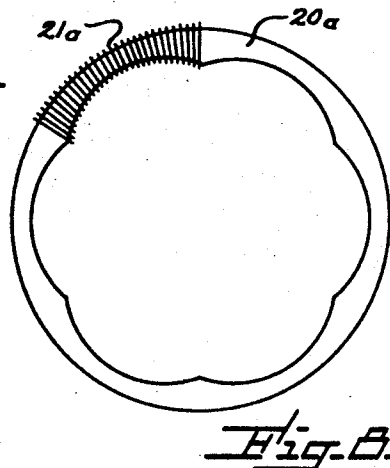
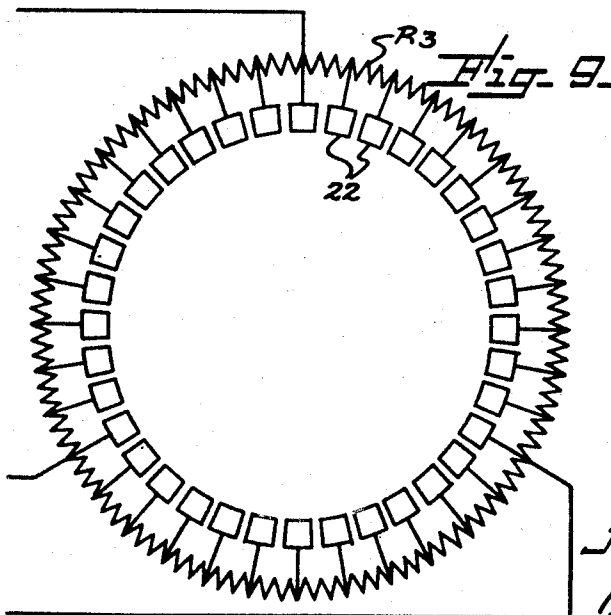
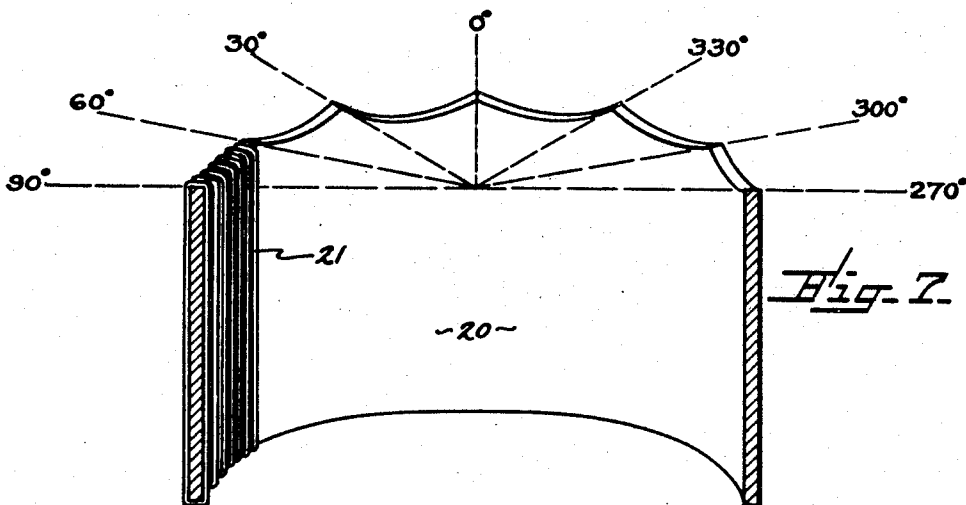
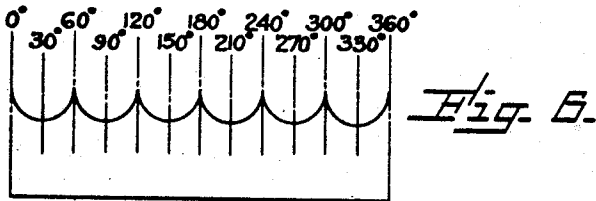
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CORRECTION OF SELSYN TRANSMITTER ERRORS

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3 Sheets-Sheet 2



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CORRECTION OF SELSYN TRANSMITTER ERRORS

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3 Sheets-Sheet 3

Fig. 10.

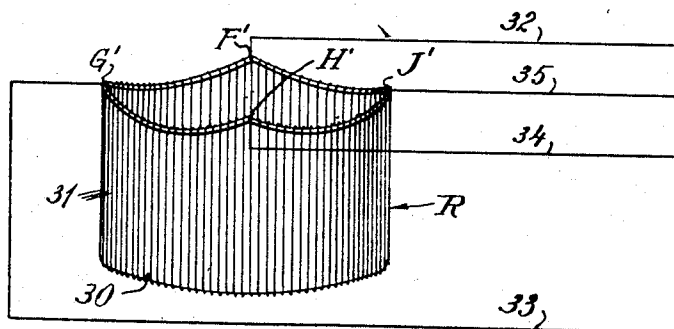


Fig. 11.

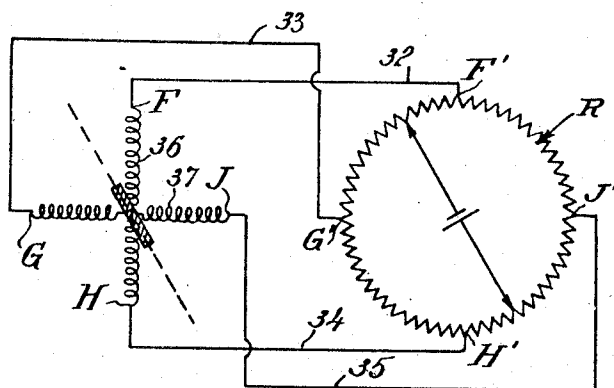
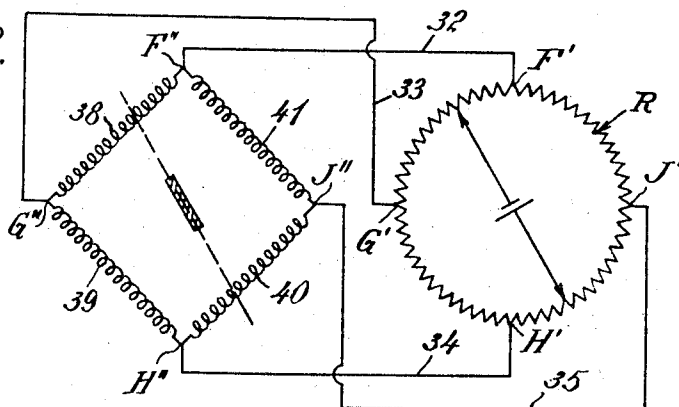


Fig. 12.



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2,432,029

CORRECTION OF SELSYN TRANSMITTER ERRORS

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Application October 5, 1945, Serial No. 620,548

6 Claims. (Cl. 201-60)

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This invention relates to the correction of transmission errors inherent in Selsyn transmission systems.

Selsyn transmission systems, whether of the two coil type, or of the three-or-more wire type, have certain inherent errors which are repetitive in succeeding rotational sectors whose angle depends on the angle between adjacent lead connections to the transmitter resistance. Thus, for instance, in a three wire Selsyn where the diametrically opposed transmitter brushes make direct contact with a lead every 60° of transmitter rotation, the error is repetitive in each 60° sector. The error in that system is such that the receiver lags the transmitter through the first 30°, from the zero and each succeeding 60° position, and then leads the transmitter through each ensuing 30° of transmitter rotation.

I have discovered that all such inherent errors may be corrected by suitable modifications of the transmitter resistance from the linear form in which it is ordinarily used. The following description will set out, in preferred and illustrative form, the details of the application of my invention to a three-wire system; and will then point out the applicability of the invention to other systems. For the purpose of such description I refer to the accompanying drawings, in which

Fig. 1 is a circuit diagram showing the essentials of a usual three-wire Selsyn system;

Fig. 2 is a diagram showing the variation between transmitter angle and receiver angle;

Fig. 3 is a diagram showing the angular error of the receiver plotted against transmitter angle;

Fig. 4 is a diagram showing the variation of the resistance modification factor with transmitter angle;

Fig. 5 is a diagram showing the developed shape of a 30° sector of a modified resistance;

Fig. 6 is a diagram showing the developed shape of a complete resistor;

Fig. 7 is a fragmentary perspective of the resistor of Fig. 6;

Fig. 8 is a diagram showing another type of resistor;

Fig. 9 is a diagram showing another resistor modification; and

Fig. 10 is a view in perspective of a modified form of the new resistor; and

Figs. 11 and 12 are diagrams showing circuits that may be used with the resistor of Fig. 10.

Fig. 1 shows the essential electrical circuiting of a typical three-wire Selsyn system, consisting essentially of a circular transmitter resistance R, to which a potential difference is applied by diametrically opposed brushes D' and E', and which is connected by the three wire circuit AA', BB', CC', to the delta windings 6, 7, 8, of the receiver. The receiver may be considered to be of the usual type with its delta-connected coils rotating in a

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two-pole magnetic field; or, as indicated in Fig. 1, may be considered as having a two-pole magnet M rotating in the field of the coils.

In such a system, where transmitter resistance R is linear with relation to the angle θ of transmitter rotation, it can be shown that

$$(1) \quad \theta = \frac{120 \tan \theta'}{\sqrt{3} + \tan \theta'}$$

where θ denotes the angle of rotation of the transmitter brush from any zero point (such as marked 0 in Fig. 1) where a brush makes direct connection with a circuit lead; and where θ' denotes the corresponding angle of rotation of the rotary element of the receiver, assuming that the receiver stands at all times in an equilibrium position with reference to the distribution of magnetic forces which are controlled by the transmitter. As seen by inspection of Equation 1 the angle θ' becomes equal to θ for values of θ equal to 0°, 30°, 60°, and, so on, as might be expected from the fact that one of the transmitter brushes B is in direct contact with a lead and the other brush B is in mid-position between two leads for every 60° position, and that the two brushes have a symmetric relation to one of the leads, and to the other two leads considered as a pair, at every intermediate 30° point (e. g. such a brush position as shown in Fig. 1.) Fig. 2 shows receiver angle θ' plotted against transmitter angle θ , and for comparison shows θ' plotted ideally as equal to θ . Comparison of the two curves shows the variation between θ' and θ for the first 60° of transmitter rotation from a zero position.

From Equation 1 it may be deduced that

$$(2) \quad \beta = \tan^{-1} \left(\frac{\sqrt{3}\theta}{120 - \theta} \right) - \theta$$

where β denotes the difference between θ' and θ ; that is, denotes the angle by which receiver angle θ' varies from transmitter angle θ . Inspection of Equation 2 shows that β is equal to zero at transmitter angles of 0°, 30°, 60° . . . etc.; that β varies symmetrically with relation to any one of those angular positions; and that β is negative (receiver lags) for the first 30° of transmitter rotation from a zero position, and is positive (receiver leads) through the next 30° of transmitter rotation from that zero position. Fig. 3 shows β plotted against θ for the first 60° of transmitter angle. Negative maximum of 1° 6' occurs at $\theta = 13^\circ 18'$, and an equal positive maximum occurs at $\theta = 46^\circ 42'$. The curve repeats itself for each 60° of transmitter rotation following that shown in Fig. 3.

As may be noted from Equations 1 and 2, the error β in the standard Selsyn system is independent of the resistance values used in the transmitter, or the relation of those values to the resistance values in the receiver. In the paper

which I later refer to, I show among other things that, to obtain maximum torque in the receiver in its positions ($\theta=30^\circ, 90^\circ \dots$ etc.) in which the torque is a minimum, the following relations should be observed:

$$(3) \quad R_1 = 0.52 \frac{E^2}{30P}$$

$$(4) \quad R_2 = 0.86R_1$$

where R_1 is the resistance of the transmitter resistance per degree, R_2 the similar unit resistance of the receiver winding, E the applied E. M. F., and P the maximum power consumed in the system. However, those considerations of maximum torque do not affect the receiver error, nor do they effect the correction provided by my invention.

In my invention, the transmitter resistance is varied from its usual linear form by a factor which is a function of the transmitter angle θ . As a result of that resistance variation receiver angle θ' is made to be equal to transmitter angle θ for all values of the latter. The requisite variation of the transmitter resistance is arrived at as outlined below.

Since the receiver error, in a system having a linear transmitter resistance ($R_1 = \text{constant}$) is symmetric with relation to each 30° position of the transmitter, it is only necessary to ascertain the required deviation of transmitter resistance for transmitter angles from 0° to 30° , then to make the deviations from 30° to 60° symmetrical with those from 30° to 0° , and then to repeat the cycle of deviation for each succeeding 60° of transmitter angle.

Referring to Fig. 1, and assuming that the resistance of a linear transmitter resistance element is R_1 per degree, or $120 R_1$ for each leg between leads C, we let αR_1 represent the ideal unit resistance of a transmitter. That is, α is a function of θ , the transmitter angle, such that θ' , receiver angle, will become equal to θ , transmitter angle.

From consideration of the circuit of Fig. 1, and equivalent electrical circuits derivable therefrom, it can be shown that the receiver angle θ' will be given as follows. Equation 1 above may be written,

$$(1a) \quad \tan \theta' = \sqrt{3} \frac{\theta}{120 - \theta}$$

In that equation, receiver angle θ' will be given with α substituted for θ ; thus,

$$(5) \quad \tan \theta' = \frac{\sqrt{3} \alpha}{120 - \alpha}$$

In order to have zero error, the conditions are that $\theta = \theta'$, and

$$\tan \theta = \frac{\sqrt{3} \alpha}{120 - \alpha}$$

Solving for α under those conditions, we obtain,

$$(6) \quad \alpha = \frac{120 \tan \theta}{\sqrt{3} + \tan \theta}$$

which gives the necessary variation of α with θ for zero error, and hence the variation of transmitter resistance with θ , since the resistance of the transmitter resistor element is, by definition, αR_1 . α is the variable modification factor for R_1 , for zero error, expressing the variation of the resistance with θ , the transmitter angle. Here again it is noted that the modification factor is independent of R_1 and R_2 , and hence is applicable to any transmitter and any receiver or set of paralleled receivers. Fig. 4 shows the variation of α

with θ , along with a linear variation for comparison.

The usual physical form of transmitter resistance element is one in which a toroidal coil is wound helically about a toroidal form which has the shape of a section of a thin walled tube with the ends of the section normal to the axis. Fig. 5 shows at OABC a development of the superficial area of such an element from 0° to 30° , and shows at OAB'C' the corresponding development of a resistance element in which one edge, C'B', is shaped for zero error. In any such resistance element, the resistance at any transmitter angle θ is equal to the area under C'B' between OC' and the vertical corresponding to θ .

Using Equation 6 and the fact that the area under CB represents non-varying resistance with respect to θ , and that the area under C'B' represents the same for a function of θ which satisfies Equation 6, it can be shown that,

$$(7) \quad F(\theta) = \frac{2\pi L}{3} \frac{1}{(\sqrt{3} \cos \theta + \sin \theta)^2}$$

where L is equal to the height or length of an equivalent (equal total resistance) resistor—the dimension OC in Fig. 5. Fig. 5 shows $F(\theta)$ as the curve C'B' plotted against θ from 0° to 30° . The plot for 30° to 60° is symmetric with C'B' about the 30° axis. The developed shape of the whole toroidal resistor then follows with five successive duplications of the shape of the first 60° ; such complete developed shape being indicated in Fig. 6.

Fig. 7 is a fragmentary perspective illustrating the physical form of the resultant resistor. In Fig. 7 the thin tubular body is shown at 20, and the helically wound resistance wire is fragmentarily shown at 21. As here shown all of the resistance variation is applied to one edge of the resistor body; but it will readily be understood that the variations which are represented by Equation 7 above may be as well distributed between the two edges.

The fully detailed derivations of the several formulae given here are contained in a paper by this applicant, published in Trans. A. I. E. E. July 1945, vol. 64. A copy of that paper is filed herewith for reference.

Other physical forms of resistor may be used. For instance, as indicated in Fig. 8, the modifying factor represented by Equation 6 may be applied to a varying thickness of a toroidal body 20a on which the coil wire 21a is wound. And Fig. 9 shows a commutator type resistor with resistance elements R_3 between successive commutator segments 22. In such a resistor the resistance variation will follow Equation 6 step by step.

By considerations and developments which are similar to those previously given, a correction is arrived at which is applicable to a two-winding Selsyn system (one employing two independent receiver coils and four connecting wires which tap the resistor at 90° spacings) and also to four-wire Selsyn system which is similar to the three-wire system here illustrated except that its receiver has four delta connected coils and connections are made to the transmitter resistance at four equally spaced points. For those two systems the following equation corresponds to Equation 6 above.

$$(8a) \quad \alpha = \frac{90 \tan \theta}{1 + \tan \theta}$$

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and the following equation corresponds to Equation 7 above.

$$(7a) \quad F(\theta) = \frac{\pi L}{2} \frac{1}{(\cos \theta - \sin \theta)^2}$$

As between the values of α (the resistance correction factor) as given by Equations 6 and 6a above the following generalization may be made.

$$(6b) \quad \alpha = \frac{a \tan \theta}{n + \tan \theta}$$

where a represents the numeric value in degrees of the angle between successive connections to the resistor, and where n represents a numeric constant.

Similarly the following generalization can be made as between Equations 7 and 7a

$$(7b) \quad F(\theta) = n' \pi L \frac{1}{(n'' \cos \theta + \sin \theta)^2}$$

where n' equals the angle between successive connections to the resistor, in degrees, divided by 180, and where n'' represents a numeric constant.

A form of the new resistor R having four equi-angularly spaced leads is illustrated in Fig. 10. This resistor includes a thin tubular core 30, upon which is helically wound the resistance wire 31. One end edge of the core is formed with projections spaced 90° to produce the desired variations and the connecting wires 32, 33, 34, 35 tap the resistor at the points of the projections F', G', H', and J'.

In Fig. 11, the system shown includes the resistor R of Fig. 10 with the connecting wires 32, 33, 34, 35 leading, respectively, from points F', G', H', and J' on the resistor to the ends F, G, H, and J of independent receiver coils 36, 37, extending at right angles to one another. The receiver is shown as including a magnet M rotating in the field of the coils.

In Fig. 12, the system shown includes the resistor R of Fig. 10 with connecting wires 32, 33, 34, 35 leading, respectively, to the ends F'', G'', H'', and J'' of delta-connected coils 38, 39, 40, and 41 of the receiver, which includes the magnet M.

I claim:

1. A circular resistor for a transmitter of a Selsyn system in which the resistor is tapped by equi-angularly spaced leads and is engaged by relatively rotating contact members, said resistor having a resistance which varies in substantial accordance with the expression

$$\frac{a \tan \theta}{n + \tan \theta}$$

wherein a represents the numeric value in degrees of the angle between successive lead connections to the resistor, wherein n represents a numeric constant, and wherein θ represents the relative angle of rotation from a predetermined zero point.

2. A circular resistor for a transmitter of a Selsyn system in which the resistor is tapped by three equi-angularly spaced leads and is engaged by two diametrically opposed and relatively rotating contact members, said resistor having a resistance which varies in substantial accordance with the expression

$$\frac{120 \tan \theta}{\sqrt{3} + \tan \theta}$$

where θ represents the relative angle of rotation with respect to a predetermined zero point.

3. A circular resistor for a transmitter of a

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Selsyn system in which the resistor is tapped by four equi-angularly spaced leads and is engaged by two diametrically opposed and relatively rotating contact members, said resistor having a resistance which varies in substantial accordance with the expression

$$\frac{90 \tan \theta}{1 + \tan \theta}$$

where θ represents the relative angle of rotation from a predetermined zero point.

4. A toroidally wound resistance coil for a Selsyn system having a transmitter in which the resistance coil is tapped by equi-angularly spaced leads and is engaged by relatively rotating contact members, said resistor having a superficial area which, measured from a predetermined zero point, varies in substantial accordance with the expression

$$n' \pi L \frac{1}{(n'' \cos \theta + \sin \theta)^2}$$

where n' is equal to the angle between successive lead connections to the resistor, in degrees, divided by 180, where n'' represents a numeric constant, where θ represents rotational angle from the predetermined zero point, and L represents a numeric constant.

5. A toroidally wound resistance coil for a Selsyn system having a transmitter in which the resistance coil is tapped by three equi-angularly spaced leads and is engaged by two diametrically opposed and relatively rotating contact members, said resistor having a superficial area which, measured from the predetermined zero point, varies in substantial accordance with the expression

$$\frac{2\pi L}{3} \frac{1}{(\sqrt{3} \cos \theta + \sin \theta)^2}$$

where L represents a numeric constant, and θ represents rotational angle from the predetermined zero point.

6. A toroidally wound resistance coil for a Selsyn system having a transmitter in which the resistance coil is tapped by four equi-angularly spaced leads and is engaged by two diametrically opposed and relatively rotating contact members, said resistor having a superficial area which, measured from the predetermined zero point, varies in substantial accordance with the expression

$$\frac{\pi L}{2} \frac{1}{(\cos \theta + \sin \theta)^2}$$

where L represents a numeric constant and where θ represents rotational angle from the predetermined zero point.

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The following references are of record in the file of this patent:

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Number	Country	Date
550,426	Great Britain	Jan. 7, 1943

Certificate of Correction

Patent No. 2,432,029.

December 2, 1947.

JOSEPH F. MANILDI

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Column 3, line 3, for that portion of the equation reading " $\theta=30^\circ$," read $(\theta'=30^\circ$; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 24th day of February, A. D. 1948.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.