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R. MURDICK

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DIRECT CURRENT FLAT CARD RESOLVER

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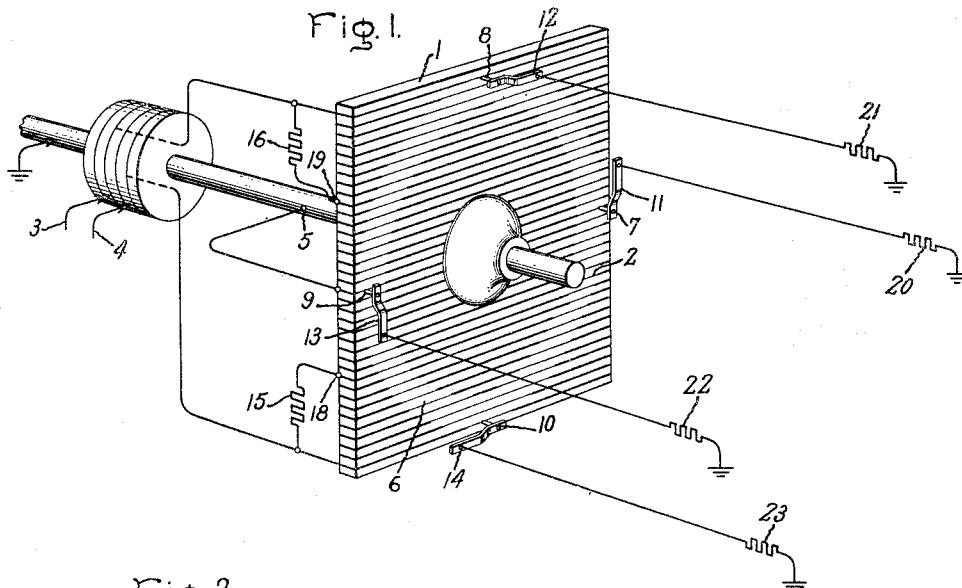


Fig. 2.

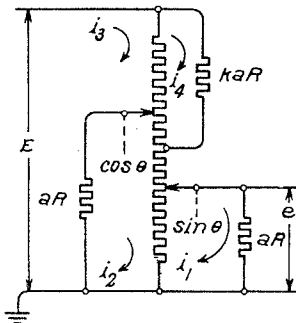


Fig. 3.

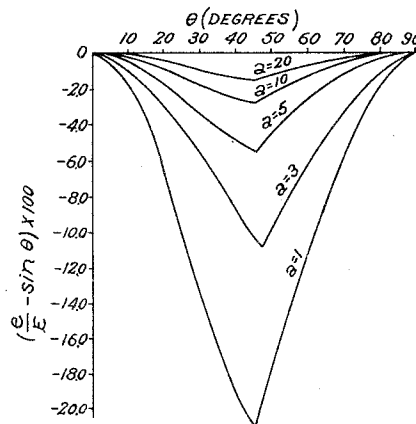
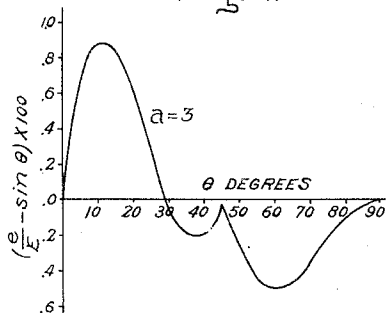


Fig. 4.



Inventor:
Robert Murdick,
by *Frank A. Mott*
His Attorney.

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DIRECT CURRENT FLAT CARD RESOLVER

Robert Murdick, Schenectady, N. Y., assignor to
General Electric Company, a corporation of
New York

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2 Claims. (Cl. 201--48)

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My invention relates to an improvement in the electrical circuit of variable voltage apparatus, and more particularly, to variable voltage apparatus of the flat card resolver type.

Where it is desired that a supply voltage vary as a function of the sine or cosine of an angle of rotation, use is commonly made of an assembly known as a direct current flat card resolver which combines the compactness and accuracy necessary for most purposes. The accuracy of the resolver is a function of the load impedance, and it has been found in particular applications, such as use with low impedance computing devices, that the error of the unmodified resolver is of such magnitude as to make its use impractical.

It is an object of the present invention to provide a compact and inexpensive voltage variation apparatus employing the flat card resolver principle which is more accurate than those heretofore in use.

It is a further object of my invention to provide a circuit network connected between points on the winding of the voltage variation apparatus which enables a compensating current to flow in the winding thereby reducing the error caused by the flow of the load current through the winding.

In carrying out my invention in one form thereof, I provide a flat card circumscribed by a winding to form a flat surface. The insulation is removed from the surface of the winding to facilitate electrical contact with a brush assembly. The center of the winding is grounded and a source of electromotive force is supplied to each half of the winding in such a manner that the potential of the winding varies along its length from a positive potential to an equal negative potential. As each brush rotates about an axis through the geometric center of the card its potential will vary sinusoidally. When a high impedance load is connected between a brush and ground, the load current through the winding is small and the voltage across the load is nearly sinusoidal in variation. But a large current causes an increased voltage drop in the winding, thus causing a marked departure from the sinusoidal variation. The present invention provides a resistance connected to points on the winding and forming a path for a loop current, which in passing through the winding opposes the load current, thereby reducing the voltage drop caused by said load current.

My invention will be better understood from the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims. In

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the drawing, Fig. 1 illustrates a modified flat card resolver and Fig. 2 is a schematic diagram of one-half the complete circuit of the resolver shown in Fig. 1. Fig. 3 is a curve illustrating the percentage error in the voltage supplied by the unmodified resolver, while Fig. 4 illustrates the decreased error obtained by use of the modified resolver.

Referring to Fig. 1, there is shown my improved direct current resolver which comprises a flat card 1 preferably formed of resin bonded, glass cloth laminate, around which is wound a series of turns of high resistance wire 2, the center of the wire being connected to the grounded shaft 5, supported in suitable bearings (not shown). Sources of electromotive force (not shown) are connected between ground and terminal 3 and between terminal 4 and ground, terminal 3 having a positive potential and terminal 4 having a negative potential, both with respect to ground. To permit electrical contact with the winding 2, a circular area 6 of insulation is buffed off leaving the winding exposed for contact with four brushes 7, 8, 9, and 10, which are mounted on spring-like arms 11, 12, 13, and 14, spaced 90° apart. The brushes 7-10 are attached to a disc structure (not shown) which is mounted on the extended shaft 5 by means of suitable bearings. The brush structure is fixed and the card assembly rotates with the shaft 5, causing relative rotational motion between the card assembly and brush structure. However, by proper construction, the card assembly may be fixed and the brush structure rotated with the shaft 5. In accordance with my invention two resistances 15 and 16 are connected from the electromotive force terminals 3 and 4 to points 18 and 19, respectively.

Designating the maximum potential of the brush track as E, where E is the magnitude of the electromotive forces applied at terminals 3 and 4, all voltages in the functions $\pm E \sin \theta$ or $\pm E \cos \theta$ may be produced. As the card assembly rotates through one complete revolution, the potential of each brush will go through a cycle having positive E as its upper limit and negative E as its lower limit. Assuming the card assembly has an initial position as shown in Fig. 1, this cyclic variation of brush 7 is a function of $\sin \theta$ where θ is the angle of clockwise rotation of the card assembly. Since brush 8 is 90° ahead of brush 7, its potential may be expressed as a function of $\cos \theta$. In like manner, brushes 9 and 10 will follow a potential variation expressed by $-\sin \theta$ and $-\cos \theta$, respectively.

When the angle of rotation is zero, as shown in Fig. 1, brush 7 contacts the center of the card winding which is connected to ground. Since load resistance 20 is connected between brush 7 and ground, the voltage across load resistance 20 is zero and no power will be supplied. A similar analysis applies to load resistance 22. However, brush 8, displaced 90° counterclockwise from brush 7, is at the top of the circular brush track and possesses maximum positive potential E with respect to ground. Brush 10, displaced 90° clockwise from brush 7, is at the bottom of the circular brush track and possesses maximum negative potential E with respect to ground. This results in a maximum voltage E across load resistances 21 and 23.

As the angle of rotation increases with clockwise rotation of the card, the potential of brush 7 increases from zero to a positive potential E and brush 9 changes from zero potential to a negative potential E . Brush 8 becomes less positive and brush 10 becomes less negative until at the end of the first quarter cycle both brushes 8 and 10 are at zero potential. During the second quarter cycle, brush 10 follows the potential variation which characterized brush 7 during the first quarter cycle, brush 7 follows in path of brush 8, brush 8 in path of brush 9, and brush 9 in the path of brush 10, each brush going through one cycle of potential variation with each revolution. Since the load resistances are connected between a brush and ground, the potential variation is impressed across the load resistances.

The potential of brush 7 is always proportional to the perpendicular distance from brush 7 to a line through the center of the brush circle and parallel the winding thereon. This vertical distance is proportional to the sine of θ and hence the potential of brush 7 is numerically equal to $E \sin \theta$, where E is the maximum potential of the brush track. The potential of the brushes 8, 9, and 10 are expressed by the functions $E \cos \theta$, $-E \sin \theta$ and $-E \cos \theta$, respectively.

Letting $2R$ be the total resistance of the card winding 2, the resistance from ground to each source of electromotive force is R . The ratio of the resistance load on one brush to the winding resistance R is designated the cascade ratio having the symbol a . Since it is desired that

$$\frac{e}{E} = \sin \theta$$

where e is the voltage supplied to the load, the error may be represented by

$$\frac{e}{E} - \sin \theta$$

The percentage error of the unmodified resolver is plotted in Fig. 3. The resistance R of the winding is constant; therefore, the cascade ratio will vary directly as the load resistance. For cascade ratios from 10 to 20, the maximum error is below 3%, but for cascade ratios below 10, the maximum error increases until for cascade ratio of 1, the maximum error reaches 20%. Since load resistance and cascade ratio are directly proportional, the error will increase with a decrease in the load resistance. The high error for low load resistances may be explained by the increased current supplied to the low resistances load. The increase in current causes an increased I. R. drop in the winding and decreases the voltage applied to the load resistance.

Fig. 2 shows the schematic form of the network on which the equations required to determine the output voltage were based. In the unmodified circuit which does not include the resistance kaR , the following equations are obtained.

$$(aR + R \sin \theta) i_1 - R \sin \theta i_2 = 0 \quad (1)$$

$$-R \sin \theta i_1 + (aR + R \cos \theta) i_2 - aR i_3 = 0 \quad (2)$$

$$-aR i_2 + [R(1 - \cos \theta) + aR] i_3 = E \quad (3)$$

From this set of equations, I_1 may be determined, and since $e = i_1 aR$, e may be determined for a given value of θ . The curves of Fig. 3 are obtained by calculating

$$\frac{e}{E} - \sin \theta$$

and plotting this difference as a function of the angle of rotation θ .

In accordance with the present invention, the resistance designated as kaR is inserted in the circuit as shown in Fig. 2 and reduces the error of the unmodified circuit. Adding this resistance kaR to the schematic diagram of Fig. 2 is necessitated by the addition of resistances 15, 16 to the resolver shown in Fig. 1. An additional loop circuit is thus added to the schematic diagram of Fig. 2 and the loop equations are changed as follows:

$$-[k_1 R - R(1 - \cos \theta)] i_2 - R(1 - \cos \theta) i_3 + (kaR + k_1 R) i_4 = 0 \quad (4)$$

$$-R \sin \theta i_1 + (aR + R \cos \theta) i_2 - aR i_3 + (k_1 - 1 + \cos \theta) R i_4 = 0 \quad (5)$$

$$-aR i_2 + [R(1 - \cos \theta) + aR] i_3 - R(1 - \cos \theta) i_4 = 0 \quad (6)$$

where k_1 is dependent on position of points 18 and 19. These Equations 4, 5, 6 may be solved with Equation 1 and a value of i_1 obtained. Similar equations are obtained for different ranges of θ and since $e = i_1 aR$, the error of the modified circuit may be computed. For a cascade ratio of three, this error is plotted in Fig. 4.

A comparison of the errors in Fig. 3 to those shown in Fig. 4 for a cascade ratio of three indicates the gain in accuracy through use of the modified flat card resolver. Fig. 4 shows that the positive error is numerically greater than the negative error. By varying k , the positive and negative values of the error may be made equal. In choosing the point of connection of the compensating resistors 15, 16, a point was chosen on horizontal lines passing through the brushes when the angle of rotation was 45°, thus making $k_1 = 0.707$. This point was chosen because, as shown in Fig. 3, the maximum error of the unmodified resolver occurred at this point. However, it is apparent that other values of k_1 may be used to obtain a desired compensation.

From the foregoing, it is seen that the invention reduces the error in the output voltage of a variable voltage apparatus, the reduction being most advantageous when the cascade ratio is below 10. With this arrangement, the error in the output voltage may be reduced to a value approximately $\frac{1}{10}$ of that obtained by use of an unmodified resolver.

While the present invention has been described by reference to particular embodiments thereof, it will be understood that numerous modifications may be made by those skilled in the art without actually departing from the invention. I, therefore, aim in the appended claims to cover all such equivalent variations as come within the

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true spirit and scope of the foregoing disclosure.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In combination, a voltage variation apparatus comprising a winding circumscribed about a card, the ends of said winding being connected to a source of electromotive force, said winding being connected to ground at a point intermediate said ends, a resistance element connected from one end of said winding to a point intermediate said one end and ground, a resistance element connected from the other end of said winding to a point intermediate said other end and ground, a contacting assembly comprising a plurality of spring-like arms having brushes affixed thereto, a shaft affixed to said card and contacting assembly to allow relative rotational motion between said assembly and said card structure.

2. In combination, a voltage variation apparatus comprising a winding circumscribed about a card, said winding having a bare circular surface portion and the ends of said winding being connected to a source of electromotive force, the center of said winding being connected to ground, a resistance element connected from one end

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of said winding to a point intermediate said one end and ground, a resistance element connected from the other end of said winding to a point intermediate said other end and ground, a rotating assembly comprising a plurality of spring-like arms having brushes affixed thereto, said brushes being in contact with said bare circular surface of said winding, a shaft affixed to said card and contacting assembly to allow relative rotational motion between said assembly and said card structure.

ROBERT MURDICK.

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