June 6, 1961 J. L. JONKE 2,986,805

METHOD OF MAKING WIRE-WOUND RESISTANCE ELEMENTS

Filed April 24, 1957 2 Sheets-Sheet 1

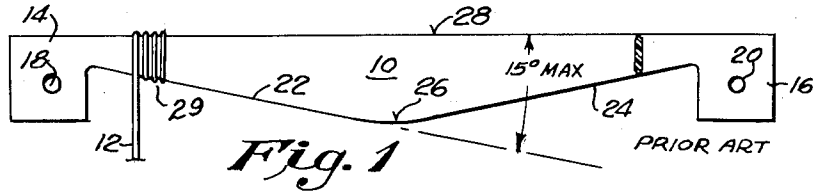


Fig. 1

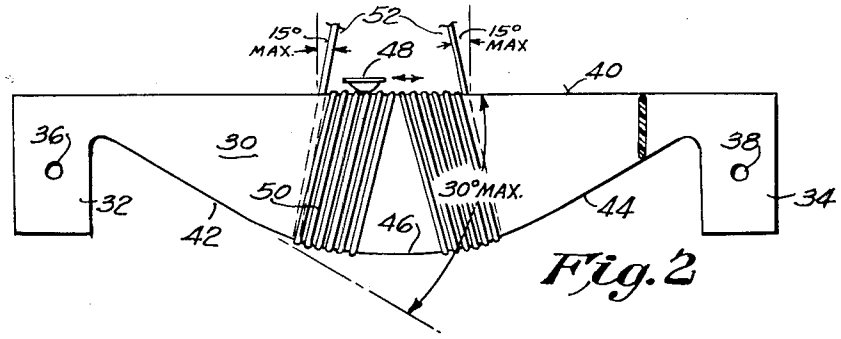


Fig. 2

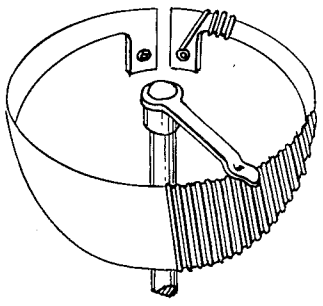


Fig. 3

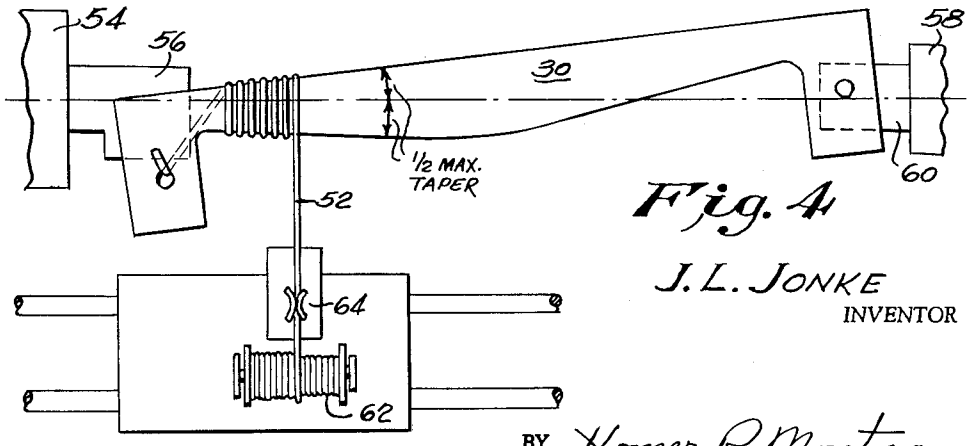


Fig. 4

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June 6, 1961 J. L. JONKE 2,986,805

METHOD OF MAKING WIRE-WOUND RESISTANCE ELEMENTS

Filed April 24, 1957 2 Sheets-Sheet 2

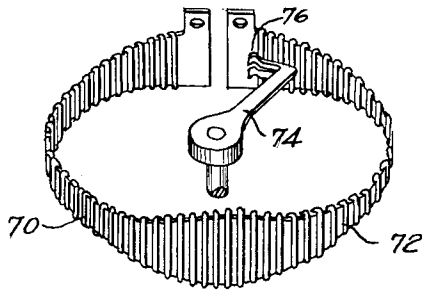


Fig. 5

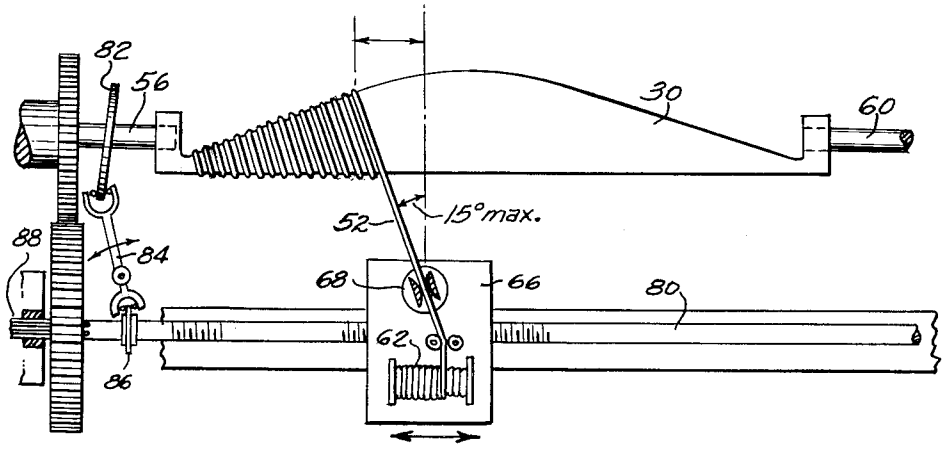


Fig. 6

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METHOD OF MAKING WIRE-WOUND RESISTANCE ELEMENTS

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2 Claims. (Cl. 29—155.62)

This invention relates generally to potentiometers and variable resistors, and more particularly to wire-wound resistance elements for use in potentiometers and variable resistors, as well as to the method and apparatus for fabricating and winding such resistance elements.

In making resistance elements of the type utilized in potentiometers or variable resistors, a length of resistance wire is wound in a particular manner on an insulating strip, commonly known as a winding card, which is generally rectangular in cross-section. Where non-linear function resistance elements are required, such as those having a sine-cosine winding, the variation in slope (the change in resistance or voltage per degree of rotation, or per inch of travel of the wiper arm), must be accompanied either by a variable spacing of the turns upon the winding card, or changes in the size or gauge of the resistance wire, or variation in the length of the turns of the resistance wire upon the winding card, or a combination of any of the foregoing variables.

For optimum accuracy and life of the resistance element, the required variation in slope is best obtained by variation of length of turn of the resistance wire upon the winding card. Varying the length of the turns of the resistance wire upon the winding card without varying any of the other parameters will eliminate inaccuracies due to a variety of factors including (1) turns shorting where very tight spacing of the resistance wire on the winding card is required to meet the function slope desired, (2) improper spacing of the turns upon the winding card caused by starting and stopping the wire winding machine in order that changes may be made in wire size or wire alloy, (3) poor angular resolution where wide spacing of turns upon the winding card is required, (4) improper resistance matching of sections where changes in wire size or wire alloy are required, and (5) variations in wire gauge and wire hardness on one winding.

To obtain the desired slope by varying the length of the turns of the resistance wire upon the winding card requires tapering the winding card such that the variation in card perimeter follows the first derivative of the function to be wound. For most functions, however, such tapers are not possible by prior art methods since their steepness would not allow the wire to be wound without turns piling up and shorting. It was usually necessary to combine all means of variation, obtaining greater accuracy when the variations in turn spacing, and the changes in wire size and alloy, were kept to a minimum. Such being the case, the design criterion in winding is to obtain the greatest variation in winding card height possible, thereby keeping variation in spacing of turns and changes of wire size to a minimum.

Experience has shown that the angle which the turns of resistance wire make with either edge of a winding card cannot vary from a perpendicular relationship by more than approximately 15 degrees without slipping of the turns. Because of this fact, the prior art methods of winding the wire perpendicular to the reference edge of the winding card limit the maximum allowable taper of the winding card to an angle of 15 degrees.

By means of this new method it is now possible to increase the maximum angle of taper from 15 degrees to approximately 30 degrees, an amount double that known

in the prior art. As stated previously, this permits a closer approximation to ideal conditions in the winding of non-linear resistance elements. An example of the increased accuracy obtainable by the use of this invention may be seen in comparison of results obtained in 3 inch sine-cosine potentiometers where the functional conformity tolerance was reduced by approximately 50%.

It is an object of this invention to provide a method of winding resistance elements of non-linear characteristics in which most or all of the non-linear characteristic or variation in slope is obtained by variation in the length of the turns of resistance wire wound upon a winding card.

It is another object of this invention to provide an improved resistance element for use in potentiometers or the like, in which the resistance element is capable of longer life and greater accuracy than those already known in the prior art.

It is another object of this invention to provide a resistance element for use in potentiometers or the like in which the resistance wire is wound around a winding card which may have a taper of as much as 30 degrees so that the desired winding characteristic can be obtained mainly by variation in length of the turns upon the winding card.

It is another object of this invention to provide a method of winding resistance wire upon a winding card which can be tapered to an angle of as much as 30 degrees, by placing the turns upon the winding card at an angle less than 90 degrees with both the reference and tapered edge.

It is another object of this invention to provide a method of winding resistance wire upon a winding card in such a manner that the maximum taper of the winding card can be greater than that obtainable by prior art methods.

It is still another object of this invention to provide a method of winding resistance wire upon a winding card having a taper greater than that necessary to maintain the turns upon the card, by feeding the wire being wound upon the card at an angle other than 90 degrees to the card.

It is another object of this invention to provide a method of winding resistance wire upon a winding card to form a resistance element having a non-linear characteristic, by wrapping turns of wire around the winding card at an acute angle to both the reference and tapered edges of the card.

The foregoing as well as other objects and advantages will become apparent when the following specification is read in conjunction with the attached drawings in which:

FIGURE 1 is a side view of a resistance element wound and fabricated by prior art methods.

FIGURE 2 is a similar view in elevation of a resistance element made in accordance with this invention.

FIGURE 3 is a perspective diagrammatic view of a potentiometer utilizing a resistance element made in accordance with this invention.

FIGURE 4 is a view showing the arrangement of one form of apparatus for winding resistance elements in accordance with this invention.

FIG. 5 is a schematic perspective view of a modified form of resistor employing the principles of the invention.

FIG. 6 is a diagrammatic showing of an alternate way of practicing the method of the invention.

In general, the new method encompassed by this invention contemplates winding resistance wire in a particular manner on a winding card which is rectangular in cross-section and varying in height with reference to one edge. The manner of winding the turns is such that cards with greater variation in height may now be wound

without the turns slipping due to the angle that the turns make with the sloping edge. Broadly speaking, the new method of winding contemplates placing the turns on the winding card at an angle other than 90 degrees with respect to both the reference and the tapered edges. This angle, however, is not permitted to exceed a critical value, approximately 15 degrees from the 90 degree angle as practiced by the prior art methods; the actual magnitude of this critical value is to some extent dependent upon the materials used in any specific embodiment. The actual angle at which the turns are placed with respect to the perpendicular from either card edge is determined in a manner to be explained below.

FIGURE 1 illustrates a resistance element made in accordance with the practices of the prior art. The reference numeral **10** indicates a winding card for the placement thereon of a predetermined number of turns of a resistance wire **12**. The winding card **10** is usually made of a thin flexible insulating material such as fiber, and is rectangular in cross-section. The winding card **10** is provided with squared-off end sections **14** and **16**. The end sections **14** and **16** are provided with mounting openings **18** and **20** respectively. In the example illustrated, the resistance element is one having a non-linear resistance characteristic, as for example a sine-cosine function. In order to obtain such a characteristic it has been found that the least inaccuracy will result if the variation in linearity is accomplished by a variation in the length of the turns contacted by the wiper arm contact instead of resorting to such means as varying the resistance wire thickness or varying the turn spacing, or varying the wire alloy. The winding card **10** is formed with tapers on one edge indicated by the reference numerals **22** and **24**, which meet in a rounded-off portion **26**. It has been determined empirically that the tapered edges **22** and **24** cannot exceed an angle of approximately 15 degrees with the straight edge **28** of the card **10**, or else the turns **29** of the resistance wire **12** will slip and not maintain their predetermined regular or irregular spacing. This fact has seriously limited the extent to which the prior art resistance elements may be wound with the entire non-linear function being taken care of by varying the length of the turns. Because of this, other expedients are resorted to, such as varying the turn spacing, the resistance wire thickness, the resistance wire alloy, and others. By means of the method to be described, it is now possible to wind equally spaced turns of uniform thickness resistance wire upon a card having tapered edges of as much as 30 degrees as illustrated in FIGURE 2.

The new resistance element made in accordance with this invention and shown in FIGURE 2 comprises a winding card **30** of rectangular cross-section made of fiber or similar flexible insulating material. The card **30** is provided with squared-off ends **32** and **34**, which have mounting holes **36** and **38** respectively. The card **30** is fabricated with one straight edge **40** and two tapered edges **42** and **44** meeting in the center of the card in a rounded-off or flattened portion **46**. A wiper contact arm **48** is mounted for sliding or wiping action on the straight edge side **40** of the card to make contact with the turns **50** of the resistance wire **52** wound in equal spacing upon the card **30**. The card edges **42** and **44** may be tapered at an angle of as much as approximately 30 degrees with the straight edge **40**, instead of the usual 15 degrees maximum as in the prior art elements illustrated in FIGURE 1.

Even though the edges **42** and **44** can be tapered at an angle twice that permissible by the prior art practices, the turns **50** remain as originally spaced and do not slip from their original place on the card **30**. This is due to the novel manner in which the turns **50** are placed upon the card **30**. In order to place winding upon a card having edges tapered at an angle as large as twice that known by the prior art, it is necessary to feed the resistance wire **52** at an acute angle to the transverse axis of the card. It has been determined that although this angle is not of itself critical it must not exceed a limit of approximately 15 degrees. The actual angle at which the wire **52** is wound upon the card **30** with respect to the transverse axis is determined by measuring the maximum angle of taper in the section (either **42** or **44**) and dividing it in half. For example, if the taper of the particular section being wound is 25 degrees, then the angle at which the wire **52** is fed and wound upon the card **30** is 12½ degrees.

The angular feed and winding of the wire **52** upon the card **30** as just described may be accomplished in a number of different ways, but a preferred method of doing this is illustrated in FIGURE 4 and will now be described. The apparatus for performing this method may be a conventional resistance element winding machine with certain modifications. The reference numeral **54** indicates the headstock of a winding machine provided with an arbor **56** to receive one end of a winding card **30**. The winding machine is also provided with a tail stock **58** and arbor **60** for receiving the other end of the card **30**. As shown in FIGURE 4, one end of the card **30** is offset so that the longitudinal axis of the card **30** forms an angle with the centerline between the two arbors **56** and **60** equal to one-half of the maximum taper angle of the card section being wound. The wire **52** is unwound from a supply reel **62** through a wire tensioning device **64** upon the tapered legs of the rotating card **30**. The supply reel **62** and the tensioning device **64** are both mounted on a movable carriage which is moved along a path parallel to the centerline between the two arbors **56** and **60** so that the wire **52** is payed out in a direction perpendicular to that centerline. The carriage and lateral feed mechanism for the supply reel **62** and tensioning means are conventional and are not detailed herein.

FIG. 6 shows an alternate arrangement for producing windings of this type. Here, the card **30** is mounted with its long axis parallel to the axis of rotation, and the carriage **66** is maintained by lead screw **80** or other driving means in advance of the winding point of the card, so that wire leaving guide **68** reaches the card **30** at an angle as indicated. With this arrangement, for reasonably close-wound turns, it is necessary to oscillate carriage **66** or the wire guide along the path direction for each turn of the card. This can be done, for example, by a swash plate **82** on the arbor shaft oscillating a lever **84** whose forked end engages a circular flange **86** fast on the lead screw. A splined connection **83** to the driving gear permits the carriage to be moved back and forth the desired amount for each revolution of the card, while the over-all motion is one of progressive advance in the winding direction.

Although the form upon which the resistance wire is wound has been illustrated and described as a flat card which is later to be bent in the form of a circle as illustrated in FIGURE 3, other forms such as toroids may be wound by this novel method. The types of windings placed upon the cards are not limited to the sine-cosine function, but may be for all applicable functions. Winding cards may consist of a single taper or multiple sections, and individual sections of a card may be of constant angle or variable angle or taper. In like manner a taper section in itself may be of constant angle or variable, and of course the turn spacing may be constant, regular or irregular. The resistance elements made in accordance with this invention may be used for both the rotary type potentiometer as illustrated in FIGURE 3 and for rectilinear potentiometers or variable resistors.

FIG. 5 of the drawings illustrates a possible form which the invention may take, characterized by the provision of tapered or inclined edges at both top and bottom of the resistor card. It will be obvious that the maximum angle of inclination of the winding turns **72** to each edge of card **70** will be that dictated by the angle of slip as de-

scribed above, but that the total rate of change of resistance, per turn of winding, can be of twice the usual value, because the angle defined between corresponding upper and lower edge points can be twice the angle between the winding turn and each edge taken individually. Since neither the top or bottom edge of such a wound card lies in a single plane, it will be preferred to use a contact or wiper arm **74** whose contact end runs about the equator of the winding; single or multiple sled-type contacts such as at **76** are suitable for this application.

It will be recognized by those familiar with the principles of mechanics that the limiting angle between a card edge and the portion of a winding turn passing about said edge is a function of the coefficient of friction between the material of the winding and the material forming the card. This coefficient, in any but an ideal or theoretical case, may also be at least a second-order function of the applied pressure, which is in turn dependent upon the tightness with which the wire is wound. Analogously to the mechanical analysis of problems involving friction, it will also be recognized that the limiting angle which will provide a stable winding is comparable to the angle of slip or angle of repose, which is the angle whose tangent is equal to the coefficient of friction. For practical cases, this angle is a constant for the materials selected, and the invention effectively provides a special form of winding which permits the card taper angle to be as large as twice the limiting angle without the winding itself at any point exceeding the critical limit as to either edge of the card.

The invention has been described in considerable detail in the interest of ready and clear understanding, but it will be apparent to those skilled in the art that various changes in the structure and method may be accomplished without departing from the principles of the invention or the scope of the appended claims.

What is claimed is:

1. The method of making a resistance element by winding a series of turns of resistance wire upon a card having one straight edge parallel to the longitudinal axis of the card and at least one edge portion tapered with respect to the longitudinal axis of the card, and opposite said straight edge, comprising the steps of supporting said card in such manner that its longitudinal axis is offset an amount sufficient to form an angle with a rotational axis equal to one-half the angle of said tapered edge, rotating said card in its offset position about said rotational axis, and winding turns of resistance wire around said card during rotation of the card, said wire being wound on said card in a direction normal to said rotational axis.

2. The method of making a resistance element by winding a series of spaced turns of resistance wire upon a card which has one straight edge parallel to the longitudinal axis of the card and at least one edge opposite said straight edge tapered with respect to the longitudinal axis of the card, and, comprising supporting said card in an offset manner so that its longitudinal axis forms an angle with a rotational axis an amount sufficient to form an angle equal to one-half the maximum angle of said tapered edge, rotating said card about said rotational axis, and winding turns of resistance wire about said card, said wire being wound on said card in a direction normal to said rotational axis.

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