

SPECIFICATION

Electric motor coil element and method of manufacturing the same

- 5 This invention relates to an electric motor coil element and a method of manufacturing the same. 5
- Various electric motors are in use such as the moving-coil, coreless, slotless and brushless types. The rotor or stator of these motors is generally constructed by winding an electrically conductive wire around the peripheral surface of a cylindrical body. Among the motors comprising such rotor or stator is a disk type whose rotor or stator is formed of a flat or disk shaped coil.
- 10 A known method of manufacturing particularly a cylindrical motor coil includes the so-called skew winding method (also referred to as "a honeycomb method") described in U.S. Patent No. 3,191,081 and the bell method. Those methods consist in winding a wire around a columnar bobbin to provide a coil of a prescribed shape. Therefore, the conventional methods have the drawbacks that difficulties arise in mechanically winding a wire at high speed resulting in a decline in the coil manufacturing efficiency. Further 10
- 15 disadvantages of the conventional coil manufacturing methods are that a bobbin wound with a wire unavoidably has a great thickness in order to withstand a mechanical force applied by the wound wire, and consequently becomes heavy; some turns of a coil are superposed on each other, thus increasing the thickness of the coil and a bobbin; and some portions of the coil become electromagnetically inactive, failing to elevate the efficiency of a motor comprising such defective coil. These undesirable events take place not 15
- 20 only in a cylindrical motor coil, but also in any other type of motor coil. It is accordingly, an object of this invention to provide coil elements which can be assembled into a motor coil capable of elevating the performance of an electric motor. 20
- Another object of the invention is to provide a method of manufacturing a motor coil efficiently and at low cost by assembling coil elements.
- 25 To this end, the present invention provides a method of manufacturing an electric motor coil element, comprising; winding a wire coaxially and helically to form an original winding having first and second opposite faces; setting a number $2n$ (where n is an integer) of division points equally spaced around the winding to divide the winding into an even number of segments; defining bending lines which pass through the division points respectively and at prescribed angles relative to respective predetermined reference lines 25
- 30 extending through the division points, and bending the original winding along the bending lines and such that the winding adopts generally annular configuration wherein the segments present portions of said first and said second faces alternately in a sequence and on a common surface region of the finished coil element. 30
- In the embodiments of the invention described hereinafter, the original winding has three types. A first type is constructed by winding a wire helically and concentrically around a columnar surface in a cylindrical 35
- form. A second type is constructed by helically and concentrically winding a wire on the same plane in the ring form. A third type is formed by winding a wire helically and concentrically in the truncated conical form. 35
- Coil elements provided by this invention include three types. A first type is constructed by arranging the respective segments of an original winding along a columnar plane in a cylindrical form. A second type is 40
- constructed by arranging the respective segments of an original winding on the same plane in the form of a star, thereby providing a flat star-shaped coil element. A third type is formed by arranging the respective segments of an original winding along a truncated conical plane, thereby providing a truncated conical coil 40
- element. These three types of coil elements can be fabricated from any of the aforesaid three types of original windings.
- 45 This invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which: 45
- Figures 1 to 3* indicate three types of original windings from which an electric motor coil element is fabricated. Figure 1 is an oblique view of a cylindrical winding. Figure 2 is a plan view of a flat ring-shaped original winding. Figure 3 is an oblique view of a truncated conical original winding;
- 50 *Figures 4 to 9* illustrate various types of electric motor coil elements. Figure 4 is an oblique view of a coil element fabricated from the original winding of Figure 1. Figure 5 is an oblique view of a coil element fabricated from the original winding of Figure 2 or 3. The coil elements of Figures 4 and 5 have such a shape capable of being fitted around an imaginary columnar plane. Figure 6 is a schematic plan view of a coil element formed of the original winding of Figure 1. Figure 7 is a schematic plan view of a coil element prepared from the original winding of Figure 3. The coil elements of Figures 6 and 7 have such a shape as is 55
- capable of being set in a region defined between the imaginary concentric circles. Figure 8 is a schematic oblique view of a coil element fabricated from the original winding of Figure 1. Figure 9 is a schematic oblique view of a coil element obtained from the original winding of Figure 2 or 3. The coil elements of Figures 8 and 9 have such a shape as is capable of being fitted around a truncated conical plane;
- 60 *Figure 10* is a deployment view of the coil element of Figure 4; 60
- Figure 11* is a deployment view of the coil element of Figure 5;
- Figure 12* is a deployment view of the coil element of Figure 8;
- Figure 13* is a deployment view of the original winding of Figure 3; and
- Figures 14 to 17* illustrate the steps of forming the coil element of Figure 5 by a method modified from that 65
- described above. Figures 14 and 16 are plan views of flat ring-shaped original windings. Figures 15 and 17 65



are deployment views of coil elements fabricated from the original windings of Figures 14 and 16.

As previously, described, there are three types of original windings from which an electric motor coil element embodying this invention can be fabricated. As seen from Figure 1, a first original winding 2 is constructed by closely winding a conductive wire around the periphery of an imaginary columnar block of a cylindrical form. A second original winding 6 is formed by winding a conductive wire concentrically on the same plane in the form of a flat ring (Figure 2). A third original winding 12 is fabricated by winding a conductive wire closely the periphery of an imaginary truncated conical block form 14 (Figure 3). An electrically conductive wire from which the above-mentioned original windings 2, 6, 12 are produced is coated with a flux and electrically insulating layer. Bobbins (not shown) used in the fabrication of the original windings have shapes matching those onto which said original windings are formed. Thus, the bobbin of the first original winding 2 has a columnar shape. The bobbin of the second original winding 6 has a flat shape.

The bobbin of the third winding has a truncated conical shape. A wire is wound about any of these bobbins in the prescribed form, and then the flux coated on the surface of the wound wire is melted by application of an organic solvent or heat. The melted flux is solidified, and then an integral body consisting of the wound wire is formed and is taken from the bobbin to provide a winding securely formed into a prescribed shape. At this time, the original windings 2, 6, 12 are all in the form of an endless band. The original winding which is constructed by winding a single wire about a bobbin has a wind-starting end and a wind-terminating end.

Coil elements 16, 18, 20 shaped as shown in Figure 4 (or 5), Figure 6 (or 7) and Figure 8 (or 9) can be respectively fabricated from the aforesaid three types 2, 6, 12 of original windings.

Description is now given of the method of manufacturing a first coil element 16 shown in Figure 4 or 5 by bending an original winding and letting the bent segments thereof extend along the periphery of an imaginary columnar block form 22.

First, a plurality of, that is, a number of $2n$ (n is an integer of 1, 2 or 3) of equal division points 24, 26 are set on the periphery of any of the original windings 2, 6, 12 (the reference numerals 24, 26 denote every two adjacent equal division points). With the first original winding 2 having a cylindrical shape, the equal division points 24, 26 are set, as shown in Figure 1, on the lower periphery of the cylindrical original winding 2. With respect to the second ring-shaped original winding 6, the equal division points 24, 26 are set, as shown in Figure 2, on the periphery of the outer diameter of the ring shape. With respect to the third original winding 12 having a truncated conical shape, the equal division points 24 and 26 are provided, as indicated in Figure 3, on the periphery of the base of the truncated cone.

Thereafter, imaginary reference lines 28, 30 are prescribed which pass through the above-mentioned equal division points 24, 26. With respect to the first cylindrical original winding 2, the imaginary reference lines 28, 30 are disposed in parallel with the axis of the cylinder. With respect to the second ring-shaped original winding 6, the imaginary reference lines 28, 30 are chosen to pass through the center 34 of said ring-shaped original winding 6. With respect to the third original winding 12 having a truncated conical shape, the imaginary reference lines 28, 30 are chosen to convergently pass through the imaginary apical point 36 of said truncated conical block form.

Further, bending lines 38, 40 are provided which pass through the equal division points 24, 26 at prescribed angles ϕ_1 , ϕ_2 to the respective imaginary reference lines 28, 30. As illustrated in Figures 1 to 3, every alternate bending line 38 define the same angle ϕ_1 with the corresponding imaginary reference line 28. Every alternate bending line 40 defines the same angle ϕ_2 with the corresponding imaginary reference line 30. Where the first coil element 16 shown in Figure 4 is fabricated, then the bending angles ϕ_1 , ϕ_2 are defined to have to following relationship:

$$\phi_1 = \phi_2 = \phi$$

Therefore, the bending lines 38, 40 divide the original windings 2, 6, 12 shown in Figures 1 to 3 into a $2n$ number of substantially equal band shaped segments 42, 44.

In practice, preliminary bending is applied to the original winding along the bending lines 38, 40 by means of a jig. With respect to the first original winding 2 of Figure 1 and the third original winding 12 of Figure 3, pressure is applied to said original windings 2, 12 in such a manner that the bending line 38 projects outward, and the bending line 40 adjacent to said bending line 38 projects inward. The outward and inward projections are alternately repeated. With respect to the second disk-shaped original winding 6, pressure is applied to said original winding 6 in such a manner that the bending line 38 projects upward and the bending line 40 adjacent to said bending line 38 projects downward. The upward and downward projections are alternately repeated. The original windings 2, 6, 12 which have been subjected to the above-mentioned preliminary bending are each fitted with a columnar jig having a diameter of substantially D and are again pressed to be bent. As a result, a coil element 16 is provided which, as shown in Figure 4 or 5, has a diameter D and a height L , and whose band shaped segments 42, 44 extend along the periphery of an imaginary columnar block form 22.

As is apparent from the above-mentioned manufacturing steps, that plane of the band-shaped segment 42 which is exposed on the surface of the coil element 16 shown in Figure 4 or 5 corresponds to the outer surface of the original windings 2, 12. That plane of the band-shaped segment 44 which is exposed on the surface of the coil element 16 corresponds to the inner surface of the original windings 2, 12. In other words, the outer and inner surfaces of the original windings 2, 12 alternately appear on the outer surface of the coil

element 16 as shown in Figure 4 or 5 as a result of bending. With respect to the coil element 16 of Figure 5 which is fabricated from the original winding 6 shown in Figure 2, the upper and lower surfaces of the original winding 6 are alternately exposed on the outer surface of said coil element 16. On the upper and lower portions of the coil element 16, the band-shaped segments 42, 44 are superposed on each other by bending. The equal division points 24 are indicated on the lower periphery of the imaginary columnar block form 22 substantially at an equal distance. The equal division points 26 are substantially equidistantly set on the upper periphery of said imaginary columnar block form 22. With the coil element 16 shown in Figure 4, the segments 42, 44 assume a straight band shape. Said segments 42, 44 are fabricated from the first original winding 2 of Figure 1. For reference, a coil element 16 fabricated from the original winding 2 of Figure 1 is shown in Figure 10. As seen from Figure 5, coil elements 16 fabricated from the original windings 6, 12 of Figures 2 and 3 have arcuate segments 42, 44, as shown in Figure 11.

For fabrication of the coil element 16 of Figure 4, the original windings 2, 6, 12 need to meet the undermentioned requirements. Description is given of each type of original winding. In this case, the bending angles ϕ_1 , ϕ_2 shown in the drawing are all equal, that is, to have the following relationship

$$\phi = \phi_1 = \phi_2 \quad \dots (1)$$

Where the coil element 16 of Figure 4 having a diameter D and a height L is fabricated from the first cylindrical original winding 2 of Figure 1, then said first cylindrical original winding 2 should have a diameter d defined by the following equation (2) or (3), and an optionally selectable width B and be bent at an angle ϕ determined by the following equation (4).

$$d = \frac{D}{\sin \phi} \quad \dots (2)$$

$$d = \frac{2nL}{\pi \cos \phi} \quad \dots (3)$$

$$\phi = \tan^{-1} (\pi/2n \cdot D/L) \quad \dots (4)$$

Where the first coil element 16 shown in Figure 5 is formed of the second flat ring-shaped original winding 6 shown in Figure 2, then said second original winding 6 should have an outer diameter R_1 defined by the following equation (5) or (6), and optionally selectable inner diameter R_2 and width B, and be bent at an angle ϕ defined by the aforesaid equation (4).

$$R_1 = \frac{\pi D}{2n \sin (\pi/2n) \cdot \sin \phi} \quad \dots (5)$$

$$R_1 = \frac{L}{\sin (\pi/2n) \cdot \cos \phi} \quad \dots (6)$$

The inner diameter R_2 of the flat ring-shaped original winding 6 is expressed as

$$R_2 = R_1 - 2B \quad \dots (7)$$

Where the first coil element 16 shown in Figure 5 is prepared from the third truncated conical original winding 12 of Figure 3, then said third truncated conical original winding 12 should have a larger diameter d_1 defined by the following equation (8) or (9), and optionally selectable apical angle δ , smaller diameter d_2 and width B and be bent at an angle defined by the aforesaid equation (4).

$$d_1 = \frac{\pi D \sin (\delta/2)}{2n \sin (\pi/2n) \sin (\delta/2) \sin \phi} \quad \dots (8)$$

$$d_1 = \frac{L \sin (\delta/2)}{\sin \{(\pi/2n) \sin (\delta/2)\} \cos \phi} \quad \dots (9)$$

The smaller diameter d_2 of the truncated conical original winding 12 is expressed as

$$d_2 = d_1 - 2B \sin (\delta/2) \quad \dots (10)$$

Description is now given of the method of fabricating the second star-shaped coil element 18 shown in Figure 6 or 7. First, an even number or a number of $2n$ (n denotes an integer of 1, 2 or 3 ...) of equal division points 24, 26 are set on the periphery of any of the original windings 2, 6, 12. With the first cylindrical original

winding 2, the equal division points 24, 26 are indicated on the periphery of the lower end portion of said cylindrical original winding 2. With the second flat ring-shaped original winding 6, the equal division points 24, 26 are defined on the periphery of the outer diameter of said ring-shaped original winding 6 as shown in Figure 2. With the third truncated conical original winding 12, the equal division points 24, 26 are set on the periphery of the base of said truncated conical original winding 12 as shown in Figure 3.

Thereafter, imaginary reference lines 28, 30 passing through the equal division points 24, 26 are specified. With the first cylindrical original winding 2, the imaginary reference lines 28, 30 are positioned in parallel with the axis 32 of said cylindrical original winding 2. With the second flat ring-shaped original winding 6, the imaginary reference lines are chosen to pass through the center 34 of said ring-shaped original winding 6.

With the third truncated conical original winding 12, the imaginary reference lines are chosen to convergently pass through the apical point 36 of an imaginary conical block form.

Thereafter, bending lines 38, 40 are prescribed which pass through the equal division points 24, 26 at angles ϕ_1, ϕ_2 , to the respective imaginary reference lines 28, 30. As seen from Figures 1 to 3, the adjacent bending lines 38, 40 are inclined in the circumferential direction at angles ϕ_1, ϕ_2 respectively. Thus, the bending lines 38, 40 divide the original windings 2, 6, 12 shown in Figures 1 to 3 into a 2n number of equal band-shaped segments 42, 44.

Preliminary bending is applied to the original windings 2, 6, 12 along the bending line 38, 40 means of a jig. With the first and third original windings 2, 12 shown in Figures 1 and 3, pressure is applied in such a manner that the bending line 38 projects outward and the bending line 40 adjacent to said bending line 38 projects inward, that is, the outward and inward projections are alternately repeated. With the second flat ring-shaped original winding 6, pressure is applied in such a manner that the bending line 38 projects upward and the bending line 40 adjacent to said bending line 38 project downward, that is, the upward and downward projections are alternately repeated. The original winding 2, 6, 12 which have been subjected to preliminary bending are fitted with a flat jig and are again pressed to be bent. As a result, a coil element 18 is provided which has an inner diameter of K2 and an outer diameter of K1 and a center 45 and wherein band-shaped segments 42, 44 extend along the outer periphery of the inner concentric circle 46 and the inner periphery of the outer concentric circle 48.

As is apparent from the above-mentioned manufacturing steps, that plane of the band-shaped segment 42 which is exposed on the outer surface of the coil element 18 shown in Figures 6 and 7 corresponds to the outer surface of the original windings 2, 12. That plane of the band-shaped segment 44 which is exposed on the outer surface of said coil element 18 corresponds to the inner surfaces of the original windings 2, 12. The outer and inner surfaces of the original windings 2, 12 alternately appear on the outer surface of the coil element 18 as shown in Figure 6 or 7. With the coil element 18 of Figure 7 fabricated from the original winding 6 of Figure 2, the upper and lower surfaces of said original winding 6 are exposed alternately. On the upper and lower portions of the coil element 16, the band-shaped segments 42, 44 are superposed on each other. The equal division points 24 are set on the periphery of an imaginary circle 46 substantially at an equal distance. The equal division points 26 are set on the periphery of an imaginary circle 48 substantially at an equal distance. The segments 42, 44 of the coil element 18 of Figure 6 fabricated from the first original winding 2 have a linear band shape. The coil elements 18 fabricated from the original windings 6, 12 shown in Figures 2 and 3 respectively have arcuate segments 42, 44.

For fabrication of the coil element 18 shown in Figures 6 and 7, the original windings 2, 6, 12 should meet the undermentioned requirements. Description is given of the respective types 2, 6, 12 of original winding. Where the second flat star-shaped coil element 18 of Figure 6 whose reference outer circle has a diameter K1 and whose reference inner circle has a diameter K2 is fabricated from the first cylindrical original winding 2 of Figure 1, then, this first original winding 2 should have a diameter d defined by the following equation (11) or (12), and optionally selectable width B and be bent at angles ϕ_1, ϕ_2 , defined by the following equations (13), (14).

$$d = \frac{n K_1 \sin (\pi / n)}{\pi \sin \phi_2} \quad \dots (11)$$

$$d = \frac{n K_2 \sin (\pi / n)}{\pi \sin \phi_1} \quad \dots (12)$$

$$\phi_1 = \tan^{-1} \left\{ \frac{\sin (\pi / n)}{\frac{K_1}{K_2} - \cos \left(\frac{\pi}{n} \right)} \right\} \quad \dots (13)$$

$$\phi_2 = \phi_1 + \frac{\pi}{n} \quad \dots (14)$$

Where the second flat star-shaped coil element 18 of Figure 6 is prepared from the second flat ring-shaped original winding 6 shown in Figure 2, then this original winding 6 should have an outer diameter R₁ defined by the following equation (15) or (16), and be bent at angles ϕ_1, ϕ_2 defined by the above-mentioned equations (13), (14).

$$R_1 = \frac{K1 \cos (\pi/2n)}{\sin \phi_2} \quad \dots (15)$$

$$R_1 = \frac{K2 \cos (\pi/2n)}{\sin \phi_1} \quad \dots (16)$$

The inner diameter R_2 and width B of the second original winding 6 of Figure 2 can be optionally selected. Where the second flat star-shaped coil element 18 of Figure 6 is fabricated from the third truncated conical original winding 12 of Figure 3, then this third original winding 12 should have a larger diameter d_1 defined by the following equation (17) or (18), and be bent at angles ϕ_1 , ϕ_2 defined by the aforesaid equations (13), (14).

$$d_1 = \frac{K1 \sin (\pi/n) \sin (\delta/2)}{2 \sin \phi_2 \sin \{(\pi/2n) \sin (\delta/2)\}} \quad \dots (17)$$

$$d_1 = \frac{K2 \sin (\pi/n) \sin (\delta/2)}{2 \sin \phi_1 \sin \{(\pi/2n) \sin (\delta/2)\}} \quad \dots (18)$$

The apical angle δ , smaller diameter d_2 and width B of the third truncated conical original winding 12 of Figure 3 can be optionally chosen.

Description is now given of the method of manufacturing a third coil element 20 by fitting any of the three types 2, 6, 12 of original winding around the periphery of an imaginary truncated conical block form shown in Figure 8 or 9.

First, an even number, that is, a $2n$ number (n denotes an integer of 1, 2 and 3 ...) of equal division points 24, 26 are set on the periphery of any of the original windings 2, 6, 12 substantially at an equal distance. With the first cylindrical winding 2, the equal division points 24, 26 are set on the lower end periphery shown in Figure 1. With the second flat ring-shaped original winding 6 shown in Figure 2, the equal division points 24, 26 are provided on the periphery of the outer diameter of the ring shape. With the third truncated conical original winding 12, the equal division points 24, 26 are set on the base periphery of the winding 12 as shown in Figure 3.

Thereafter, imaginary reference lines 28, 30 are specified which pass through the equal division points 24, 26. With the first cylindrical original winding 2, the imaginary reference lines 28, 30 are disposed in parallel with the axis of an imaginary cylindrical block form. With the second flat ring-shaped original winding 6, the imaginary reference lines 28, 30 are chosen to convergently pass through the center 34 of said ring-shaped original winding 6. With the third truncated conical original winding 12, the reference lines 28, 30 are arranged to convergently pass through the apical point 36 of an imaginary truncated conical block form.

Further, bending lines 38, 40 are specified which pass through the equal division points 24, 26 at prescribed angles ϕ_1 , ϕ_2 to the imaginary reference lines 28, 30. As seen from Figures 1 to 3, the adjacent bending lines 38, 40 are inclined respectively at angles ϕ_1 , ϕ_2 in the circumferential direction. Therefore, the bending lines 38, 40 divide the original winding 2, 6, 12 shown in Figures 1 to 3 into a $2n$ number of band shaped segments 42, 44.

Preliminary bending is applied to the respective original windings 2, 6, 12 by means of a jig. With the first and third original windings 2, 12 of Figures 1 and 3, pressure as applied in such a manner that the bending line 38 projects outward, and the bending line 40 adjacent to said bending lines 38 projects inward. Outward and inward projections are alternately repeated. With the second flat ring-shaped original winding 6, pressure is applied in such a manner that the bending line 38 projects upward, and the bending line 40 adjacent to said bending line 38 projects downward. Upward and downward projections are alternately repeated. The original windings 2, 6, 12 which have been subjected to the above-mentioned preliminary bending are each fitted with a truncated cone jig and again pressed to be bent. As a result, a coil element 20 is formed whose segments 42, 44 extend along the periphery of an imaginary truncated conical block form 50 shown in Figures 8 and 9 which has a larger diameter $D1$, smaller diameter $D2$ and an angle γ at an imaginary apical point 51.

As apparent from the above-mentioned manufacturing steps, that plane of the segment 42 which is exposed on the outer surface of the coil element 20 shown in Figures 8 and 9 corresponds to the outer surface of the original windings 2, 12. That plane of the segment 44 which is exposed on the outer surface of the coil element 20 corresponds to the inner surface of the original windings 2, 12. The outer and inner surfaces of the respective original windings 2, 12 alternately appear on the outer surface of the coil element 20 as a result of bending. With the coil element 20 of Figure 9 fabricated from the flat ring-shaped original winding 6 of Figure 2, the upper and lower surfaces of said flat ring-shaped original winding 6 alternately appear on the outer surface of said coil element 20. On the upper and lower portions of the coil element 20, the segments 42, 44 of said original winding 6 are superposed on each other as a result of bending. The equal division points 26 are defined substantially at an equal distance on the periphery of the upper smaller diameter of an imaginary truncated conical block form 50. The equal division points 24 are set substantially at an equal distance on the periphery of the lower larger diameter of said imaginary truncated conical block

form 50. The segments 42, 44 of the coil element 20 of Figure 8 fabricated from the first cylindrical original winding 2 of Figure 1 have a straight band shape. The segments 42, 44 of the coil element 20 of Figure 9 prepared from the flat ring-shaped original winding 6 of Figure 2 and the truncated conical original winding 12 of Figure 3 have an arcuate band shape. Thus, the coil element 20 is constructed as illustrated in Figure 9.

For fabrication of the coil element 20 shown in Figures 8 and 9, the original windings 2, 6, 12 should meet the undermentioned requirements. Discription is given of the respective types 2, 6, 12 of original winding. Where the third truncated conical coil element 20 is fabricated from the first cylindrical original winding 2 of Figure 1 by causing the bent segments of said original winding 2 to extend along the periphery of an imaginary truncated conical block form having an apical angle γ , larger diameter $D1$ and smaller diameter $D2$, then this cylindrical original winding 2 should have a diameter d defined by the following equation (19) or (20) and be bent at angles ϕ_1 , ϕ_2 respectively defined by the following equations (21), (22).

$$d = n/\pi \cdot \frac{D1 \sin \{(\pi/n) \sin (\gamma/2)\}}{\sin (\gamma/2) \sin \phi_2} \quad \dots (19)$$

$$d = n/\pi \cdot \frac{D2 \sin \{(\pi/n) \sin (\gamma/2)\}}{\sin (\gamma/2) \sin \phi_1} \quad \dots (20)$$

$$\phi_1 = \tan^{-1} \left[\frac{\sin \{(\pi/n) \sin (\gamma/2)\}}{\frac{D1}{D2} - \cos \{(\frac{\pi}{n}) \sin (\frac{\gamma}{2})\}} \right] \quad \dots (21)$$

$$\phi_2 = \phi_1 + \pi/n \sin (\gamma/2) \quad \dots (22)$$

Where the third coil element of Figure 9 is fabricated from the second flat ring-shaped original winding 6 of Figure 2, then said second original winding 6 should have an outer diameter R_1 defined by the following equation (23) or (24) and be bent at angles ϕ_1 , ϕ_2 defined by the aforesaid equations (21) and (22).

$$R_1 = \frac{D1}{2 \sin \phi_2} \cdot \frac{1}{\sin (\gamma/2)} \cdot \frac{\sin \{(\pi/n) \sin (\gamma/2)\}}{\sin (\pi/2n)} \quad \dots (23)$$

$$R_1 = \frac{D2}{2 \sin \phi_1} \cdot \frac{1}{\sin (\gamma/2)} \cdot \frac{\sin \{(\pi/n) \sin (\gamma/2)\}}{\sin (\pi/2n)} \quad \dots (24)$$

Where the coil element 20 of Figure 9 is formed of the third truncated conical original winding 12 of Figure 3, then said third original winding 12 should have a larger diameter d_1 defined by the following equation (25) or (26) and be bent at angles ϕ_1 , ϕ_2 respectively defined by the aforementioned equation (21) and (22).

$$d_1 = \frac{D1}{2 \sin \phi_2} \cdot \frac{\sin (\delta/2)}{\sin (\gamma/2)} \cdot \frac{\sin \{(\pi/n) \sin (\gamma/2)\}}{\sin \{(\pi/2n) \sin (\delta/2)\}} \quad \dots (25)$$

$$d_1 = \frac{D2}{2 \sin \phi_1} \cdot \frac{\sin (\delta/2)}{\sin (\gamma/2)} \cdot \frac{\sin \{(\pi/n) \sin (\gamma/2)\}}{\sin \{(\pi/2n) \sin (\delta/2)\}} \quad \dots (26)$$

The equations (21), (22), (25) and (26) are the fundamental forms of other equations. Therefore, these equations (21), (22), (25) and (26) are first proved.

Where the third coil element 20 is deployed as shown in Figures 8 and 9 in which the bent segments of the original winding extend along the periphery of an imaginary truncated conical block form, then the third coil element is positioned, as shown in Figure 12, in a region defined between two concentric circles respectively having diameters $2F1$, $2F2$. The central angle Ψ which the deployed coil element 20 defines with the center 52 of deployment is expressed by the following equation.

$$\Psi = 2 \pi \sin (\gamma/2) \quad \dots (27)$$

The equal division points 24, 26 divide the periphery of a circle having a larger diameter $D1$ (Figures 8 and 9) into equal parts. Straight distances ℓ between all the adjacent equal division points 24, 26 are the same. As seen from Figure 12, therefore, lines connecting the equal division points 24, 26 to the deployment center 52 divide the central development angle Ψ into a $2n$ number of equal segments. Therefore, an angle defined by the equal division points 24, 26 is $\Psi/2n$. Thus, all the triangles defined by every adjacent equal division points 24, 26 and the deployment center 52 have the same shape. As seen from Figure 12, a triangle has interior angles $\Psi/2n$ and ϕ_1 and an exterior angle ϕ_2 . The respective sides of said triangle have lengths ℓ , $F2$, $F1$. When, therefore, the sine theorem is applied, the following equation (28) results.

$$\frac{F1}{\sin \phi_2} = \frac{F2}{\sin \phi_1} = \frac{\ell}{\sin(\Psi/2n)} \quad \dots (28)$$

5 This equation (29) may be modified into the following equations (29) and (30). 5

$$\ell = F1 \times \frac{\sin(\Psi/2n)}{\sin \phi_2} \quad \dots (29)$$

$$10 \quad \ell = F2 \times \frac{\sin(\Psi/2n)}{\sin \phi_1} \quad \dots (30) \quad 10$$

15 When deployed, the third truncated conical original winding 12 indicates an arcuate band shape, which has a deployment center 54 and deployment center angle ϕ . Since, in Figure 13, straight lines ℓ between the respective adjacent equal division points 24, 26 are the same, an angle defined by said straight line ℓ with the deployment center 54 is $\phi_0/2n$. Therefore, the straight distance ℓ between the adjacent equal division points 24, 26 and deployment center angle ϕ_0 are respectively expressed by the following equations (31) and (32) 15

$$20 \quad \ell = 2G1 \sin(\phi/4n) \quad \dots (31) \quad 20$$

$$\phi = 2\pi \sin(\delta/2) \quad \dots (32)$$

The following equation (33) is derived from the figure of Figure 3

$$25 \quad d1 = 2G1 \sin(\delta/2) \quad \dots (33) \quad 25$$

The following equations (34) and (35) result from the figure of Figure 8.

$$30 \quad D1 = 2F1 \sin(\gamma/2) \quad \dots (34) \quad 30$$

$$35 \quad D2 = 2F2 \sin(\gamma/2) \quad \dots (35) \quad 35$$

Substituting the equation (31) for the equation (33), the following equation results.

$$40 \quad d1 = \frac{\ell \sin(\delta/2)}{\sin(\phi/4n)} \quad \dots (36) \quad 40$$

Substituting the equation (29) for the equation (36), the following equation is derived.

$$45 \quad d1 = \frac{F1 \cdot \sin(\delta/2) \cdot \sin(\Psi/2n)}{\sin \phi_2 \cdot \sin(\phi/4n)} \quad \dots (37) \quad 45$$

Further substituting the equation (34) for the equation (37), the following equation is produced.

$$50 \quad d1 = \frac{\sin(\delta/2) \cdot \sin(\Psi/2n)}{2\sin(\gamma/2) \cdot \sin(\phi/4n)} \cdot \frac{D1}{\sin \phi_2} \quad \dots (38) \quad 50$$

Substituting the equations (30) and (35) for the equation (36), the following equation is obtained.

$$55 \quad d1 = \frac{\sin(\delta/2) \cdot \sin(\Psi/2n)}{2\sin(\gamma/2) \cdot \sin(\phi/4n)} \cdot \frac{D2}{\sin \phi_1} \quad \dots (39) \quad 55$$

Substituting the equations (27) and (32) for the equation (38) and substituting the equations (27) and (32) for the equation (39), the aforesaid equations (25) and (26) are formed.

The ratio of F1 to F2 is expressed as follows from the equation (28) and equations (34) and (35).

$$60 \quad \frac{F1}{F2} = \frac{\sin \phi_2}{\sin \phi_1} = \frac{D1}{D2} \quad \dots (40) \quad 60$$

where the above equation (40) is substituted by the following equation

$$\phi_2 = \phi_1 + \Psi/2n \quad \dots (41)$$

and the addition theorem is applied, then the following equation is derived.

$$\frac{F_1}{F_2} = \cos(\Psi/2n) + \cot \phi_1 \sin(\Psi/2n) = \frac{D_1}{D_2} \quad \dots (42)$$

Where the above equation (42) is deformed then the aforementioned equation (21) is obtained. Where the above equation (41) is substituted by the equation (27), then the aforesaid equation (22) results.

Theoretically, the previously described equations (2), (3), (5), (8), (9), (11), (12), (15), (16), (17), (18), (19), (20), (23) and (24), are derived from the equations (25) and (26). The aforesaid equations (1), (4), (13) and (14) result from the equations (21), (22). Where the angle γ has a small value, then the coil element is cylindrically formed of an original winding whose bent segments extend along the periphery of an imaginary columnar block form. Where the angle γ indicates 180° , then the coil element becomes flat. Where the angle δ has a small value, then the original winding takes a cylindrical shape. Where the angle δ shows 180° , then the original winding is ring-shaped.

As a example, description is given of the method of fabricating the first coil element 16 of Figure 4 from the cylindrical winding of Figure 1.

Assuming $\gamma = 0$ and $\delta = 0$ in the equations (25) and (26), then the following equations result.

$$\sin(\gamma/2) \div \gamma/2$$

$$\sin(\delta/2) \div \delta/2$$

$$\sin\{\pi/2n \sin(\delta/2)\} \div \pi/2n \cdot \delta/2$$

$$\sin\{\pi/n \sin(\gamma/2)\} \div \pi/n \cdot \gamma/2,$$

d_1 is expressed by either of the following equations:

$$d_1 = \frac{D_1}{\sin \phi_2} \quad \text{or}$$

$$d_1 = \frac{D_2}{\sin \phi_1} \quad \dots (43)$$

Since $\gamma = 0$ in the equation (22), the following equation is obtained:

$$\phi_2 = \phi_1 + \pi/n \cdot \gamma/2 \div \phi_1$$

Therefore, the previously described equation results:

$$\phi_1 = \phi_2 = \phi \quad \dots (1)$$

Derived from the above equation (43) is the aforesaid equation:

$$d = \frac{D}{\sin \phi} \quad \dots (2)$$

Since the distance ℓ between the respective adjacent equal division points 24, 26 is expressed as $\ell = \pi D/2n$ as seen from Figure 10 the following equation results:

$$\tan \phi = \frac{(\pi/2n D)}{L}$$

Therefore, the previously mentioned equation is obtained:

$$\phi = \tan^{-1}(\pi/2n \cdot D/L) \quad \dots (3)$$

Thus, the aforesaid equation is established:

$$d = \frac{2n/\pi L \tan \phi}{\sin \phi} = \frac{2nL}{\pi \cos \phi} \quad \dots (4)$$

Description is now given with reference to Figures 14 to 17 of another method of fabricating a coil element 18 from the flat ring-shaped winding 6 of Figure 2 by causing the bent said original winding 6 to extend along the periphery of an imaginary cylindrical block form. Where the coil element 18 is formed by bending the flat ring-shaped original winding 6, then it generally meets the practical purpose to make said coil element 18 by bending said flat ring-shaped original winding 6 along two or four bending lines 38, 40.

Where the coil element 6 is fabricated from a flat ring-shaped original winding by causing the bent original winding to extend along the periphery of an imaginary cylindrical block form having a diameter D and height L as shown in Figure 4, then the method of manufacturing said coil element 6 comprises the step of drawing a reference circle 60 with a radius r around the center 34 of the flat ring-shaped original winding 6 as shown in Figures 14 and 16. The radius r is defined by the following equation:

$$r = \frac{\pi D}{4} = 0.78D \quad \dots (44)$$

The diameter g1 of the outer periphery 62 of the flat winding 6 is determined from the radius r of the above-mentioned reference circle 60. Where the flat ring-shaped original winding 6 is bent along two bending lines 38, 40, then the outer diameter g1 is defined by the following equation:

$$g1 = L \quad \dots (45)$$

The reason why the above-equation (45) can be established is that as seen from Figure 14 showing the flat ring-shaped original winding 6 bent along two bending lines 38, 40 and also from Figure 15 indicating the deployment of the coil element 18 fabricated from said flat ring-shaped original winding 6, the vertical lengths (Figure 15) defined by every two adjacent segments of said ring-shaped original winding 6 do not change at all, even when said original winding 6 is bent.

Where the flat original winding 6 is bent along four bending lengths, then the outer diameter g1 of the coil element 18 is defined by the following equation:

$$g1 = \sqrt{2(L^2 + r^2)} \quad \dots (46)$$

This equation is later proved with reference to Figures 16 and 17. After the reference circle 60 is specified and the diameter g1 of the outer periphery 62 of the flat ring-shaped original winding 6 is defined, division points 63, 65 are set on the periphery of said reference circle 60 to divide said periphery into equal segments. Bending lines 38, 40 are prescribed which respectively pass through the aforesaid division points 63, 65 at an angle θ defined by the undermentioned equation (47) to a straight line 68 connecting said division points 63, 65 to the center 34 of said reference line 60

$$\theta = \frac{180}{2n}(n = 1 \text{ or } 2) \quad \dots (47)$$

The bending lines 38, 40 divide the flat original winding 6 into equal segments 64, 66 or 68, 70, 72, 74.

The flat ring-shaped original winding 6 is bent along the bending lines 38, 40 in such a manner that the respective segments of said bent winding 6 are directed downward and upward alternately along the periphery of an imaginary cylindrical block form, thereby providing a coil element 18 whose deployment chart is given in Figure 15 or 17.

As apparent from the foregoing description, the inner diameter g2 of the flat-ring shaped original winding 6 is unrelated to any of the aforesaid equations, and consequently may be optionally selected as a rule. However, said inner diameter g2 should be made equal to or larger than the diameter 2r of the reference circle 60, that is, should have a relationship $2r \leq g2$ relative to said diameter 2r. The reason for this is that in case of $g2 \leq 2r$, the bending lines would have to be set again on the outer periphery of the flat ring-shaped original winding 6.

Brief description is given of the above-mentioned equation $\theta = 180/2n$. Referring to Figure 16, where the flat ring-shaped original winding 6 is bent along four bending lines, a distance ℓ between the intersection points 76 and 78 which the bending lines 38 and 40 respectively define with the outer periphery 62 of the flat ring-shaped original winding 6 is expressed as follows.

$$\ell = \sqrt{2} \cdot g1/2$$

Where the original winding 6 is fabricated into the coil element 18, as shown in Figure 17, then the aforesaid intersection points 76, 80 lie on the same periphery of an imaginary cylindrical block form. As seen from the illustrated steps of manufacturing the coil element 18, a distance m (Figure 17) between said junctions 76, 80 is 2r. The three equidistantly arranged division points 76, 78, 80 collectively define an isosceles triangle, whose two facing sides have a length ℓ alike, and whose base side m has a length 2r. Therefore, the height L of the imaginary cylindrical block form is expressed as



$$L = \sqrt{\ell^2 - (m/2)^2} = \sqrt{\ell^2 - r^2}$$

Therefore, the following equations results:

$$L = \sqrt{\frac{g1^2}{2} - r^2} \quad 5 \quad 5$$

$$2L^2 = g1^2 - 2r^2$$

$$g1 = \sqrt{2(L^2 + r^2)} \quad 10 \quad 10 \quad \dots (46)$$

The values defined by the aforesaid numerous equations well serve the purpose, provided they substantially represent what is indicated, though they may not exactly satisfy the corresponding equations. It will be noted that the practical manufacturing steps are generally accompanied with errors, failing to let the above-mentioned equations be fully satisfied, and that the magnitudes of such errors vary with the shape and size of an original winding and those of the resultant coil element.

As described above, the method of this invention can produce an electric motor coil element efficiently and at low cost. Further as apparent from the manufacturing steps, the respective turns of the original winding are regularly arranged, enabling magnetic energy to be effectively produced. Therefore, an electric motor constructed by assembling the coil elements embodying this invention is much more improved in various properties than has been possible in the past.

25 CLAIMS

1. A method of manufacturing an electric motor coil element, comprising;
winding a wire coaxially and helically to form an original winding having first and second opposite faces;
setting a number $2n$ (where n is an integer) of division points equally spaced around the winding to divide
the winding into an even number of segments;
defining bending lines which pass through the division points respectively and at prescribed angles
relative to respective predetermined reference lines extending through the division points, and
bending the original winding along the bending lines and such that the winding adopts generally annular
configuration wherein the segments present portions of said first and said second faces alternately in a
sequence and on a common surface region of the finished coil element.

2. A method according to claim 1 wherein the original winding has a cylindrical shape.

3. A method according to claim 1 wherein the original winding has a flat ring shape.

4. A method according to claim 1 wherein the original winding has a truncated conical shape.

5. A method according to any preceding claim wherein the common surface region comprises a
generally cylindrical surface of an imaginary cylindrical block form.

6. A method according to any one of claims 1 to 4 wherein the finished coil element comprises a flat
star-shaped winding said segments being disposed in a region defined between two concentric circles.

7. A method according to claim 1, wherein the coil element is fabricated from a cylindrical original
winding having a diameter d , the surface region on which the segments of said cylindrical original winding
extends comprising the periphery of an imaginary cylindrical block having a height L and diameter D ; the
bending lines define angle ϕ with the reference lines which are set in parallel with the axis of said cylindrical
original winding and pass through the division points; the diameter d of said cylindrical original winding is
substantially defined by either of the following equations:

$$d = \frac{D}{\sin \phi} \quad 50 \quad 50$$

or

$$d = \frac{2nL}{\pi \cos \phi} \quad 55 \quad 55$$

and the bending angle ϕ is substantially determined by the following equation:

$$\phi = \tan^{-1} \left(\frac{\pi}{2n} \cdot \frac{D}{L} \right) \quad 60 \quad 60$$

8. A method according to claim 1, wherein the coil element is formed of a flat ring-shaped original



$$L = \sqrt{\ell^2 - (m/2)^2} = \sqrt{\ell^2 - r^2}$$

Therefore, the following equations results:

$$L = \sqrt{\frac{g1^2}{2} - r^2}$$

$$2L^2 = g1^2 - 2r^2$$

$$g1 = \sqrt{2(L^2 + r^2)}$$

.... (46)

The values defined by the aforesaid numerous equations well serve the purpose, provided they substantially represent what is indicated, though they may not exactly satisfy the corresponding equations. It will be noted that the practical manufacturing steps are generally accompanied with errors, failing to let the above-mentioned equations be fully satisfied, and that the magnitudes of such errors vary with the shape and size of an original winding and those of the resultant coil element.

As described above, the method of this invention can produce an electric motor coil element efficiently and at low cost. Further as apparent from the manufacturing steps, the respective turns of the original winding are regularly arranged, enabling magnetic energy to be effectively produced. Therefore, an electric motor constructed by assembling the coil elements embodying this invention is much more improved in various properties than has been possible in the past.

CLAIMS

1. A method of manufacturing an electric motor coil element, comprising; winding a wire coaxially and helically to form an original winding having first and second opposite faces; setting a number $2n$ (where n is an integer) of division points equally spaced around the winding to divide the winding into an even number of segments;

defining bending lines which pass through the division points respectively and at prescribed angles relative to respective predetermined reference lines extending through the division points, and

bending the original winding along the bending lines and such that the winding adopts generally annular configuration wherein the segments present portions of said first and said second faces alternately in a sequence and on a common surface region of the finished coil element.

2. A method according to claim 1 wherein the original winding has a cylindrical shape.

3. A method according to claim 1 wherein the original winding has a flat ring shape.

4. A method according to claim 1 wherein the original winding has a truncated conical shape.

5. A method according to any preceding claim wherein the common surface region comprises a generally cylindrical surface of an imaginary cylindrical block form.

6. A method according to any one of claims 1 to 4 wherein the finished coil element comprises a flat star-shaped winding said segments being disposed in a region defined between two concentric circles.

7. A method according to claim 1, wherein the coil element is fabricated from a cylindrical original winding having a diameter d , the surface region on which the segments of said cylindrical original winding extends comprising the periphery of an imaginary cylindrical block having a height L and diameter D ; the bending lines define angle ϕ with the reference lines which are set in parallel with the axis of said cylindrical original winding and pass through the division points; the diameter d of said cylindrical original winding is substantially defined by either of the following equations:

$$d = \frac{D}{\sin \phi}$$

or

$$d = \frac{2nL}{\pi \cos \phi}$$

and the bending angle ϕ is substantially determined by the following equation:

$$\phi = \tan^{-1} \left(\frac{\pi}{2n} \cdot \frac{D}{L} \right)$$

8. A method according to claim 1, wherein the coil element is formed of a flat ring-shaped original



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winding having an outer diameter R1, the segments of said flat ring-shaped original winding extending along the periphery of an imaginary cylindrical block having a diameter D and height L; the bending lines define an angle ϕ with the reference lines connecting the equal division points to the center of said flat ring-shaped original winding; the outer diameter of said flat ring-shaped original winding is substantially defined by either of the following equations:

$$R1 = \frac{\pi D}{2n \sin\left(\frac{\pi}{2n}\right) \sin \phi}$$

10 or

$$R1 = \frac{L}{\sin\left(\frac{\pi}{2n}\right) \cdot \cos \phi}$$

15

and the bending angle ϕ is substantially determined by the following equation:

$$\phi = \tan^{-1}\left(\frac{\pi}{2n} \cdot \frac{D}{L}\right)$$

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9. A method according to claim 1, wherein the coil element is prepared from a truncated conical original winding which has a larger diameter d1 and whose apical point has an optionally selected angle δ , the bent segments of said truncated conical original winding extending along the periphery of an imaginary cylindrical block having a diameter D and height L; the bending lines define an angle ϕ with the reference lines connecting the equal division points to the imaginary apical point of said truncated conical original winding; the larger diameter d1 of said truncated conical original winding is substantially defined by either of the following equations:

30

$$d1 = \frac{\pi D \sin(\delta/2)}{2n \sin\left\{\left(\frac{\pi}{2n}\right) \sin(\delta/2)\right\} \cdot \sin \phi}$$

35 or

$$d1 = \frac{L \sin(\delta/2)}{\sin\left\{\left(\frac{\pi}{2n}\right) \sin(\delta/2)\right\} \cos \phi}$$

40

and the bending angle ϕ is substantially determined by the following equation:

45

$$\phi = \tan^{-1}\left(\frac{\pi}{2n} \cdot \frac{D}{L}\right)$$

10. A method according to claim 1, wherein the coil element is fabricated from a cylindrical original winding having a diameter d in a flat star form which is disposed in a region defined between an outer reference circle having a diameter K1 and an inner reference circle which is set concentric with said outer reference circle and has a diameter K2; the bending lines alternately define angles ϕ_1, ϕ_2 with the reference lines which are set in parallel with the axis of said cylindrical original winding and pass through the equal division points; the diameter d of said cylindrical original winding is substantially defined by either of the following equations:

55

$$d = \frac{nK1 \sin(\pi/n)}{\pi \sin \phi_2}$$

60

or

$$d = \frac{nK2 \sin(\pi/n)}{\pi \sin \phi_1}$$

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and the bending angles ϕ_1, ϕ_2 are substantially determined by the following equations:

$$\phi_1 = \tan^{-1} \left\{ \frac{\sin(\pi/n)}{K1/K2 - \cos(\pi/n)} \right\}$$

$$\phi_2 = \phi_1 + \frac{\pi}{n}$$

11. A method according to claim 1, wherein the coil element is fabricated from a flat ring-shaped original winding having an outer diameter R1 in a flat star form which is disposed between an outer reference circle having a diameter K1 and an inner reference circle which is set concentric with said outer reference circle and has a diameter K2; the bending lines alternately define angles ϕ_1, ϕ_2 with the reference lines connecting the equal division points to the center of said flat ring-shaped original winding; the outer diameter R1 of said flat ring-shaped original winding is substantially defined by either of the following equations:

$$R1 = \frac{K1 \cos(\pi/2n)}{\sin \phi_2}$$

or

$$R1 = \frac{K2 \cos(\pi/2n)}{\sin \phi_1}$$

and the bending angles ϕ_1, ϕ_2 are substantially determined by the following equations:

$$\phi_1 = \tan^{-1} \left\{ \frac{\sin(\pi/n)}{K1/K2 - \cos(\pi/n)} \right\}$$

$$\phi_2 = \phi_1 + \frac{\pi}{n}$$

12. A method according to claim 1, wherein the coil element is fabricated from a truncated conical original winding which has a larger diameter d1 and whose imaginary apical point defines an optionally selected angle δ , in a flat star form which is disposed between an outer standard circle having a diameter K1 and an inner standard circle which is set concentric with said outer reference circle and has a diameter K2; the bending lines alternately define angles ϕ_1, ϕ_2 along the periphery of said truncated conical original winding with the reference lines connecting the equal division points to the imaginary apical point of said truncated conical original winding; the larger diameter d1 of said truncated conical original winding is substantially defined by either of the following equations:

$$d1 = \frac{K1 \sin(\pi/n) \cdot \sin(\delta/2)}{2 \sin \phi_2 \cdot \sin\{(\pi/2n) \sin(\delta/2)\}}$$

$$d1 = \frac{K2 \sin(\pi/n) \cdot \sin(\delta/2)}{2 \sin \phi_1 \cdot \sin\{(\pi/2n) \sin(\delta/2)\}}$$

and the bending angles ϕ_1, ϕ_2 are substantially determined by the following equations

$$\phi_1 = \tan^{-1} \left[\frac{\sin(\pi/n)}{K1/K2 - \cos(\pi/n)} \right]$$



$$\phi_2 = \phi_1 + \frac{\pi}{n}$$

13. A method according to claim 1, wherein the coil element is fabricated from a cylindrical original winding having a diameter d , the bent segments of said cylindrical original winding extending along the periphery of an imaginary truncated conical block form having an apical angle γ , larger diameter $D1$ and smaller diameter $D2$; the bending lines alternately define angles ϕ_1, ϕ_2 with the reference lines which are set in parallel with the axis of said cylindrical original winding and pass through the equal division points; the diameter d of said cylindrical original winding is substantially defined by either of the following equations

$$d = \frac{n}{\pi} \cdot \frac{D1 \sin \{(\pi/n) \cdot \sin (\gamma/2)\}}{\sin (\gamma/2) \cdot \sin \phi_2}$$

$$d = \frac{n}{\pi} \cdot \frac{D2 \sin \{(\pi/n) \cdot \sin (\gamma/2)\}}{\sin (\gamma/2) \cdot \sin \phi_1}$$

- and the bending angles ϕ, ϕ_2 are substantially determined by the following equations:

$$\phi_1 = \tan^{-1} \left[\frac{\sin \{(\pi/n) \cdot \sin (\gamma/2)\}}{D1/D2 - \cos \{(\pi/n) \cdot \sin (\gamma/2)\}} \right]$$

$$\phi_2 = \phi_1 + \frac{\pi}{n} \sin \left(\frac{\gamma}{2} \right)$$

14. A method according to claim 1, wherein the coil element is fabricated from a flat ring-shaped original winding having an outer diameter $R1$, the bent segments of said flat ring-shaped original winding extending along the periphery of imaginary truncated conical block form having an apical angle γ , larger diameter $D1$ and smaller diameter $D2$; the bending lines alternately define angles ϕ_1, ϕ_2 with the reference lines connecting the equal division points to the center of said flat ring-shaped original winding; the outer diameter $R1$ of said flat ring-shaped original winding is substantially defined by either of the following equations:

$$R1 = \frac{D1}{2 \sin \phi_2} \cdot \frac{1}{\sin (\gamma/2)} \cdot \frac{\sin \{(\pi/n) \sin (\gamma/2)\}}{\sin (\pi/2n)}$$

or

$$R1 = \frac{D1}{2 \sin \phi_1} \cdot \frac{1}{\sin (\gamma/2)} \cdot \frac{\sin \{(\pi/n) \sin (\gamma/2)\}}{\sin (\pi/2n)}$$

- and the bending angles ϕ_1, ϕ_2 are substantially determined by the following equations:

$$\phi_1 = \tan^{-1} \left[\frac{\sin \{(\pi/n) \cdot \sin (\gamma/2)\}}{D1/D2 - \cos \{(\pi/n) \cdot \sin (\gamma/2)\}} \right]$$

$$\phi_2 = \phi_1 + \frac{\pi}{n} \sin \left(\frac{\gamma}{2} \right)$$

15. A method according to claim 1, wherein the coil element is fabricated from a truncated conical original winding which has a larger diameter $d1$ and whose imaginary apical point defines an optionally selected angle, the bent segments of said truncated conical original winding extending along the periphery of an imaginary truncated conical block form having an apical angle γ , larger diameter $D1$ and smaller



diameter D2; the bending lines alternately defines angles ϕ_1, ϕ_2 with the reference lines along the periphery of said truncated conical original winding; the larger diameter d1 of said truncated conical original winding is substantially defined by either of the following equations:

$$d1 = \frac{D1}{2\sin \phi_2} \cdot \frac{\sin (\delta/2)}{\sin (\gamma/2)} \cdot \frac{\sin \{(\pi/n) \sin (\delta/2)\}}{\sin \{(\pi/2n) \sin (\delta/2)\}}$$

or

$$d1 = \frac{D2}{2\sin \phi_1} \cdot \frac{\sin (\delta/2)}{\sin (\gamma/2)} \cdot \frac{\sin \{(\pi/n) \sin (\gamma/2)\}}{\sin \{(\pi/2n) \sin (\delta/2)\}}$$

and the bending angles ϕ_1, ϕ_2 are substantially determined by the following equations:

$$\phi_1 = \tan^{-1} \left[\frac{\sin \{(\pi/n) \sin (\gamma/2)\}}{D1/D2 - \cos \{(\pi/n) \sin (\gamma/2)\}} \right]$$

$$\phi_2 = \phi_1 + \frac{\pi}{n} \sin \left(\frac{\gamma}{2} \right)$$

16. A method according to claim 1 wherein the finished coil element is formed of two of said segments extending along the periphery of an imaginary cylindrical block form having a height L and diameter D, and wherein the two segments are fabricated by the steps of:

30 closely winding a single wire to provide a flat ring-shaped original winding having an outer diameter g1; specifying a reference circle which is set concentric with said flat ring-shaped original winding and has a radius r;

setting two said division points on the periphery of said reference circle to divide said periphery into two equal parts;

35 providing bending lines which pass through said equal division points at a prescribed angle θ to reference lines connecting the equal division points to the center of an imaginary circle; and

bending the two equal segments of said flat ring-shaped original winding in such a manner that said first and second faces are presented alternately.

17. A method according to claim 16, wherein the radius r of the reference circle is substantially set at 0.78 D; the bending angle θ is defined to be substantially 90°; and the outer diameter g1 of the flat ring-shaped original winding is made substantially equal to the height L of an imaginary cylindrical block form.

18. A method according to claim 1 wherein the finished coil element is formed of four segments extending along the periphery of an imaginary cylindrical block form the four segments being fabricated by the steps of:

45 closely winding a single wire to provide a flat ring-shaped original winding having an outer diameter g1; specifying a reference circle which is set concentric with said flat ring-shaped original winding and has a radius r;

setting four division points on the periphery of said reference circle to divide said periphery into four equal parts;

50 providing bending lines which pass through said equal division points at a prescribed angle θ to reference lines connecting the equal division points to the center of the reference circle; and

bending the four equal segments of said flat ring-shaped original winding about the bending lines in such a manner that said first and second faces are presented alternately in sequence.

19. A method according to claim 18 wherein the radius r of the reference circle is set at 0.78 D; the bending angle θ is chosen to be 45°; and the outer diameter g1 of said flat ring-shaped original winding is chosen to be substantially $\sqrt{2(L^2 + r^2)}$.

20. A method of manufacturing an electric motor coil element, substantially as hereinbefore described with reference to the accompanying drawings.

21. An electric motor coil element manufactured by a method according to any preceding claim.

60 22. An electric motor coil element substantially as hereinbefore described with reference to the accompanying drawings.