Nov. 10, 1964 S. M. ORIGONI ETAL 3,156,076

MANUFACTURE OF HIGH ACCURACY THROUGH BORE SYNCHRO

Filed April 26, 1960 2 Sheets-Sheet 1

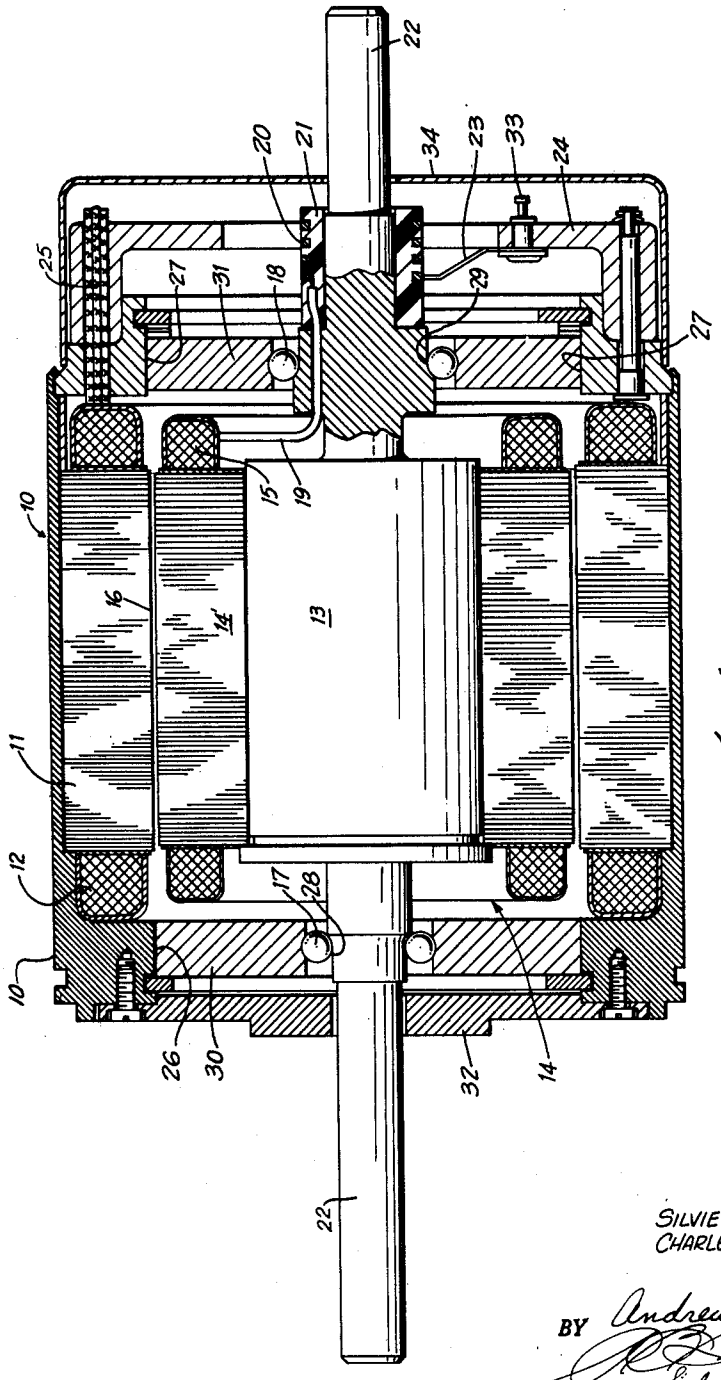


Fig. 1

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Fig. 2

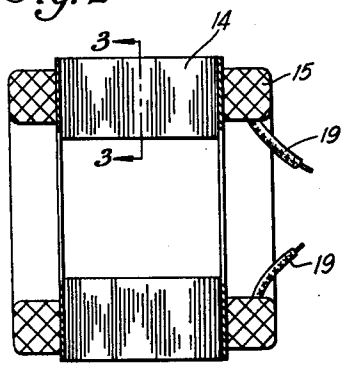
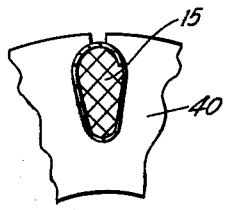


Fig. 3



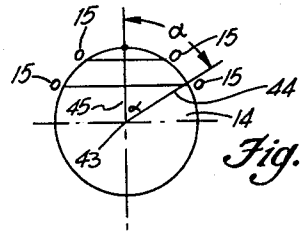


Fig. 4

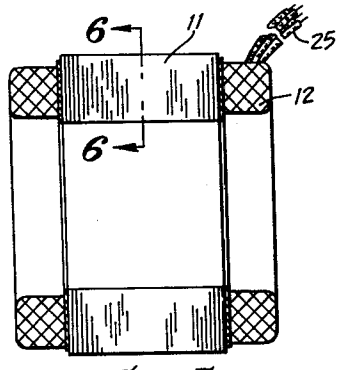


Fig. 5

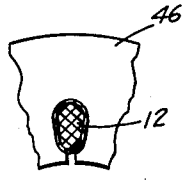


Fig. 6

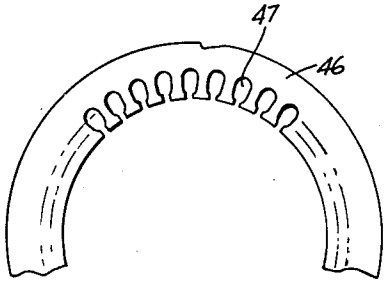


Fig. 7

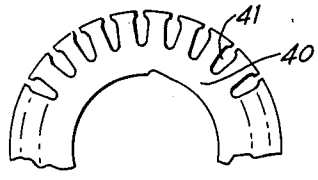


Fig. 8

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3,156,076

MANUFACTURE OF HIGH ACCURACY THROUGH BORE SYNCHRO

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5 Claims. (Cl. 51—281)

This invention relates generally to improvements in dynamoelectric synchros and more particularly to improvements in the process of making such synchros, and in the construction of the synchro to improve the accuracy of such devices to within one minute of arc or better.

It is, accordingly, a principal object of the invention to provide an alternating current synchro of greater accuracy than the conventional type of synchro.

A further object is to provide a synchro construction having a uniform air gap between the rotor and stator members during relative rotation therebetween and a minimum of eccentricity and angular variation between the stator and rotor.

A still further object is to provide an improved method of manufacturing such a synchro.

Other objects and many additional advantages will be more readily understood by those skilled in the art after a consideration of the following specification taken with the accompanying drawings, wherein:

FIGURE 1 is a longitudinal sectional view illustrating details of one preferred synchro construction according to the invention;

FIGURE 2 is a longitudinal sectional view of one preferred rotor construction;

FIGURE 3 is an enlarged section taken along lines 3—3 of FIGURE 2, illustrating the rotor slot construction;

FIGURE 4 is a schematic diagram of the coil arrangement for assistance in understanding the preferred coil winding arrangement in the rotor;

FIGURE 5 is a longitudinal sectional view similar to FIGURE 2 illustrating one preferred stator constaruction;

FIGURE 6 is an enlarged section taken along lines 6—6 of FIGURE 5, illustrating the stator slot construction, and

FIGURES 7 and 8 are elevational views of portions of the stator and rotor laminations, respectively.

Referring now to FIGURE 1 for a detailed consideration of a preferred embodiment of the invention and its manner of construction, there is shown a synchro comprising an outer housing **10** supporting a stator assembly, including a stator core **11** provided with stator windings, generally indicated as **12**, and being disposed peripherally about the inside of the housing **10**.

Within the housing and surrounded by the stator and the windings **12** thereof, is positioned a cylindrical rotor assembly **14** including a core **14'** having windings **15** about the outer circumference thereof that are uniformly spaced from the stator windings by an air gap **16**. Rotor assembly **14** also includes a central shaft **13** having a pair of hub portion extensions **22** at opposite ends thereof, that in turn are rotatively supported by ball-bearings **17** and **18** or other type of anti-friction bearings, thus enabling the rotor member **14** to be rotated as a unit within the housing and stator.

For energizing the rotor windings **15**, individual leads **19** (one shown in FIG. 1), taken from the various windings **15**, are connected with individual commutator rings **20** supported in a spaced arrangement on a molded or otherwise formed non-conducting commutator cylinder **21** that in turn is supported on and rotatable with the rotor assembly **14**. Fine wire brushes **23**, connected with terminals **33** supported by a stationary end wall **24**

of the housing, engage the commutator rings **20** while they are rotated to transmit electrical currents to and from the rotor windings **15**, as desired. Since the stator windings are fixed and stationary in the housing **10**, they are energized through fixed leads **25** and stationary terminals (not shown).

According to the present invention, there are provided a number of novel construction features that considerably increases the accuracy and precision of the synchro, reducing the error to not greater than one minute of arc. Among others, there is provided a construction that maintains substantially uniform the width of annular air gap **16** between the rotor and stator for all rotative positions of the rotor member. This is accomplished by reducing to a minimum, consistent with manufacturing accuracy, the eccentricity of the rotor with respect to the stator by so constructing and interfitting the various surfaces of both members that they are originally made coaxial with one another with a high degree of precision and interfitted in the same manner. Other features include improvements in the construction and arrangement of the slots and windings in the rotor and stator members for the purpose of achieving a sinusoidal distribution of the magnetic flux, thereby minimizing the amplitude of undesirable slot harmonics, and raising the frequency of the fundamental slot harmonic, all to the end of further reducing the error in the synchro.

Referring to FIGURE 1 for an understanding of the novel mode of fabrication which minimizes the eccentricity of the rotor relative to the stator, the stator and housing are initially machined by means of a through bore type technique. More specifically, the stator **11** and windings **12** are initially inserted and suitably fastened in place within the housing **10**. Thereafter, the inner peripheral surface of the stator surrounding the air gap **16** and the housing bearing bore surfaces **26** and **27**, are all simultaneously ground in one operation to roundnesses and taper tolerances in the order of 30 millionths of an inch or better. This simultaneous internal grinding or honing of the stator surface and housing bearing journals insures that all of these surfaces are made precisely coaxial with one another to a degree not obtainable if these surfaces were separately machined.

In a second operation, the rotor assembly **14** is made and assembled with the windings **15** provided thereon. Thereafter in a single operation the outside peripheral surface of the rotor core **14'** is ground and polished on ball centers to a roundness of at least 20 millionths of an inch or better while at the same setting and with the same precision, the rotor shaft extension **22** are ground and polished at the locations **28** and **29** to provide the inner race journals for the balls of the ball-bearings **17** and **18**. This simultaneous grinding and polishing of the ball bearing inner race angular contact journals **28** and **29** with the outside surface of the rotor core **14'** insures that all of these surfaces are made precisely coaxial with one another about the synchro central axis to a degree not obtainable if these surfaces were separately machined. Additionally, it is noted that the inner race journals **28** and **29** for the balls of the ball-bearings are formed directly on the rotor shaft extensions **22** and hence made precisely coaxial with the outside periphery of the rotor.

After the stator and rotor structures have been machined in this manner, the cylindrical members **30** and **31** forming the outer races for the bearings are line lap fitted to the housing bearing journal surfaces **26** and **27**, by line lapping the surfaces **26** and **27** to accept the bearing outer race members **30** and **31**. The outer bearing race members **30** and **31** are, of course, previously precision ground and polished, whereby this manner of

assembly thereof to the housing journals 26 and 27 permits but a minimum degree of eccentricity.

In the remaining series of operations, the end plates 32 and 24, brushes 23, electrical connections and the like are made, assembled and connected by bolts or other suitable fasteners, as shown, and the outer right-hand cover plate 34 is finally added to complete the improved synchro construction.

It is to be particularly emphasized that the inside peripheral surface of the stator 11 is made precisely coaxial with the housing assembly bearing journal surfaces 26 and 27, which in turn are made precisely coaxial with the surfaces 28 and 29 on the rotor shaft extensions 22 that form the inner race journals for the balls of the ball-bearings 17 and 18. Consequently, the inner surface of the stator defining one circumferential surface of the air gap 16 is precisely coaxial with the inner race journals 28 and 29 on the rotor shaft. Moreover, the inner race journals 28 and 29 are also made precisely coaxial with the outer peripheral surface of the rotor core 14' defining the second circumferential surface of air gap 16, whereby it is believed evident that the confronting circumferential stator and rotor surfaces defining the air gap 16 are also precisely coaxial with one another to provide a constant air gap width between these members for all relative rotative positions therebetween.

As generally indicated above, there is also provided, according to the present invention, improvements in the construction of the stator and rotor laminations and in the manner of inserting the windings and their order of insertion to provide a sinusoidal distribution of the magnetic flux with a minimized amplitude of the fundamental slot harmonic. There is also provided an improved arrangement of the number of slots and windings on the stator and rotor to raise the frequency of the fundamental slot harmonic, as is desired.

For example, according to one preferred embodiment of the invention, the stator is provided with thirty-six evenly distributed slots and a total of nine windings thereon in overlapping relationship, and the rotor is provided with twenty-eight slots and a total of seven evenly distributed windings thereon. Each winding on both the stator and rotor is provided with four equally spaced coils, one in each quadrant, with each coil occupying two slots. Consequently, with this arrangement, each slot symmetrically contains, in complete overlapping relationship, the wires of two coils to reduce the error, and the lowest order harmonic being generated is the two hundred and fifty second (252nd).

Referring to FIGURES 2 to 8, for a more complete understanding of the construction of the stator and rotor assemblies, FIGURE 8 illustrates a sector of one of the rotor laminations 40 having the slots 41 formed about the periphery thereof. A series of such laminations 40 are stacked together, with the slots 41 in aligned array, to form the body portion of the rotor assembly 14—as shown in FIGURE 2, and the turns of the winding coils 15 are inserted into the channels formed by the aligned slots, as illustrated in FIGURE 3.

To obtain the desired sinusoidal distribution of the magnetic flux, the turns are distributed about the rotor in direct proportion to the sine of their respective pitch angles, as illustrated in the diagrammatic view of FIGURE 4. Referring to FIGURE 4, there is schematically represented an end view of the rotor assembly 14 having a central axis 43 passing therethrough. The pitch angle α of the windings is the angle formed between vertical line 45 and a radial line 44 extending from the central axis 43 to the periphery of the rotor assembly 14. As shown, therefore, the turns of the windings 15 are distributed in direct proportion to the sine of the pitch angle α.

FIGURES 5, 6 and 8 illustrate similar details of the stator construction showing in FIGURE 7 a stator lamination 46 having inwardly opening slots 47 therein distributed uniformly about its inner periphery. A plurality of stator laminations such as 46 are stacked together with their slots in alignment, as shown in FIGURE 5, and the turns of the stator coils 12 are inserted in the slotted openings best shown in FIGURE 6.

To further reduce the amplitude of the undesired fundamental slot harmonic, the turns of the stator and rotor windings are also skewed along the length of these members.

What is claimed is:

1. A method of fabricating a high-precision dynamoelectric device in which a cylindrical rotor member having a coaxial shaft extension at each end is mounted for coaxial rotation in a hollow cylindrical housing and stator assembly by means of respective ball bearing sets journaling the shaft extensions in the housing, said method comprising:

precision grinding the stator assembly to produce a cylindrical inner surface thereon while simultaneously grinding journals in the housing for the outer races of the ball bearing sets, said journals consisting of respective cylindrical surfaces coaxially disposed adjacent each end of the housing and stator assembly;

precision grinding the rotor member to produce, in a single setting and operation, a cylindrical outer surface thereon complementary to said stator assembly cylindrical inner surface and, on each of the shaft extensions, respective ground and polished, coaxial, inner ball-races for the ball bearing sets, located complementary to the outer race journals ground on the housing and stator assembly; and

line lap fitting a ball bearing outer race member into each of said outer race journals.

2. A method of fabricating a high-precision dynamoelectric device in which a cylindrical rotor member having a coaxial shaft extension at each end is mounted for coaxial rotation in a hollow cylindrical housing and stator assembly by means of respective ball bearing sets journaling the shaft extensions in the housing, said method comprising:

precision grinding the stator and housing assembly to produce simultaneously a pair of coaxially-spaced cylindrical inner surfaces of equal diameter on said housing each adjacent a respective end thereof and, intermediate said surfaces, a third coaxially-aligned cylindrical inner surface of equal diameter on the stator, each of said pair of surfaces constituting a journal for the outer race member of a ball bearing set;

precision grinding the rotor member to produce, in a single setting and operation, a cylindrical outer surface thereon complementary to said stator assembly cylindrical inner surface and, on each of the shaft extensions, respective ground and polished, coaxial, inner ball-races for the ball bearing sets, located complementary to the outer race journals ground on the housing and stator assembly; and

line lap fitting a ball bearing outer race member into each of said outer race journals.

3. A method according to claim 2 wherein the inner cylindrical surface of the stator and said outer race journals are line ground to a tolerance in the order of 30 millionths of an inch; and

the outer cylindrical surface of the rotor and said inner ball races are ground and polished to a tolerance in the order of 20 millionths of an inch.

4. A method of fabricating a high-precision dynamoelectric device in which a cylindrical rotor member having a coaxial shaft extension at each end is mounted for coaxial rotation in a hollow cylindrical housing and stator assembly by means of respective ball bearing sets journaling the shaft extensions in the housing, said method comprising:

providing a hollow cylindrical housing member having coaxially mounted therein a stator assembly includ-

ing a laminated core of hollow cylindrical configuration;

precision grinding the inner surface of said core to a predetermined diameter while simultaneously grinding respective bearing journals adjacent the ends of said housing to the same diameter as, and exact concentricity with, said inner surface;

providing a rotor member including a cylindrical laminated core and a coaxial cylindrical extension of smaller diameter at each end;

precision grinding the circumferential surface of said rotor core to a predetermined diameter and with the same setting of the grinding apparatus and in the same operation grinding and polishing respective coaxial ball bearing inner race surfaces on said cylindrical extensions; and

line lap fitting a ball bearing outer race member in each of said bearing journals.

5. A method of fabricating a high-precision dynamoelectric device in which a cylindrical rotor member having a coaxial shaft extension at each end is mounted for coaxial rotation in a hollow cylindrical housing and stator assembly by means of respective ball bearing sets journaling the shaft extensions in the housing, said method comprising:

simultaneously line grinding the stator inside diameter and housing bearing outer race journals in a single operation;

grinding the outside diameter of the rotor and, at the same setting and in a single operation, grinding and polishing the rotor shaft extensions to provide the inner race seat for the balls of the ball-bearing sets; and

line lap fitting the outer ball-bearing race to the housing outer race bearing journals.

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