ABSTRACT

The disclosure illustrates a method and apparatus for reinforcing ultra-centrifuge rotors to enable operation at significantly increased rates. The rotor is selectively reinforced around its periphery by a sleeve comprising a plurality of turns of a boron filament impregnated with a curable epoxy resin. The boron filament may be wound on a spindle to preform a sleeve which then is telescoped over the periphery of the rotor, or it may be wound directly on the rotor itself. An additional variation shows the boron filament wound on various spindles to preform a series of coaxial interfitting sleeves telescoped over the periphery of the rotor.

6 Claims, 4 Drawing Figures
REINFORCING ULTRA-CENTRIFUGE ROTORS

The present invention relates to ultra-centrifuges and more particularly to rotors incorporated in an ultracentrifuge assembly.

In recent years there has been a need by medical research for more effective centrifugation from batch-type centrifuges. This has been done by increasing the R.P.M.'s of the centrifuge rotors to as high as 48,000.

This is known as an ultra-centrifuge that subjects its contents to an extremely high centrifugal force field. However, this same force field causes the stresses in the rotor to approach such enormous proportions that the material cannot resist the forces produced by the centrifugal multiplication of its own weight. Attempts have been made to form the rotors from a low density, high strength material, such as titanium. However, this material has a strength to weight ratio that still limits the upper R.P.M.'s that can be achieved.

Accordingly, it is an object of the present invention to substantially increase the maximum capable operating R.P.M. of an ultra-centrifuge rotor in a simplified and economical fashion.

This end is achieved by winding a plurality of turns of a low density, high strength, high modulus filamentary material so that it forms a sleeve around the periphery of a rotor. The filamentary material then is impregnated with a curable resin. The sleeve selectively reinforces the periphery of the rotor.

In a more specific aspect of the invention the filamentary material comprises a boron filament.

The above and other related objects and features of the present invention will be apparent from a reading of the description of the disclosure shown in the accompanying drawing and the novelty thereof pointed out in the appended claims.

In the drawing:

FIG. 1 illustrates a step in a method embodying the present invention for reinforcing the periphery of an ultra-centrifuge rotor;

FIG. 2 shows an ultra-centrifuge rotor whose periphery is reinforced using the method shown in FIG. 1;

FIG. 3 shows an enlarged view of an alternate embodiment of the present invention; and

FIG. 4 shows still another embodiment of the present invention.

Turning first to FIG. 2 there is shown an ultra-centrifuge 10 comprising a rotor element 12 rotatably driven by a low torque, high R.P.M. motor 14. The rotor 12 as herein illustrated is for a batch-type centrifuge. The liquid to be separated into its constituents is placed in a central bowl 16 containing various baffles and bleed passages (not shown to simplify the description of the invention). The rotor is rotated to separate the constituents according to their specific gravity, as is the usual practice for centrifuges. The rotor 12 has an annular peripheral wall 18 which is positioned at a rather substantial distance from the axis of rotation of the rotor. When the rotor is rotated at R.P.M.'s approaching 48,000, the internal hoop stresses limit the maximum R.P.M. that can be obtained. Therefore, in accordance with the present invention the peripheral wall 18 of the rotor 12 is selectively reinforced as follows:

A spindle 20 is mounted on a shaft 22 rotatably driven by a suitable motor 24. A plurality of turns of a low density, high strength, high modulus filamentary material 26 is wound around the periphery of spindle 20 by the rotation of motor 24. The filamentary material 26 is wrapped in a predetermined pattern by feeding it through a guide 28 displaceable in a slot 30 in arm 32. An articulated link 34 extends from guide 28 to a crank arm 36 driven by motor 38. Motor 38 is synchronized with motor 24 so that a predetermined pattern results from winding the filamentary material 26 onto spindle 20. The filamentary material 26 passes around guide rollers 40 and through receptacle 42 containing a curable resin material 44. Filamentary material 26 is fed from a supply reel 46 which is appropriately braked to produce a given pretension in the filamentary material 26 for relatively tight winding onto spindle 20.

Preferably the filamentary material 26 is comprised of a boron filament having an average diameter of approximately 0.0056 inch. This boron filament, for example, may be manufactured by vapor depositing a mixture of boron trichloride and hydrogen onto thin tungsten substrates. This type of boron filament is available from the Avco Systems Division of Avco Corporation, Lowell Industrial Park, Lowell, Mass. 01851. The curable resin material may be a mixture of 89% resin with 11% hardener by weight. The resin and hardener may be selected from a wide variety of brands well known to those skilled in the art. Brands that have given acceptable results are: ERL-2256 Epoxy Resin, available from Union Carbide, and Curing Agent Z, available from Shell.

The boron filamentary material 26 is wound onto spindle 20 and saturated with the resin material. It should be pointed out that the boron filament 26 may be applied wet, as shown in FIG. 1, or applied dry and then impregnated with the resin. The spindle 20 is wound with a large number of turns to produce a number of layers of boron filament. It has been found that 48 layers, for example, produce a sleeve 48 with a predetermined thickness (FIG. 2). After the boron filament is wound and the resin cured, the sleeve 48 is slipped off of the spindle 20. The sleeve 48 is then telescoped over the peripheral wall 18 of the rotor 12 to selectively reinforce its periphery.

Preferably the diameter D of the spindle 20 is selected to be as near as the outside diameter Ds of the rotor 12 as manufacturing tolerances will allow to produce an ultimate zero clearance fit between the sleeve 48 and the peripheral wall 18 of rotor 12. It has been found that manufacturing variations in size can be compensated for by selecting the diameter D of spindle 20 to be approximately 0.003 under the diameter Ds of rotor 12. This results in an interference fit between sleeve 48 and the periphery of rotor 12. To telescope the sleeve 48 over the periphery of rotor 12 the sleeve 48 is heated to expand it and the rotor 12 cooled to contract so that the two fit together. When they have reached equilibrium temperatures the sleeve 48 is tightly held on the periphery of rotor 12.

The sleeve 48 of the boron filament substantially reinforces the periphery of the rotor 12 and enables a significant increase in the maximum R.P.M.'s attainable. It has been found that the maximum R.P.M.'s can be increased from 48,000 to 56,000 R.P.M. The reason for the substantial increase in performance is that the boron filament is an extremely low density, high strength, high modulus material. Typical properties of the boron filament are: a density of 0.994 lbs./in.³, a modulus of 58 x 10⁶ PSI, and a tensile strength of 500,000 lbs. per square inch. The modulus of elasticity
of the boron is substantially greater than that for the titanium in the wall 18. Therefore, the sleeve of boron filament resists deformation due to the hoop stresses far greater than the titanium in the peripheral wall 18 of the rotor 12 thereby preventing deformation of the titanium.

Referring to FIG. 3 there is shown an alternate embodiment of the present invention. In this embodiment the peripheral wall 18' of the rotor 12 is reinforced by three sleeves 50, 52 and 54. The total thickness of these sleeves is the same as the thickness of the sleeve 48 shown in FIG. 2. It has been found that the windings are compacted and quite uniform in their spacing in the initial turns making up the sleeve 48. The turns thereafter tend to be less uniform and have a lower degree of compaction. Therefore each sleeve 50, 52 and 54 is preformed from a smaller number of turns than that for sleeve 48 and then telescoped into one another to form the resultant reinforcing sleeve for the periphery of wall 18'.

The sleeves 50, 52 and 54, respectively, are formed by winding on three separate spindles using the procedure shown in FIG. 1 and described above. The diameter of the spindle for sleeve 50 is approximately the outer diameter of wall 18'. The diameters for the spindles used to form sleeves 52 and 54 are progressively larger. The boron filament is wound on the various spindles to a predetermined thickness so that the sleeves interfit with one another with a zero clearance.

For manufacturing convenience the sleeves may be formed with an interference fit relative to each other and to the wall 18' of rotor 12'. These are assembled by the heating and cooling method illustrated for the method of FIGS. 1 and 2. For example, sleeve 50 is cooled, sleeve 52 heated and telescoped over sleeve 50. Then both sleeves 50 and 52 are cooled. Sleeve 54 is heated and telescoped over sleeve 52. The coaxial interfitting sleeves 50, 52 and 54 are heated and telescoped over rotor 18' which has been cooled.

The methods described above are directed to an embodiment where the boron filament is wound on a spindle, cured, and then placed over the rotor 12. In the embodiment shown in FIG. 4 the boron filament is wound directly on the periphery of wall 18'' of rotor 12''. The boron filament windings form a sleeve 56 which is received in an annular recess 58 around the periphery of wall 18'. However, the sleeve may be wound directly on the smooth exterior surface of the rotor with generally equal results.

Each of the methods described above enable a high degree of reinforcement of the periphery of ultracentrifuge rotors which greatly increases the maximum operating R.P.M.'s.

While a preferred embodiment of the filamentary material has been shown, it should be apparent to those skilled in the art that other materials with similar properties may be used with equal results. For example, graphite in an epoxy matrix could be used.

Having thus described the invention, what is claimed as novel and desired to be secured by Letters Patent of the United States is:

1. A reinforced ultra-centrifuge rotor comprising:
   a. a titanium bowl element; and
   b. a plurality of turns of a filamentary material having a lower density, higher modulus of elasticity and higher tensile strength than titanium, secured around the periphery of said rotor element, whereby the maximum rate of rotation of said rotor is substantially increased.

2. A reinforced centrifuge rotor as in claim 1 wherein said filamentary material comprises a boron filament.

3. A reinforced centrifuge rotor as in claim 1 wherein said filamentary material comprises graphite in an epoxy matrix.

4. A reinforced centrifuge rotor as in claim 1 wherein said filamentary material is preformed in the shape of a sleeve and telescoped over the periphery of said annular rotor element.

5. A reinforced centrifuge rotor as in claim 1 wherein said filamentary material is formed from a plurality of preformed sleeves of multi-layers of filamentary material, each being formed from a single run of material and telescoped over one another and over the outer periphery of said rotor element.

6. A reinforced centrifuge rotor as in claim 1 wherein:
   a said annular rotor element has an annular groove formed in the outer periphery thereof; and
   b said filamentary material is positioned around the periphery of said rotor element in said annular groove.
Notice of Adverse Decision in Interference

In Interference No. 100,429, involving Patent No. 3,913,828, P. A. Roy, REINFORCING ULTRA-CENTRIFUGE ROTORS, final judgment adverse to the patentee was rendered Mar. 10, 1983, as to claims 1, 2, 4, 5 and 6.

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