

[54] **SPOKED DISC FLYWHEEL**

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[51] Int. Cl. **F16c 15/00**

[58] Field of Search..... **74/572, 230.1, 230.15; 301/5.3, 5.7, 7, 63 R, 66; 161/56, 60**

[56] **References Cited**

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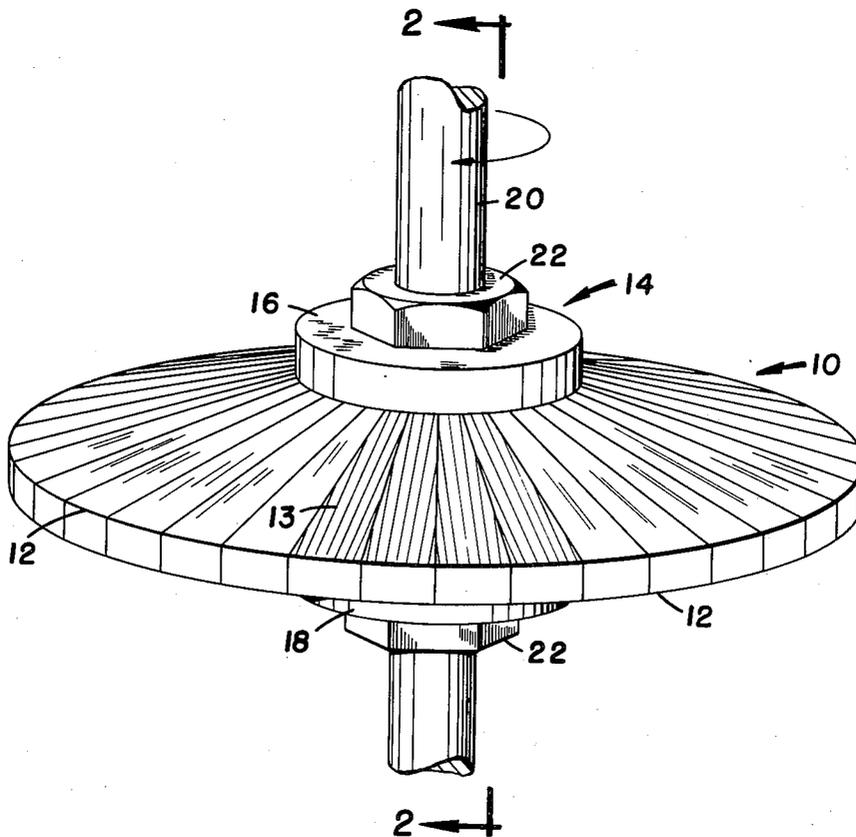
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 Kenneth E. Darnell

[57] **ABSTRACT**

A rotary energy storage device comprised of rod-like, essentially anisotropic members which extend radially from the perimeter of a central hub. The radial orientation of the rod-like members cause the unsupported portions of the members, i.e., those portions of the members not attached to or embedded in the central hub, to be in pure tension during rotation of the device. The rod-like members are shaped such that they are thicker axially at their inner ends and taper to a flattened conformation at their outer ends, the degree of taper allowing the members to be contiguous to each other along their lateral surfaces such that the members effectively form a solid disc. The swept volume of the rotary device is thereby continuously occupied by the essentially anisotropic members, thus maximizing energy stored per unit volume. The present rotor configuration may be preferably formed of essentially uniaxial filamentary composite materials, such as wood, due primarily to the reduced costs of fabrication. Formation of the members of wood rather than high tensile strength filamentary composites provides the additional advantage of reducing the load which the central hub is required to carry.

10 Claims, 11 Drawing Figures



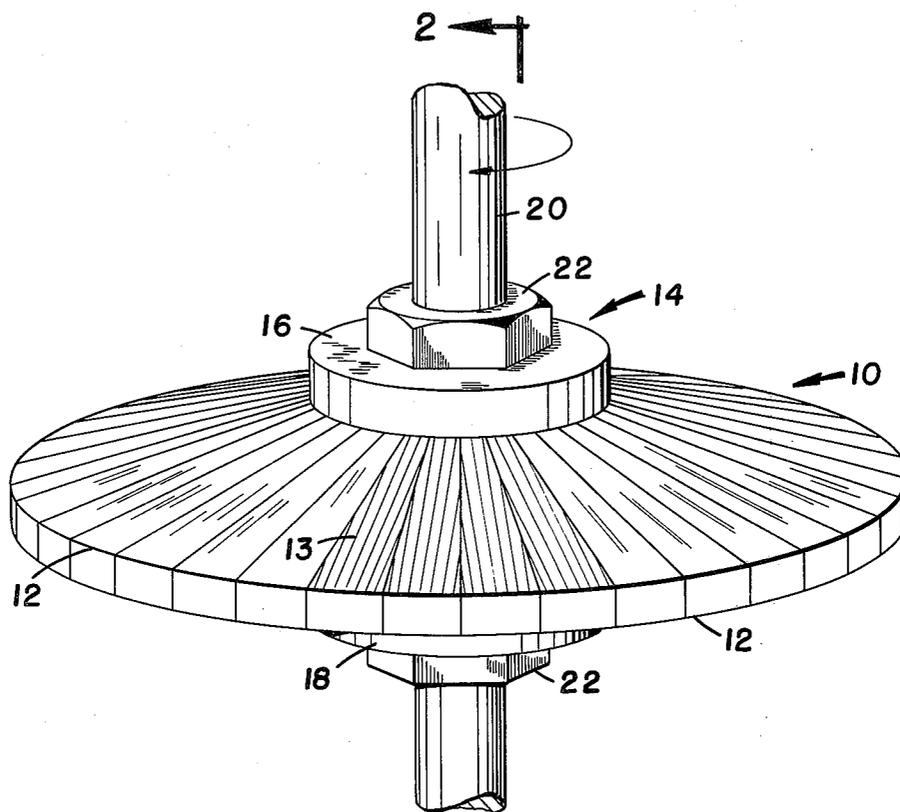
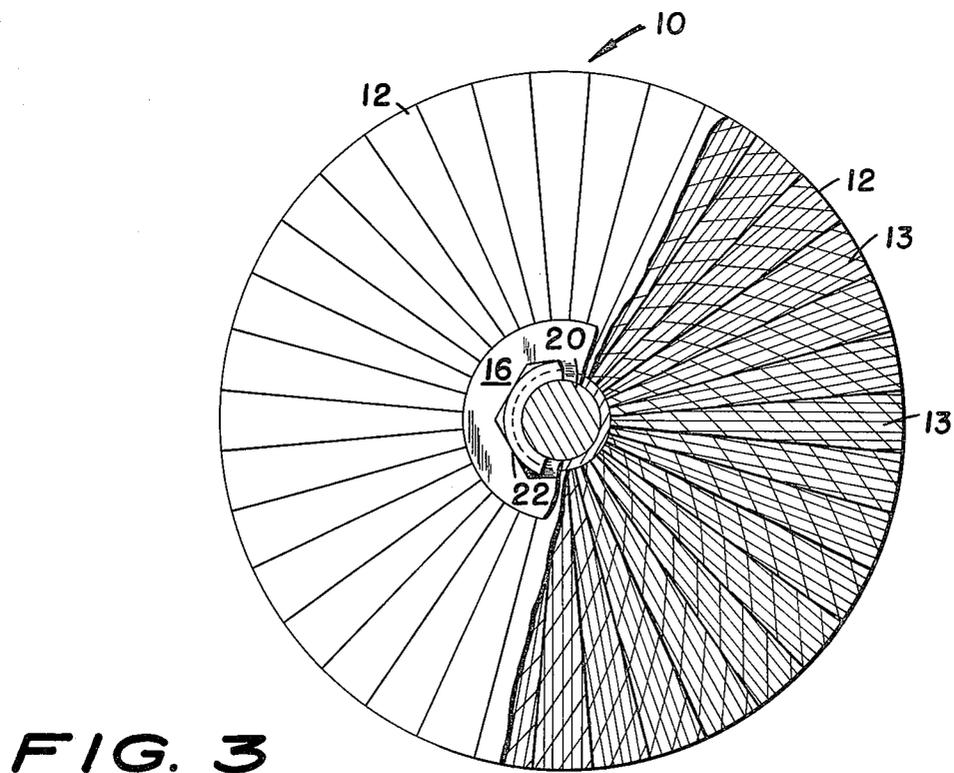
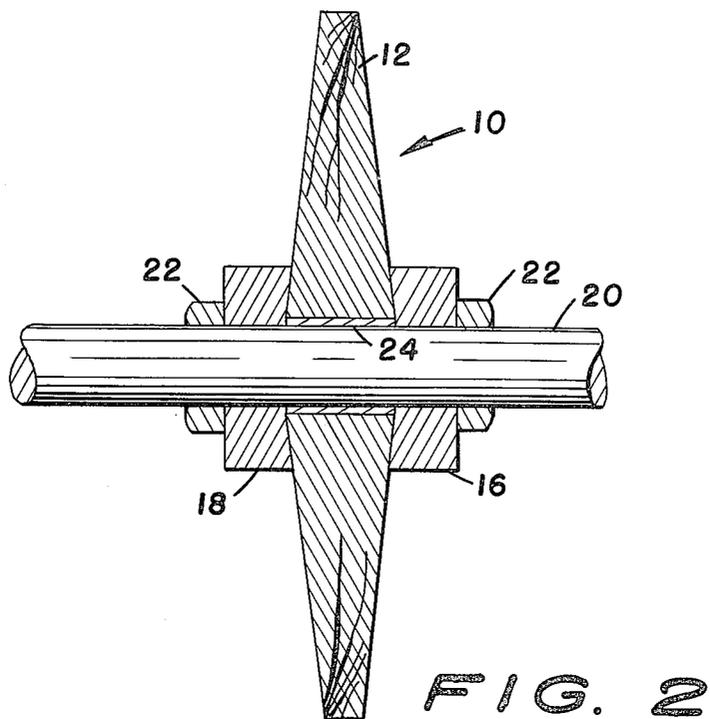


FIG. 1



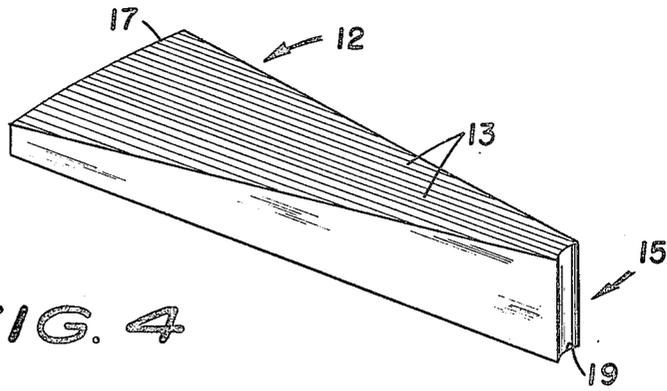


FIG. 4

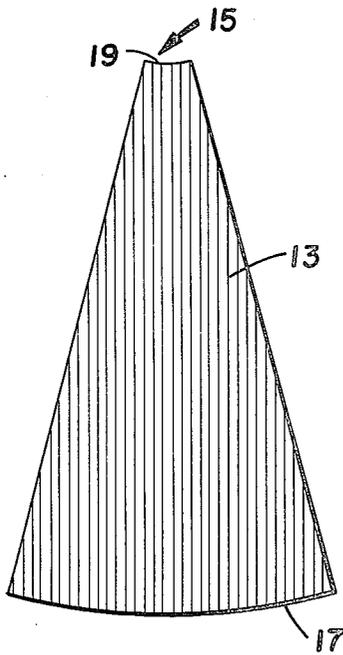


FIG. 5

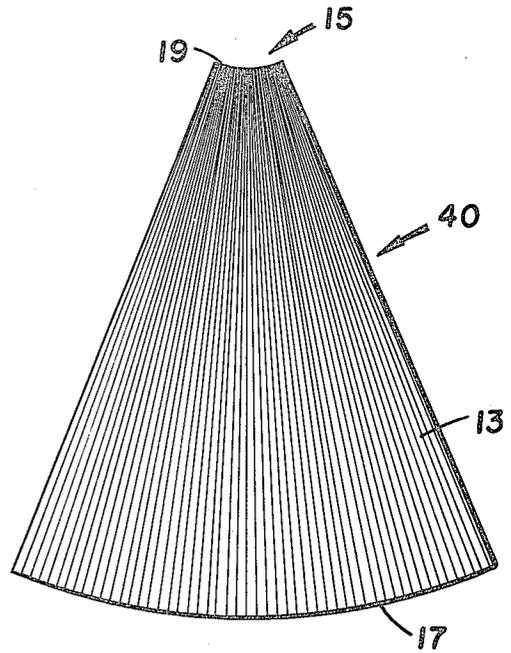


FIG. 6

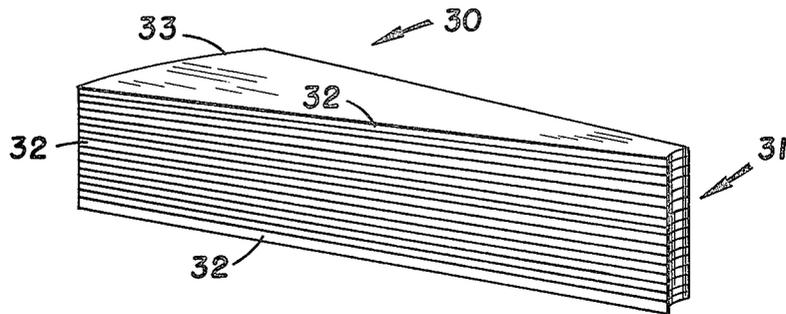


FIG. 7

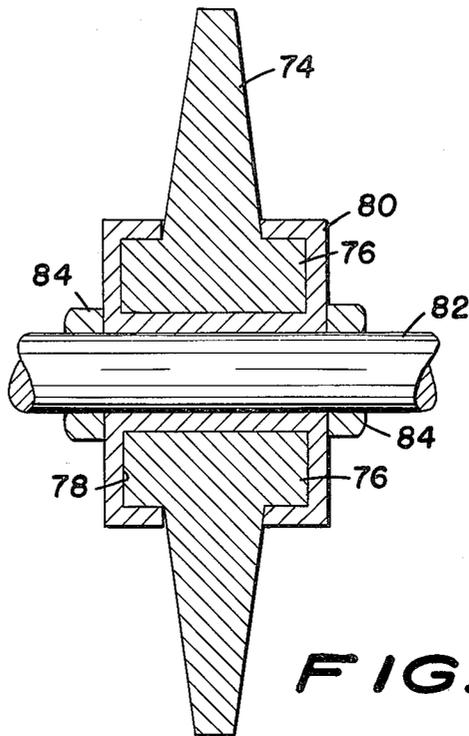


FIG. 10

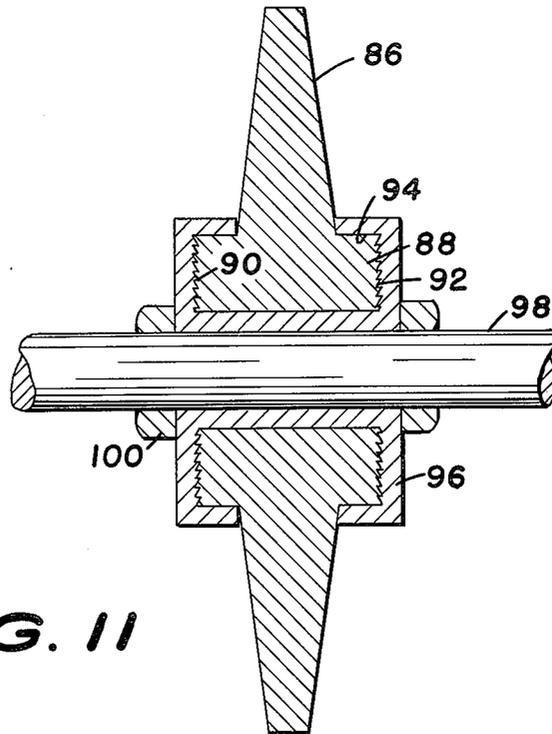


FIG. 11

SPOKED DISC FLYWHEEL**STATEMENT OF GOVERNMENT INTEREST**

The invention herein described was made in the course of or under a contract or subcontract thereunder, with the Department of the Navy.

BACKGROUND OF THE INVENTION**1. Field of the Invention**

The invention relates to energy storage devices, such as flywheels, and particularly to performance-optimized high-speed rotary structures. Application of the invention ranges from use as the sole energy storage source in a quiet, pollution-free vehicle to various static power supply energy storage applications.

2. Description of the prior art

The flywheel has been used for centuries as an efficient energy storage device. Since the flywheel is an inertial device governed by the laws of kinetic energy, maximum performance is attained at maximum speed, the performance being generally quadrupled with a two-fold increase in speed. The speed of a rotating body, however, cannot be increased beyond its bursting limit. Materials used to fabricate high-energy flywheels must have large specific strengths (strength/density) to enable the structure to be rotated at a high velocity. High strength steel has ordinarily been chosen as flywheel material. However, the strength/density ratio of an isotropic steel structure is substantially less than that obtainable with modern anisotropic filamentary materials. High strength filamentary materials typically exhibit substantially greater strength/density characteristics over the best isotropic materials, such as steel or titanium. Only a small portion of this strength advantage can be used in most prior art flywheels due to the inherent isotropic stresses in these structures. In a rim type flywheel, stresses normal to the wound filaments exist at all locations other than the outer edge. Additionally, the problem of attachment of the rim to the hub, requiring additional weight, has been a principal factor inhibiting further development of this flywheel structure.

The embodiments of the present rotational energy storage device feature a flywheel rotor structure of comparable useable energy density and volumetric efficiency to a comparable steel flywheel but at lower cost. The structure of the invention permits substantial utilization of the uniaxial strength of filamentary-type materials while packaging these materials within a compact volume. The nature of the present structures allows for the utilization of essentially uniaxial filamentary composite materials, such as wood and wood products, which provide energy storage structures with high cost efficiencies.

The significance of the present energy storage device is best understood by its application to a static power supply, an application wherein size is relatively inconsequential. In a solar home, for example, electric energy is most economically stored in batteries at the present time. However, even the best available batteries must be replaced many times during the desired lifetime of the solar power supply system, thereby making their actual cost excessive. A kinetic energy storage device used in conjunction with an electric generator can easily be designed to last the desired lifetime of the solar home system. To further reduce costs of such system, the present invention permits effective utilization

of low cost materials resulting in a flywheel having a fraction of the cost of a steel flywheel having comparable performance.

SUMMARY OF THE INVENTION

The invention provides high performance inertial energy storage devices wherein a central hub holds a multiplicity of essentially anisotropic filamentary elements in radiating or substantially radiating disposition to a hub. The filamentary elements are disposed within rod-like members which are preferably shaped such that they are thicker axially at their inner ends, and thicker peripherally at their outer ends, the degree of taper allowing the members to be contiguous or very nearly contiguous to each other along their lateral surfaces when disposed about the periphery of the hub, the members thereby effectively forming a solid disc. As is true with other rotary inertial energy storage devices, the rated performances of the present structures are directly proportional to the specific strength of the material used in the construction thereof. By utilizing the large specific strengths of filamentary materials, i.e., by aligning the individual filamentary elements within each rod-like member such that the elements are substantially parallel to the major stress component acting thereon, substantial energy density is obtained. The filamentary elements in each rod-like member may be substantially aligned along extended radii extending from the center of rotation of the structure. Alternatively, an effective, relatively less costly structure is obtained by forming the rod-like members from a material such as wood, wood products, or uniaxial fiberglass. All of the filamentary elements in the members are then not aligned radially from the center of rotation of the particular structure as will be further described hereinafter, but the elements will be substantially disposed in the direction of the major stress component acting thereon and, particularly in the case of wood, the transverse strength of the members is adequate to meet the transverse loading on the elements thereby caused.

Accordingly, it is an object of the invention to provide high power-density energy storage devices having a high energy density capabilities at relatively low costs.

It is a particular object of the invention to provide rotary energy storage structures formed of filamentary elements formed into rod-like members shaped to be thicker axially at the inner ends thereof and tapering such that the members are contiguous to each other along the lateral surfaces thereof, thereby effectively forming a solid disc.

A further object of the invention is to provide relatively inexpensive rotary energy storage structures formed of a grain-like substantially uniaxial material, such as wood or wood products, wherein the transverse strength of the material accommodates lateral stresses on the structures.

Additional objects, advantages, and uses of the invention will become apparent from the following detailed description of the preferred embodiments thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective of an optimized embodiment of the invention;

FIG. 2 is a section taken through line 2—2 of FIG. 1;

FIG. 3 is a top view of the FIG. 1 embodiment of the invention partially in section to illustrate the filament material comprising the spoke members;

FIG. 4 is a perspective of one of the tapered members of FIG. 1;

FIG. 5 is a planar view taken through a member such as is shown in FIG. 4 and illustrating the disposition of filamentary elements therein;

FIG. 6 is a planar section taken through a member such as is shown in FIG. 4 and illustrating an alternative disposition of filamentary elements therein;

FIG. 7 is a perspective of an untapered member formed of lamination;

FIG. 8 is a planar section partially shown of an embodiment of the invention wherein the members are held in sockets formed by flat, finger-like members which extend radially from a hub structure;

FIG. 9 is an elevational section of an alternate embodiment of the invention wherein the spoke members flare at their inner ends and are held in a mating device in a hub structure;

FIG. 10 is an elevational section of an alternate embodiment of the invention wherein the spoke members are formed with respective enlargements at their inner ends, the enlargements being held in a mating groove in a hub structure; and,

FIG. 11 is an elevational section of an alternate embodiment of the invention wherein the spoke members are formed with respective enlargements at their inner ends, the enlargements being held in a mating groove in a hub structure, the enlargements and the mating groove having mating notches providing force-resisting surfaces.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The performance, i.e., the stored kinetic energy of a rotating body, is directly proportional to the useable specific strength of the material used in the fabrication of the body. The several embodiments of the present invention are configured to take advantage of the high tensile strengths of essentially anisotropic filamentary materials and, particularly, composite, substantially uniaxial, filamentary materials such as wood and wood products. The strength characteristics of filamentary materials which are becoming increasingly more available are described by me inter alia in U.S. Pat. Nos. 3,672,241, 3,737,694 and 3,698,262. While the present invention finds use for the materials described in these patents, the preferred embodiments of the invention have the ability to make particularly effective use of a composite filamentary material such as wood. Accordingly, it is deemed desirable to provide herein a brief discussion of this particular material in order to illustrate the utility thereof for the present application, a utility doubtlessly unfamiliar to practitioners in the art despite the disclosure thereof by me and others in an energy storage device of different construction disclosed in U.S. Pat. No. 3,788,162.

The particular use of wood gives an energy storage capability to the present invention which favorably compares to presently available optimized steel flywheels but which compares favorably to the safety considerations inherent in filamentary flywheels such as are described in the patents identified above. A further significant feature of the invention is the sharply lower cost of the present structures when wood is em-

ployed as the composite filamentary structural material, the use of wood yielding high cost efficiencies relatable to other materials as energy stored per dollar. The use of bamboo in the present invention also yields substantially cost efficiencies.

The operating environment of the present invention is conducive to the use of wood as the composite filamentary structural material of which the invention may be formed. For example, operation of the invention will be nominally at room temperature and in a non-corrosive or contaminating environment (i.e., in a vacuum wherein significant quantities of oxygen or water vapor are also excluded). Since the embodiments of the present invention comprise structures wherein unsupported sections of rod-like members are substantially radially oriented from a center of rotation and are thus in pure tension during operation of the structure, the strong unidirectional strength characteristics of wood are particularly applicable to use in said structure. The present structures are also improved in certain embodiments thereof by a transverse load resisting capability of relatively low magnitude, a capability particularly found in wood. Further, the present structures do not require the structural material of use to have a high modulus of elasticity or light weight. In fact, for a given strength-to-density ratio. The use of relatively heavier materials minimized flywheel volume.

Despite the variability found in different species of wood or in different qualities due to growth defects in woods of the same species, the size and geometry of the rod-like members which may be formed of wood in the present invention allow degrading factors to be substantially eliminated. From an internal structural standpoint, wood is seen to be formed of elongated tubular elements known as cells which are essentially arranged in parallel relation to each other. The cells vary in dimension and wall thickness with their position in the tree, the age, conditions of growth, and species of tree from which a particular wood is taken. The walls of the cells are formed principally of chain molecules of cellulose, highly polymerized from glucose residues, and oriented as a partly crystalline material. These chains are aggregated in the cell wall at a variable angle, roughly parallel to the axis of the cell. The cells are cemented together by an amorphous material known as lignin. In general terms, wood is comprised of 60% cellulose, 28% lignin, and 12% sugar and extractive. Thus, the structural composite portion of the wood only accounts for about 88% of its weight. The specific gravities of these constituents is approximately 1.5 regardless of the species of the wood, thereby accounting for the fact that the ultimate strengths of various woods are similar when compared at equal densities. This property holds despite the wide variance found in the microstructural comparisons of the various species of wood. The microstructure of wood is similar to the highly oriented unidirectional "whisker" composite. The structural cells of wood, like many such whiskers, average about 0.04 mm in breadth and about 4.0 mm long. However, wood differs from anisotropic whisker composites in that the ratio of "transverse" strength to "parallel" strength can be as much as 30% for wood while usually being less than 10% for whisker composites. In the present structure, this transverse strength capability proves advantageous.

For the application to which the present invention is directed, the working strength of wood can realistically

be improved dramatically over those values relied upon for "typical" applications, such as house construction. For example, since wood members used in the present structures would seldom be greater than two feet in length, wood members without defects are easily identified and used. The environment in which the present structures operate, i.e., a vacuum, prevents the development of defects due to insects, fungi, oxygen degradation, and degeneration due to moisture. The high molecular weights of cellulose and lignin prevent sublimation of the wood in the vacuum environment. Time degradation, particularly in the absence of the factors noted above, is easily accepted if a realistic operating design level such as 50% of tensile strength, is provided.

The strength of wood is further improved by careful elimination of the moisture content of the wood. The moisture in green wood is held absorbed in part by the cell walls and in part within the cavities of the cells. As the wood is dried, the cells walls do not give off moisture until the adjacent cavities are empty. The condition in which the cell walls are fully saturated and the cell cavities are empty is known as the fiber saturation point. The moisture in the wood at this point is about 30% of the weight of the wood. At moisture contents higher than this point, the strength of the materials is not affected. At lower moisture contents, the strength of the wood increases substantially. Wood employed in most prior applications is dried to about 13% moisture by weight, which is the moisture level typically reached by the wood if "seasoned" in air. Taking the moisture of the wood to the level of the relatively moisture-free environment of the present invention requires either baking of the wood, subjection to a vacuum, or the use of moisture-absorbing volatile solvents. Maximum strength is obtained at zero moisture content.

It should also be stated here that the rod-like members to be described hereinafter may also be laminarily formed. Wood may be used in this manner as can other essentially anisotropic filamentary materials. By removing relatively thin layers of wood from the raw material, inspection for defects can be carefully made and drying of the thin laminae more readily accomplished. Compression of these treated laminae in a well-known fashion to form a unitary structure result in substantially increases in strength, even at the relatively low compression forces employed in lamination of plywood products commonly available. The use of relatively higher pressures in the lamination process produces even greater strengths. Further, laminae thinner than the 1/48 inch thicknesses normally employed for plywood fabrication can also be employed to advantage. Compression of such laminae increases the density of the product as well as the strength. However, since the strength increases more rapidly than does the density, there is also a slight net increase in the strength-to-density ratio. This density increase is desirable when wood is used as the structural material since the total weight of the flywheel structure is then contained within a smaller volume. Thus, even though the energy content of wood can be made comparable to steel in terms of watt-hours/pound, more volume is required to accommodate a pound of wood than a pound of steel, even when the wood is laminated as described. However, the total volume of a steel flywheel system as opposed to that of a wood flywheel system is not directly proportional to the densities of the flywheel structural

material alone, due to the necessity in the steel flywheel system for other components, such as failure containment structures which are of equal or larger volumes than the volume of a wood flywheel. The safety and cost advantages of the present structures, particularly with wood or bamboo as the structural material, far exceed those of a comparable steel flywheel. The use of higher strength anisotropic filamentary materials, such as Kevlar, a well-known DuPont fiber, also yields substantial performance advantages to the present structures from the standpoint of energy and power density.

An additional factor to be considered in the formation of the present structure from laminated materials is the possibility of increasing strength the transverse direction, i.e., against the "grain" in the case of wood, to increase strength in that direction. For example, one ply in ten could be turned transversely to the direction of the majority of the plies to lend increased transverse strength. Laminate strength is also affected by the strength of the adhesive used and the amount thereof and method of its application. Adhesives previously employed in the production of plywood are actually of inferior strength when compared to presently available adhesives. Wood-based materials, such as wood impregnated with thermosetting resins with or without compression of the wood, may also be employed as a structural material in the present invention. Wood compressed by processes which cause the lignin to flow between the fibers to eliminate internal stresses is also useful, as well as products comprised of multiple sheets of resin-impregnated paper laminated together under high pressure, which material is substantially anisotropic in nature.

Bamboo, though taxonomically classified as a grass, exhibits anisotropic characteristics which qualify it for use as a structural material in the present structures and for kinetic energy storage in general. According to presently known data, bamboo appears to be capable of at least a useable energy of approximately 19 watt-hrs/pound compared to 8 watt-hrs/ pound from most wood materials.

A first embodiment of the present invention is seen in FIGS. 1, 2, and 3 to comprise a disc-like rotor 10 formed of rod-like spoke members 12 as disposed about the periphery of hub 14. The hub 14 comprises clamping shells 16 and 18 which can be held on rotary shaft 20 by hub fasteners 22 or by other fastening means. The shells 16 and 18 clamp the spoke members 12 together to form a solid dish structure, the members 12 being further attached by adhesive or other fastening means to an internal annular hub 24 held between the shells 16 and 18. The shaft 20 may extend through centrally disposed annular bores in the internal hub 24, the shells 16 and 18, and the fasteners 22 as shown, or may be comprised of two portions which terminate on either side of the rotor 10.

The rod-like spoke members 12 may be formed as shown in FIGS. 1 through 4, FIG. 4 most clearly illustrating the preferred shape of the members 12. The spoke members 12 are comprised of substantially anisotropic filamentary elements 13 such as have been described in detail hereinafter. The members 12 may be formed of wood stock wherein the filamentary elements, or grain, of the wood extends substantially radially of the rotor 10 from the axis of rotation thereof taken longitudinally through the shaft 20. When viewing the member 12 alone as in FIG. 4, the filamentary

elements 13 are seen to be disposed in substantially parallel alignment from an inner end 15 thereof to an outer end 17 thereof, as seen in FIG. 5. The material used to form the member 12 may be any composite filamentary material such as fiberglass, wood, etc. such as is described hereinabove. The filamentary elements 13 at the outer edges of the outer end 17 do not lie exactly along a radius drawn from the axis of rotation, but, due to the transverse strength of a material such as wood or due to the provision of transverse strength in the material used such as by transverse disposition of filaments therein as described hereinabove, the transverse loading on these filamentary elements 13 is accommodated. The members 12 are seen to be substantially "pie-shaped" when viewed from a plan orientation, the members 12 being relatively narrow at their inner ends 15 and fanning out to relatively wide at their outer ends 17. The inner ends 15 are arcuately contoured at 19 to mate with the periphery of the internal hub 24. The outer ends 17 also are arcuately contoured to each contribute to the formation of a smooth circular perimetric contour, thus the side edges of the spoke members 12 fit together to form a solid disc in much the same manner as pieces of pie form a well-known dessert.

When the spoked members 12 are viewed from an elevation orientation, such as can best be seen in FIG. 2, the inner ends 15 of the members are seen to be thicker than are the outer ends 17, thereby giving the rotor 10 a tapered disc shape. As can be seen inter alia in FIG. 7, a spoked member 30 can be the same thickness at its inner end 31 as at its outer end 33, thereby forming a rotor of substantially right circular cylindrical proportions when viewed from an elevation orientation. The member 30 is seen to be comprised of lamina 32 built up in a substantially planar fashion according to well-known techniques. The elements 13 is each lamina 32 are disposed therein as seen in either FIG. 5 or FIG. 6. The member 12 could alternatively be formed of laminations such as 32.

FIG. 6 is a section taken through a spoke member 40 comprised of filamentary elements 13 which are disposed in a substantially non-parallel relation within the member 40, but which, when the members 40 are disposed within a rotor such as 10 in FIG. 1, substantially lie along radii emanating from the axis of rotation of the rotor in the plane of the elements 13. The member 40 is shown to be thicker axially near the hub than at the fanned, relatively flattened tip or outer end thereof. Alternatively, the member 40 could be shaped in the manner of the member 30 shown in FIG. 7.

The particular structures shown in FIGS. 1 through 7 and described herein are particularly suited to the use of wood as the filamentary material forming the elements 13 and thus the spoke members 12, 30, and even 40. The load which must be carried by the hub 14 is approximately four times less when wood is employed due to the ratio of its strength to that of typical "modern" anisotropic filaments referred to hereinabove. Thus, bonding of the spoke members 12 to the shells 16 and 18 and to the internal hub 24 is facilitated due to the more modest loading.

The spoke members 12 best seen in FIGS. 1, 3, and 5 are seen to have outer ends 17 which are arcuate in conformation and subtends angles of approximately 10° taking the vertex of said angles at the axis of rotation of the rotor 10. It should be understood that this angle is merely illustrative, it being possible to form the

rotor 10 from any desired number of spoke members 12 in the same fashion that it is possible to divide a circle into any desired number of pie-shaped sectors. From a practical standpoint the number of spoke members 12 would typically be more than 3 and not over 72.

The spoke members 12 may be held by means other than the hub 14 in other embodiments of the invention. Referring particularly to FIG. 8, spoke members 12 are seen to be held about a shaft 50 by an annular hub 52 having radially extending fingers 54 disposed circumferentially therearound. Adjacent fingers 54 form sockets into which one each of the spoke members 12 may be disposed, the side surfaces of the fingers 54 providing plane flat areas which are bondable to the innermost side surfaces of the spoke members 12.

FIG. 9 shows spoke members 60 which flare at their inner ends to provide flanged insets 62, the insets 62 fitting into an annular groove 64 disposed circumferentially around a hub 66. Opposing sides 68 of the annular groove 64 are beveled to provide contact surfaces against which the flanged insets 62 on the members 60 may bear on rotation of the flywheel structure. The hub 66 is further fitted onto a shaft 70 and may be held thereon by hub fasteners 72.

FIG. 10 shows spoke members 74 having inner ends 76 enlarged in the form of a rectangular solid, the ends 76 fitting into an annular chamber 78 formed in a hub 80. The chamber 78 is essentially rectangular in cross-section and holds the ends 76 snugly therein. The hub 80 is further fitted onto a shaft 82 and may be held thereon by hub fasteners 84.

FIG. 11 shows a further embodiment of the invention to comprise spoke members 86 having enlarged inner ends 88 similar to those of FIG. 10. However, the ends 88 are formed with notches 90 which mate with notches 92 in an annular chamber 94 in hub 96. The notches 90 and 92 are directed toward the center of the flywheel structure in order to provide contact surfaces resisting the outward force exerted on the spoke members 86 by virtue of rotation of the flywheel. The hub 96 is further fitted on a shaft 98 and may be held thereon by hub fasteners 100.

The invention may be practiced in fashions other than that specifically outlined herein without departing from the invention as defined by the following claims.

What is claimed is:

1. An energy storage structure rotatable about an axis of rotation extending transversely therethrough, the structure comprising a plurality of anisotropic filamentary elements,

a multiplicity of the elements being bonded together into individual spoke-like members which are arranged into a disc-like configuration, inner ends of the members being thicker axially than the outer ends of the members and outer ends of the members being thicker peripherally than the inner ends of the members; and,

hub means holding the spoke-like members, the members extending radially from the hub means about the periphery thereof.

2. The energy storage structure of claim 1 wherein the spoke-like members are formed of wood, at least the centrally disposed filamentary grain of the wood in each member extending radially from the axis of rotation of the structure.

3. The energy storage structure of claim 2 wherein the filamentary elements of the wood extend essentially radially from the axis of rotation of the structure.

4. The energy storage structure of claim 1 wherein the filamentary elements in each spoke-like member are parallel to each other and are parallel to the longitudinal axis of the member.

5. The energy storage structure of claim 1 wherein the filamentary elements in each spoke-like member extend essentially radially from the axis of rotation of the structure.

6. The energy storage structure of claim 1 wherein the filamentary elements are laminated together to form the spoke-like members.

7. The energy storage structure of claim 1 wherein the hub means comprise: finger-like projections extending radially from the axis of rotation of the structure, adjacent projec-

tions forming sockets into which the inner ends of individual spoke-like members are held.

8. The energy storage structure of claim 1 wherein each spoke-like member flares at its inner end to form a flanged inset, and wherein the hub means comprises an annular groove into which the flanged inset of each of the members fits.

9. The energy storage structure of claim 1 wherein each spoke-like member is formed with an enlargement at its inner end, and wherein the hub means comprises an annular groove into which the enlargement of each of the members fits.

10. The energy storage structure of claim 9 wherein the enlargement of each of the members and the annular groove are formed with opposed notches, the notches mating to further hold the enlargements within the annular groove.

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