United States Patent

[11] 3,589,835

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[21] Appl. No. 842,487
[22] Filed July 17, 1969
[45] Patented June 29, 1971
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[54] **VARIABLE STIFFNESS ROTOR**
23 Claims, 15 Drawing Figs.

[52] U.S. Cl. 416/103, 416/138, 416/140, 416/141, 416/149
[51] Int. Cl. B64c 27/48
[50] Field of Search 416/103, 135, 138, 141, 148, 149

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ABSTRACT: A multibladed rotor having the blades connected to the hub by a hinge mechanism and having a variable stiffness spring extending between the hub and the blade across the hinge mechanism to vary the stiffness of the connection between the blade and the hub.

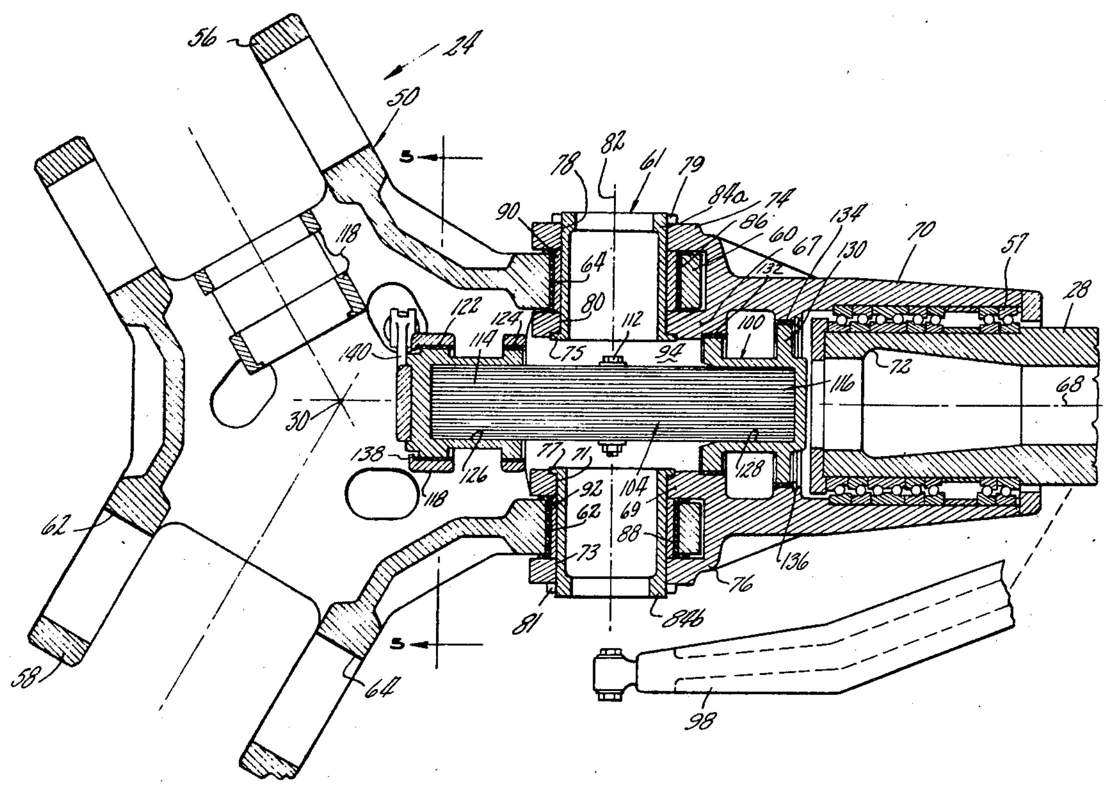


FIG_1

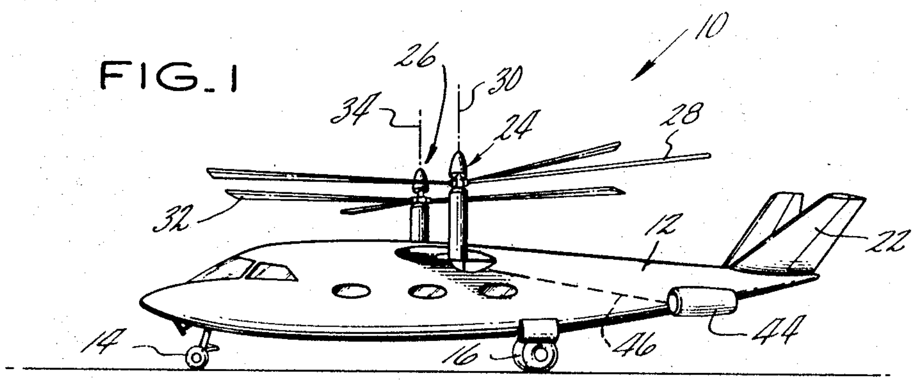
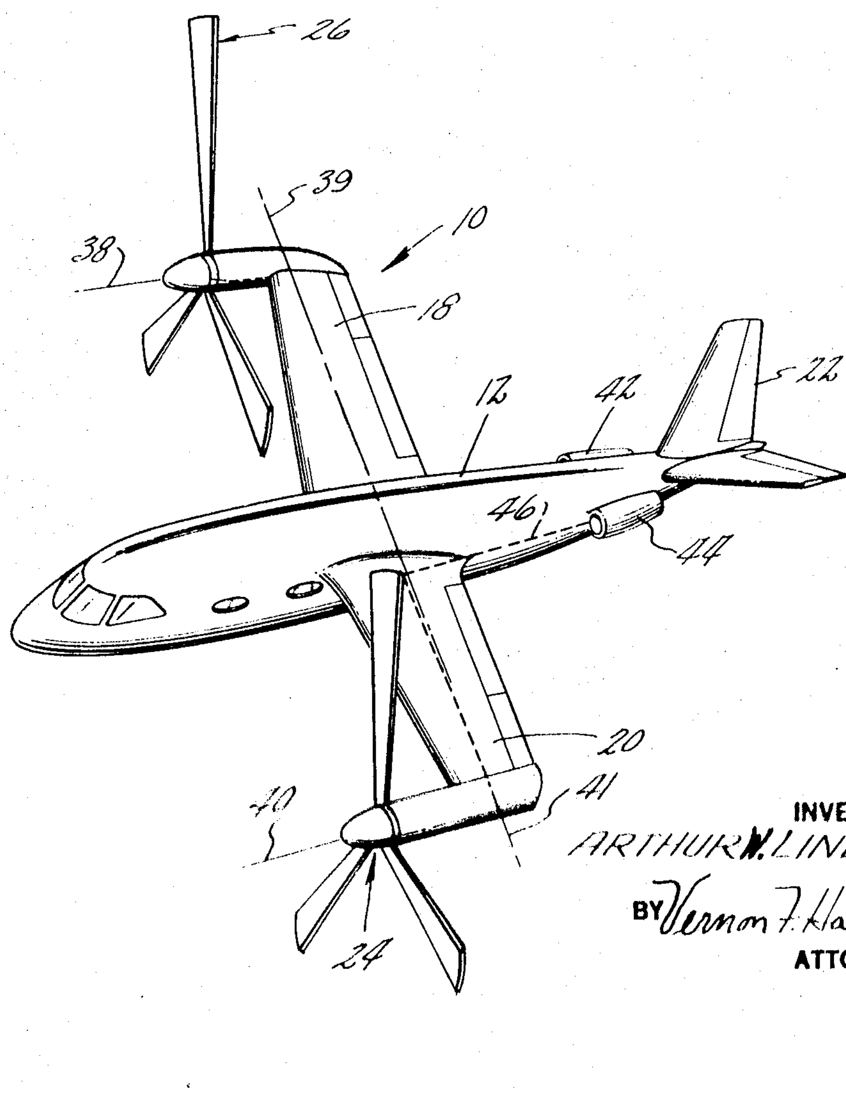


FIG_2



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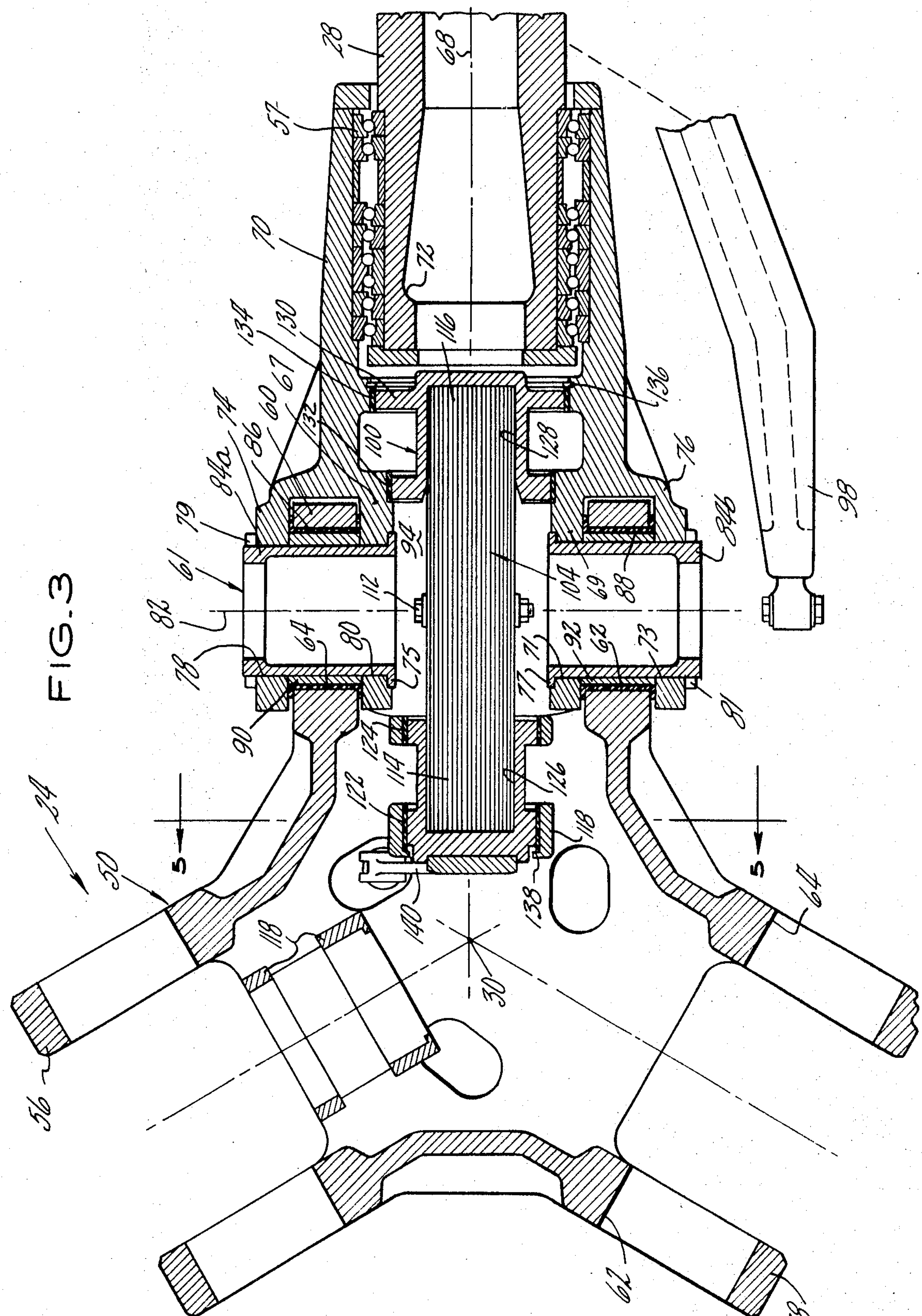


FIG. 3

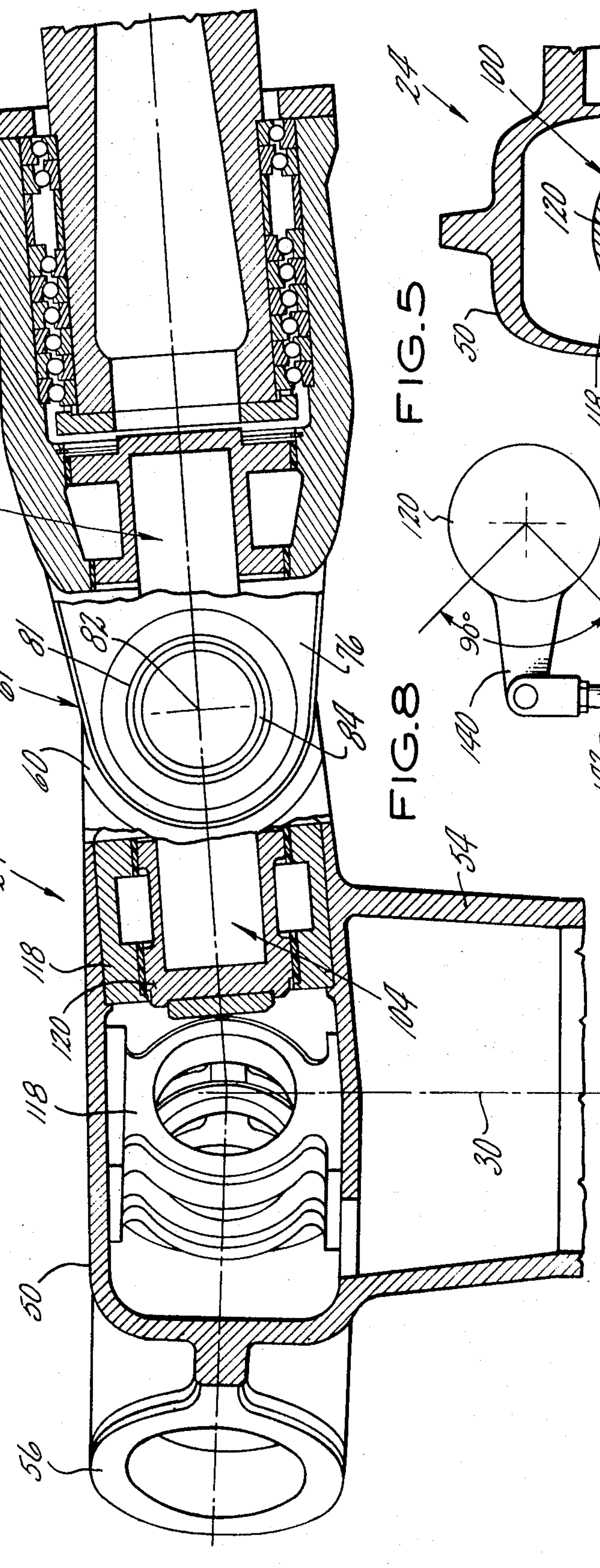


FIG. 4

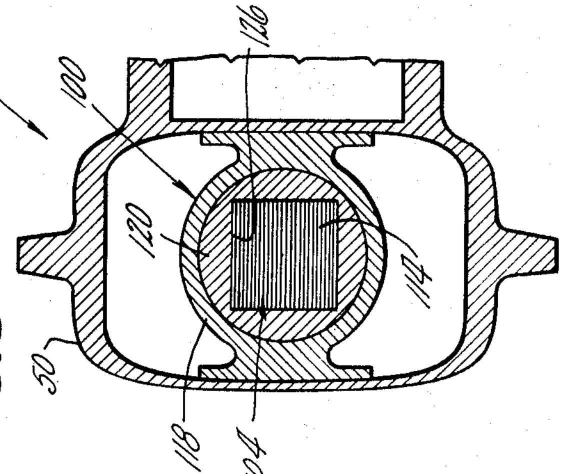


FIG. 5

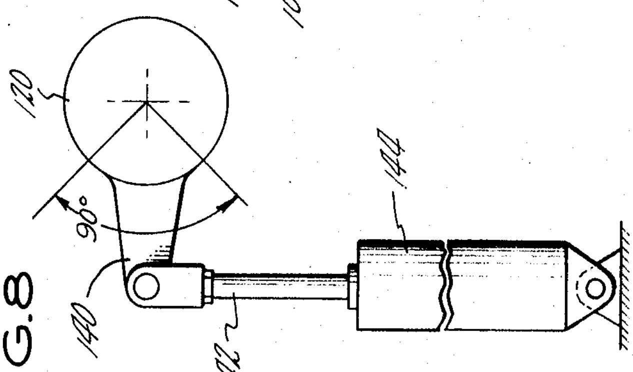


FIG. 8

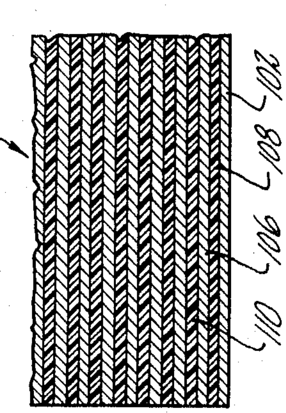


FIG. 6

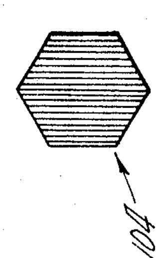


FIG. 7

FIG.9

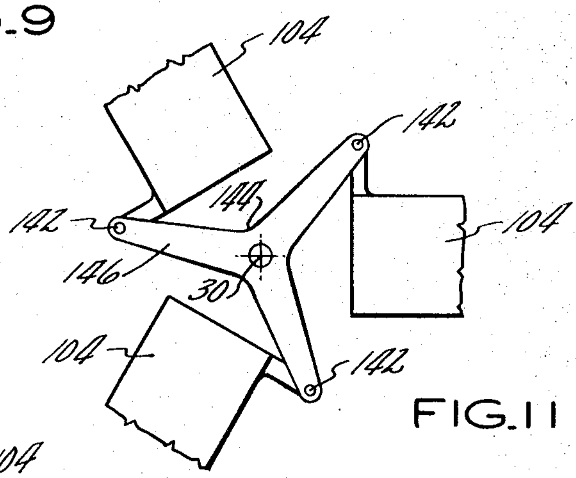


FIG.10

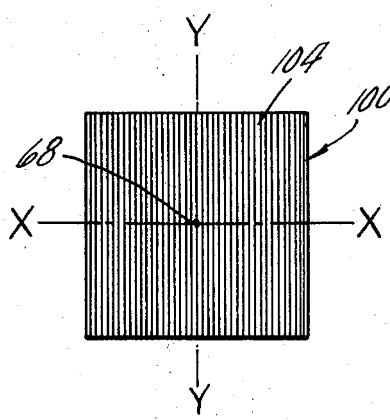


FIG.12

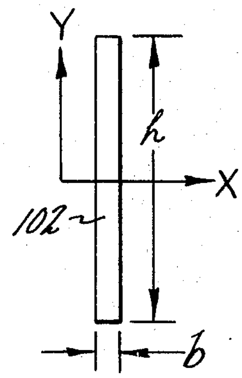


FIG.11

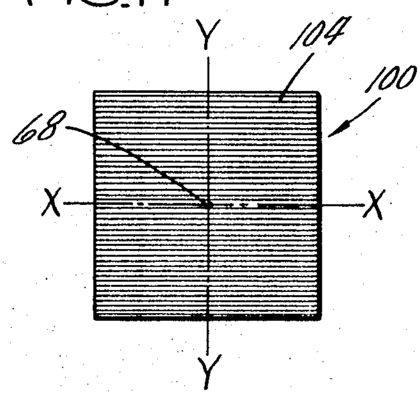


FIG.13

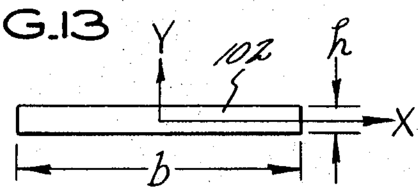


FIG.14

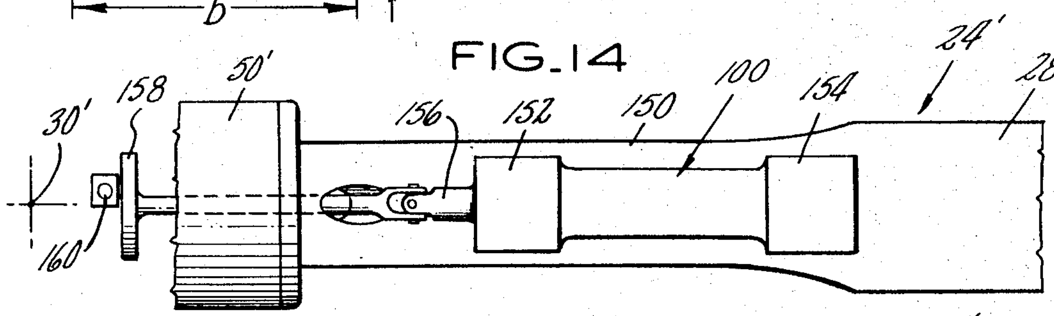
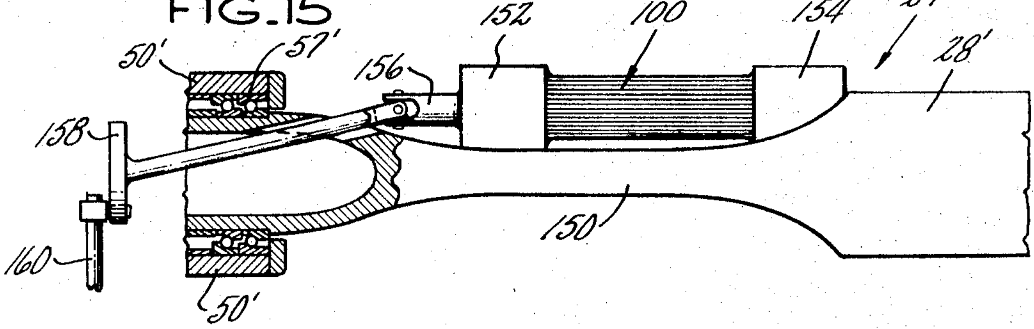


FIG.15



VARIABLE STIFFNESS ROTOR

BACKGROUND OF THE INVENTION

1. Field of Invention

This invention relates to rotors wherein the rotor blades are connected to the rotor hub through a hinge or other type of pivot connection and wherein a variable stiffness spring extends between the hub and the blades to be actuatable between a first position wherein the rotor has the characteristics of a rigid rotor and a second position wherein the rotor has the characteristics of a nonrigid rotor, that is a flapping, articulated or flexing rotor and intermediate rotor stiffness positions therebetween.

2. Description of the Prior Art

In the rotor prior art, rotors have been conventionally fabricated so as to be articulated as shown in U.S. Pat. Nos. 2,815,821 and 2,418,030 or to be rigid as shown in U.S. Pat. Nos. 3,106,964 and 2,653,670. While certain rotor constructions use spring members to connect the blade to the hub to thereby form a flexing rotor, such as in U.S. Pat. No. 2,949,967, these rotors are otherwise conventional articulated rotors and the springs are of constant as opposed to variable stiffness.

In the past, rotors were designed to be either rigid or articulated depending upon which type of rotor best suited most performance regimes of the aircraft and it was understood that compromise performance would be encountered in the regimes where the rotor design selected is inferior.

Experience has shown that in many fields there are requirements for stiff rotors and for highly flexible rotors and a given rotor will provide better performance if operating as a rigid rotor during certain operating regimes and as a flexible or articulated rotor during other operating regimes. It is therefore desirable to have a rotor which can operate both as a highly stiff rotor and as a highly flexible rotor.

For example, in convertiplanes which include rotors which tilt between helicopter positions and propeller positions, a flexible or articulated rotor is desirable in the helicopter mode and during the transition to the propeller mode to reduce blade root moments developed during transient maneuvers and different loading conditions. However, in the propeller mode the airflow is axial and a rigid rotor design is more desirable.

In addition, in helicopter rotors per se, there are particular flight regimes in which rigid rotors are considered to be superior to articulated rotors and vice versa. For example, a rigid rotor can develop control moments without the large angles of tilt of the tip path plane required by an articulated rotor. This effects the rotor fuselage clearance required in the aircraft design. In a compound type of vehicle, the rigid rotor can provide aircraft control moments even though it supports only a minimum percentage of the aircraft gross weight. This is unlike an articulated rotor which requires lift on the rotor to develop control moments.

Still considering a helicopter rotor per se, an articulated rotor is deemed to be superior to a rigid rotor during forward flight where the blade flapping is used to relieve blade root moments.

In other rotors, such as fluid pumps, turbine and compressor rotors and so forth, a requirement for rigid rotor and flexible rotor operation may exist at different times during the operation of a single rotor and the teachings of this invention would be equally applicable thereto.

SUMMARY OF INVENTION

A primary object of the present invention is to provide a bladed rotor of variable stiffness.

In accordance with the present invention, a rotor which has blades pivotally or otherwise connected to the hub in articulated form, includes a variable stiffness spring extending between the blades and the hub across the connection and the spring is adjustable to vary the stiffness of the spring and hence the rotor.

In accordance with the present invention, the variable stiffness spring is formed by stacking a plurality of laminates, such as spring steel, and positioning the laminate stack in a first position wherein they present maximum stiffness to bending and a second position wherein they present minimum stiffness to bending and intermediate positions therebetween for intermediate degrees of stiffness. By proper selection of the number and characteristics of the laminates, the stiffness ratio of the spring between its first and second positions can be accurately controlled.

In accordance with a further aspect of the present invention, the cross-sectional shape of the laminate pack or stack can be of any desired shape such as square, rectangular in any direction, octangular, oval and circular and the cross-sectional shape can be chosen, without compromising the spring characteristics, to accommodate environmental physical constraint problems such as a clearance problem, or to accommodate a physical strength problem in a mating or coacting part, and for other reasons which will be obvious to those having skill in the art.

The invention provides stiffness control of the rotor so that rotor stiffness can be varied to alleviate problems which are encountered during rotor operation, for example, if the rotor is being operated as a highly stiff or rigid rotor and develops resonance problems, spring flexibility and hence rotor flexibility can be changed to alleviate the resonance problem. By way of further example, if the rotor is a helicopter rotor operating as a soft or articulated rotor during hover operation and aircraft control problems are encountered, the spring stiffness and hence the rotor stiffness can be increased to improve aircraft control.

In accordance with a further feature of this invention, layers of low-friction material, such as Teflon, are positioned between adjacent laminates of the laminate or spring pack.

In accordance with a further feature of this invention, the stiffness of all the blades of a rotor is varied simultaneously and to the same degree or the blade stiffness may be varied individually to any desired degree.

In accordance with another feature of this invention, the various laminates of the laminate pack or spring pack are connected at substantially their midpoint by any convenient mechanism.

In accordance with another feature of this invention, the variable stiffness spring could be used in a rotor under design and development to determine optimum stiffness thereof for utilization in final rotor design.

Still another feature of the present invention is that the rotor stiffness can be varied in flight.

Still another feature of the present invention is that it can be used to restrain blade flapping and droop.

In accordance with still a further aspect of the invention, the variable stiffness spring is mounted so as to be free of blade centrifugal loading.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side view of a modern convertiplane shown in the helicopter mode of operation utilizing the invention.

FIG. 2 is a showing of the FIG. 1 convertiplane in flight in the propeller mode of operation.

FIG. 3 is a partial showing of the top view of a rotor, partially in cross section, utilizing the variable stiffness spring across the flapping hinge of an articulated rotor.

FIG. 4 is a side view of the rotor shown in FIG. 3, partially broken away and in cross section for purposes of better illustration.

FIG. 5 is a cross-sectional view taken along line 5–5 of FIG. 3.

FIG. 6 is a partial showing of a spring or laminate pack to illustrate the construction thereof.

FIG. 7 is a cross-sectional showing of a spring pack of modified cross-sectional shape.

FIG. 8 is a side view of an actuator connected to the variable stiffness spring to actuate a single spring between positions which are substantially 90° apart.

FIG. 9 is a showing of a control mechanism for varying the position of a plurality of spring packs simultaneously and to the same positions and degree of stiffness.

FIG. 10 is a cross-sectional showing of a spring pack in its maximum stiffness position.

FIG. 11 is a showing of a spring pack in its minimum stiffness position.

FIG. 12 is a cross-sectional of a single laminate from the FIG. 10 spring pack in its maximum stiffness position.

FIG. 13 is a cross-sectional of a single laminate of the FIG. 11 spring pack in its minimum stiffness position.

FIG. 14 is a partial top view of the variable stiffness spring used in a semirigid rotor.

FIG. 15 is a side view of the variable stiffness spring of FIG. 14.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. 1 and 2, we see modern convertiplane **10** which includes fuselage **12** which is supported from the runway by landing gear **14** and **16**, which may be of the tricycle type. Wings **18** and **20** project laterally from the opposite sides of fuselage **12** and tail section **22** is positioned at the after end of the fuselage. Tiltable rotors **24** and **26** are positioned at the tips of wings **18** and **20** and are shown positioned in FIG. **1**, in the helicopter mode of operation, where in rotor **24** and blades **28** thereof rotate about axis of rotation **30** and rotor **26** and blades **32** thereof rotate about axis of rotation **34**. Rotors **24** and **26** may be pivoted or tilted about axes **39** and **41** between their FIG. **1** positions and their FIG. **2** propeller mode of operation positions, wherein rotor **26** pivots about axis of rotation **38** and rotor **24** pivots about axis of rotation **40**. Rotors **24** and **26** are driven by one or more engines **42** and **44** which are connected thereto in any convenient fashion by conventional drive mechanism **46**.

Engines **42** and **44** may be of the type more fully described in U. S. Pat. Nos. 2,711,631 and2,747,367, and rotors **24** and **26** may be of the type more fully described in U.S. Pats. Nos. 2,984,306 and 3,080,927.

It should be borne in mind that while our invention is being disclosed in the environment of a tiltable rotor which is used both as a helicopter rotor and as an aircraft propeller, it could as well be used on a helicopter rotor only or on a propeller rotor only, or by any rotor in which blades are flexible with respect to the hub. The tilt-rotor convertiplane **10** is used to illustrate an environment of our invention because a rotor of minimum stiffness is desired in the helicopter mode of operation and a rotor of maximum stiffness is desired in the propeller mode of operation.

Now referring to FIGS. 3—5, we see the invention in greater particularity and it should be borne in mind that rotor **26** is preferably identical with rotor **24** shown. Rotor **24** consists of rotor hub **50** which is mounted in conventional fashion for rotation about rotor axis of rotation **30** from rotor drive shaft **54** which projects from and is supported by fuselage **12**. Rotor **24** has a plurality of equally spaced projecting units **56**, **58**, and **60** projecting therefrom and with each including spaced aligned apertures, such as **62** and **64** therein.

A plurality of blades **28** project from hub **50** and are mounted for rotation therewith about axis **30** and for pitch change motion with respect thereto about feathering axis **68** by the action of blade-cuff **70** which envelops and supports blade root end **72** through feathering or stack bearings **57**. The other end of cuff **70** includes spaced face members **74**, **67**, **76**, and **69** which have aligned apertures **78**, **80**, **73**, and **71** therein, and which are in alignment with and concentric with corresponding aligned apertures **62** and **64** of projections **60** about blade flapping axis **82**. Flapping hinge **61** pivotably connects blade-cuff **28**, **70** to hub **50**. Flapping hinge cylinder **84** extends through aligned apertures **62**, **64**, **71**, **73**, **78**, and **80** so as to pivotally connect cuff **70** and blade **28** to blade hub **50** about flapping axis **82**. Preferably, bearings of any convenient type, such as dry bearings of the carbon ceramic of Teflon type **86** and **88** are positioned between apertures **62** and **64** and bushing **90** and **92**, which surrounds flapping hinge cylinder **84**. It will be noted that hinge cylinder **84** is separated into two spaced parts **84*a*** and **84*b*** which are located in spaced relation about and along flapping axis **82** to leave aperture **94** therebetween. Flapping hinge sleeve **84*a*** and **84*b*** are retained in position by the coaction of flange ends **75** and **77** coacting with end nuts **79** and **81**.

It will be seen that with this construction, centrifugal loading of blade **28** will be passed through stack bearing **57** to blade-cuff **70** and then through flapping hinge **61** to rotor hub **50**. In conventional fashion, blade pitch horn **98** connects to blade **28** and is caused to be actuated by a swashplate (not shown) so as to cause blade **28** to pivot about feathering axis **68** with respect to cuff **70** and hub **50**, thereby varying blade pitch either collectively or cyclically or both. It should be borne in mind that while in the construction shown in FIGS. 3 and 4, cuff **70** serves to connect blade root **72** to hub **50**, the connection could be made direct therebetween through flapping hinge **61** if blade pitch variation were not desired and could also be made directly between blade **66** and hub **50** as in FIG. 14. Blade-cuff **70** should be considered a part of blade **28**, however, except for purposes of blade pitch variation.

The construction shown in FIGS. 3 and 4 is an articulated rotor with the blade and cuff unit **66**—**70** free to pivot or articulate with respect to hub **50** through flapping hinge **61**. If a soft spring were caused to extend between hub **50** and blade-cuff unit **28**, **70** the flapping action would be virtually unimpeded and articulated rotor performance would continue to be achieved. If, however, a stiff spring were positioned between hub **50** and blade-cuff unit **28**, **70** there would be very severe resistance to flapping motion and therefore rotor **24** would operate as a rigid rotor. It is accordingly the purpose of this invention to place a variable stiffness spring **100** between hub **50** and blade-cuff unit **28**, **70** and that construction will now be described.

The variable stiffness spring **100** comprises a plurality of metal or other material laminates or sheets, such as **102**, stacked in side-by-side relation to form spring or laminate pack **104**. As best shown in FIG. **6**, spring pack **104** preferably includes a stack-up of layers, sheets or laminates of metal, such as **102** and **106**, with layers **108** and **110** of low-friction material, such as Teflon, sandwiched therebetween. Preferably, but not necessarily, a connecting mechanism such as bolt and nut unit **112** extends through a slot in all of the layers of spring pack **104** for support purposes. It is essential to the operation of variable stiffness spring **100** that the various laminates at the opposite ends **114** and **116** of spring pack **104** be free to translate or move longitudinally with respect to one another, that is, to move with respect to one another substantially in the direction of feathering axis **68**. It is also important that the various laminates at the opposite ends **114** and **116** of spring pack **104** be restrained substantially from moving with respect to one another laterally, that is, in a direction perpendicular to feathering axis **68** and flapping axis **82** when the laminates are in their FIG. 3 stiff spring position. To permit translation of the ends of the various laminates at end **114** of spring **100**, stationary cylindrical member **118** is supported in and may be a part of hub **50** or may be separate therefrom but connected thereto in conventional fashion. Member **118** is shaped to receive inner cylindrical member **120** therewithin so as to permit rotary motion of member **120** within member **118** concentrically about flapping axis **68**.

Conventional dry bearings **122** and **124** are preferably positioned between fixed cylinder **118** and rotatable cylinder **120**. As best shown in FIG. **5**, rotatable cylinder **120** has rectangular aperture **126** therein of selected shape to receive end **114** of spring pack **104** therein with sufficient looseness to permit longitudinal movement (in and out of plane of paper in FIG. 5) between adjacent laminates yet restrain lateral movement (left and right in FIG. 5 therebetween. It should be borne in mind that while spring pack **104** is illustrated in FIGS. 3—5 to be substantially square in cross section, the spring pack could be of any selected shape in cross section such as square, rectangular with its major axis in any selected direction, oval, circular or, as best shown in FIG. 7, of a polygon shape. The opposite end **116** of spring pack **104** is received in a correspondingly shaped aperture **128** of rotatable ring member **130**, which is supported for rotation within cuff **70** and preferably has dry ring bearings **132** and **134** between the mating OD flanges of cylindrical member **130** and the ID, female flanges of cuff **70**. Cylindrical member **130** is prevented from translating toward blade **28** by a conventional snap ring **136** (see FIG. 3) and is prevented from translating toward axis of rotation **30** by lip **138** of fixed cylindrical member **118**. It will accordingly be seen that spring pack **104** is positioned so as to extend through flapping axis **82** and with its opposite ends supported in hub **50** and blade-cuff **28**, **70** so as to form a spring member therebetween when blade-cuff **28**, **70** attempts to articulate or pivot about flapping axis **82**.

As best shown in FIGS. **3** and **8**, rotatable cylindrical member **120** has horn or crank member **140** extending laterally therefrom and may be actuated in any conventional fashion to rotate through 90° so as to cause spring pack **104** to move from its FIG. **3—5** stiff spring position to a position 90° therefrom, which will be the soft spring or articulated rotor position. One such actuating mechanism is shown in FIG. **8** wherein connecting rod **142** pivotally connects to crank **140** and is caused to actuate at pilot command by hydraulic piston-cylinder arrangement or electric motor **144**.

In many installations it will be desirable to cause the stiffness of each of the blades to be equal and to vary the same amount and accordingly, as best shown in FIG. **9**, it may be desirable to connect the various spring packs **104** through their individual links **142** to star or plate member **146**, which is in turn caused to translate along axis **30** by one or more prime movers, such as electric motor or hydraulic piston-cylinder **144**.

While variable stiffness spring **104** is shown in FIGS. **3—5** to extend substantially equal distances on opposite sides of flapping hinge **82** and feathering hinge **68** and to have its major axis perpendicular to the former and parallel to the latter, this positioning of the spring **100** is not essential.

To explain the operation of variable stiffness spring **100**, reference will now be made to FIGS. **10—13**. FIGS. **10** and **12** show spring pack **104** and an individual laminate **102** thereof in their maximum stiff spring or rigid rotor position. FIGS. **11** and **13** show spring pack **104** and individual laminate **102** thereof in their minimum stiffness or articulated rotor position, 90° from the FIG. **10—12** position.

It can be shown mathematically that the moment of inertia I of a rectangular laminate can be represented by the following equation:

$$\text{Equation 1} \qquad I=1/12\, bh^3$$

where I is the moment of inertia of the laminate, b is the width of the laminate and h is the height of the laminate.

By viewing FIGS. **12** and **13**, it will be noted that the base of the laminate b in the FIG. **12** construction is very small while the height h of the laminate therein is very large and therefore its moment of inertia I_x will be large. It will also be noted that in FIG. **13**, the base of the laminate b is very large while the height h thereof is very small so that its moment of inertia I_x is comparatively small. In practice, a spring pack consisting of 88 laminates of spring steel .040 inch thick and approximately 4 inches wide produces a variable stiffness spring whereon the spring in its stiff FIG. **10** and **12** positions has a moment of inertia I_x equal to 19.6 in.^{4} and wherein the moment of inertia I_x when in the FIG. **11** and **13** position equals 0.00191 in.^{4}. Accordingly, the ratio of moments of inertia for spring pack **104** when in its FIG. **10** and **12** stiff spring or rigid rotor position compared to its FIG. **11** and **13** soft spring or flexible rotor position is 10,300 to 1. In other words, spring pack **104** is 10,300 times as stiff in its FIG. **10** position than when in its FIG. **11** position, when the spring pack is fabricated as stated above. Accordingly, a bending force which establishes a 1 inch deflection in spring **104** in the FIG. **11** position, will establish a 0.0001 inch deflection in spring **104** in the FIG. **10** position.

As spring pack **104** is rotated to intermediate positions between its FIG. **10** and FIG. **11** end positions, the stiffness of the spring varies with each such position so that spring **100** is actually a variable stiffness spring which can be varied in stiffness not only to its FIG. **10** maximum stiffness position and to its FIG. **11** minimum stiffness position, but also to intermediate stiffnesses of the positions therebetween.

It will be evident to those skilled in the art that this variable stiffness spring can be utilized to produce a rotor which is articulated when the spring is in its soft spring or minimum stiffness position and to produce a rotor which is rigid when the spring is in its hard spring or maximum stiffness position and that the pilot accordingly is free to choose between rigid rotor operation and articulated rotor operation during the modes of operation when each has its particular advantage. In addition, this variable stiffness spring could be used to soften the stiffness of an otherwise rigid acting rotor should such "rigid rotor" get into resonant vibration. In addition, such a variable stiffness spring could be used as a test or calibration device during the initial testing of a rotor in its development stage so as to determine therefrom the stiffness of rotor required for optimum rotor performance.

While the rotor illustrated herein is an articulated rotor with provisions for articulated motion about a flapping hinge, it should be borne in mind that the invention could as well be used with an articulated rotor having a lead-lag hinge only or with a rotor having both a lead-lag and a flapping hinge with a variable stiffness spring being used with each hinge.

In addition, such springs could as well be positioned within rotors which have no hinges but which are designed to have inherent flexibility and would serve to vary the stiffness thereof as well.

Viewing FIGS. **14** and **15** we see variable stiffness spring **100** used in semirigid rotor **24′** which includes hub **50′** mounted for rotation about axis of rotation **30′** and having a plurality of blades **28′** projecting from hub **50′** for rotation therewith and supported therefrom through stack bearings **57′** to permit pitch change motion therebetween, if desired, and including flexible section **150** about which blade **28′** bends with respect to hub **50′**. In such a construction, variable stiffness spring **100**, which is of the same construction as shown in FIGS. **2—5**, is supported above blade **28′** by bearing members **152** and **154** to be pilot actuated through link **156** to ring **158** and which is caused to rotate by the pilot through the actuation of pilot operated link **160**. It will be obvious to those skilled in the art that spring member **100** in the FIGS. **14** and **15** construction could as well have extended between hub **50** and station **154** of blade **28′**.

I wish it to be understood that I do not desire to be limited to the exact details of construction shown and described, for obvious modifications will occur to a person skilled in the art.

I claim:

1. A rotor having:

a. a hub mounted for rotation about an axis of rotation,

b. a plurality of blades projecting from said hub for rotation therewith,

c. a hinge member connecting each of said blades to said hub so that said blade is capable of articulating motion thereabout with respect to said hub,

d. a variable stiffness spring mounted so as to be free of blade centrifugal loading and extending between said hub and said blade and extending across said hinge member.

2. Apparatus according to claim **1** wherein said variable stiffness spring includes a plurality of laminates of selected dimension and positioned in stacked relation to form a spring pack and with the ends thereof free to move longitudinally relative to one another.

3. Apparatus according to claim **2** wherein said variable stiffness spring comprises a plurality of metal laminates of selected height and width stacked with respect to one another to form a spring pack and so that the ends thereof are positioned on opposite sides of the axis of the hinge member and are free to move relative to one another toward or away from the hinge axis.

4. Apparatus according to claim 3 and including means to move said spring pack to a first position wherein each laminate presents a cross section of maximum stiffness and to a second position wherein each laminate presents a cross section of minimum stiffness.

5. Apparatus according to claim 4 wherein in said first position said laminates individually present a cross section of greater height than width, and wherein, in said second position, said laminates individually present a cross section of greater width than height to thereby vary the stiffness of the spring pack.

6. Apparatus according to claim 2 wherein said spring pack is of rectangular cross section.

7. Apparatus according to claim 2 wherein said spring pack is of cross section other than rectangular.

8. A helicopter rotor having:

a. a hub mounted for rotation about an axis of rotation,
b. a plurality of blades projecting from said hub for rotation therewith,
c. a hinge member connecting said blades to said hub for articulating motion with respect to said hub thereabout,
d. a variable stiffness spring member mounted so as to be free of blade centrifugal loading and including a spring pack comprising a stack of laminate members stacked in loose relation with respect to one another and extending across said hinge member axis,
e. means supporting the first end of said spring pack in said hub so that said laminates are free to move longitudinally with respect to one another but are restrained from moving laterally with respect to one another,
f. means to support the other end of said spring pack in said blade so that the ends of the laminates thereof are free to move longitudinally with respect to one another but are restrained from moving laterally with respect to one another,
g. means to move said spring pack to a first position wherein said laminates present maximum stiffness to bending about the hinge member axis so that said rotor is operable as a rigid rotor and to a second position wherein said laminates present minimum stiffness to bending about said hinge member axis so that said rotor is operable as an articulated rotor.

9. Apparatus according to claim 8 wherein said actuating means includes means to position said spring pack in intermediate positions between said first and second positions.

10. Apparatus according to claim 9 wherein said spring pack consists of a selected number of metal sheet laminates of selected cross section dimension and wherein each of said laminates presents a cross section of greater height than width when in said first position and a cross section of greater width than height when in said second position so as to constitute a spring of variable stiffness.

11. Apparatus according to claim 10 and including a layer of low-friction material sandwiched between adjacent laminates of said spring pack.

12. Apparatus according to claim 11 wherein each of said laminates is of the same cross-sectional shape and is of the same height and width and of selected number to produce a variable spring of selected stiffness ratio when in said first and said second positions.

13. Apparatus according to claim 12 wherein said laminates are of different cross-sectional dimension so that the cross section of the spring pack is of selected shape and constitutes a spring of desired stiffness when in said first position and to constitute a spring of desired stiffness when in said second position.

14. Apparatus according to claim 8 wherein said hinge member is a flapping hinge.

15. Apparatus according to claim 8 wherein each of said laminate members is identical and is of rectangular shape and of rectangular cross section and wherein said spring pack is of rectangular cross section.

16. Apparatus according to claim 8 and including means joining said laminate members of said spring pack.

17. Apparatus according to claim 8 wherein said variable stiffness spring member is the same for each of said blades and including:

a. means to cause said variable stiffness spring members to vary in stiffness simultaneously and to the same degree.

18. A helicopter rotor having:

a. a hub member mounted for rotation about an axis of rotation,
b. a plurality of blades projecting radially from said hub member and having a root end,
c. a blade-cuff supporting said blades for pitch change motion about a blade feathering axis,
d. a hinge member connecting said cuff to said hub so that said blade and cuff are supported for pivot motion about the hinge member axis from said hub member,
e. a variable stiffness spring mounted so as to be free of blade centrifugal loading and extending across said hinge member axis and supported at its opposite ends in said hub member and said cuff.

19. Apparatus according to claim 18 wherein said variable stiffness spring includes a plurality of metal sheets of selected cross-sectional shape and positioned in stacked relation with respect to one another.

20. Apparatus according to claim 19 and including means to support one end of said sheets in said hub so that said sheets are free to move longitudinally with respect to one another but are substantially restrained from lateral motion with respect to one another and means to support the other end of said sheets in said cuff so that said sheets are free to move longitudinally with respect to one another but are restrained from moving laterally with respect to one another and means to pivot said sheets so stacked between a first position wherein each of said sheets presents a cross section of maximum height and minimum width with respect to said hinge axis so as to constitute a spring of maximum stiffness extending across said axis between said hub and said cuff and a second position wherein each of said sheets presents a cross section of minimum height and maximum width with respect to said hinge axis so that said sheets so stacked constitute a spring of minimum stiffness between said hub and said cuff across said hinge axis.

21. Apparatus according to claim 20 and wherein said hinge member is a flapping hinge.

22. Apparatus according to claim 18 and including means to support said variable stiffness spring in said hub and said cuff so that blade centrifugal loading is not imparted thereto but passes through said cuff and hinge member to said hub member.

23. A helicopter rotor having:

a. a hub mounted for rotation about an axis of rotation,
b. a plurality of blades projecting from said hub for rotation therewith, and having a flexible section therein,
c. a variable stiffness spring mounted so as to be free of blade centrifugal loading and extending across said flexible section and mounted for flexing motion therewith.