United States Patent

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[54] **SEAL STRUCTURE FOR RIGID SIDEWALL HOVERCRAFT**
9 Claims, 7 Drawing Figs.

[52] U.S. Cl. 114/67, 180/116
[51] Int. Cl. B63b 1/38
[50] Field of Search 114/67.1

[56] **References Cited**

UNITED STATES PATENTS

3,027,860 4/1962 Priest 114/67
3,198,274 8/1965 Cocksedge 114/67
3,473,503 10/1969 Gunther 114/67
3,478,836 11/1969 Eckered et al. 114/67
3,481,296 12/1969 Stephens 114/67

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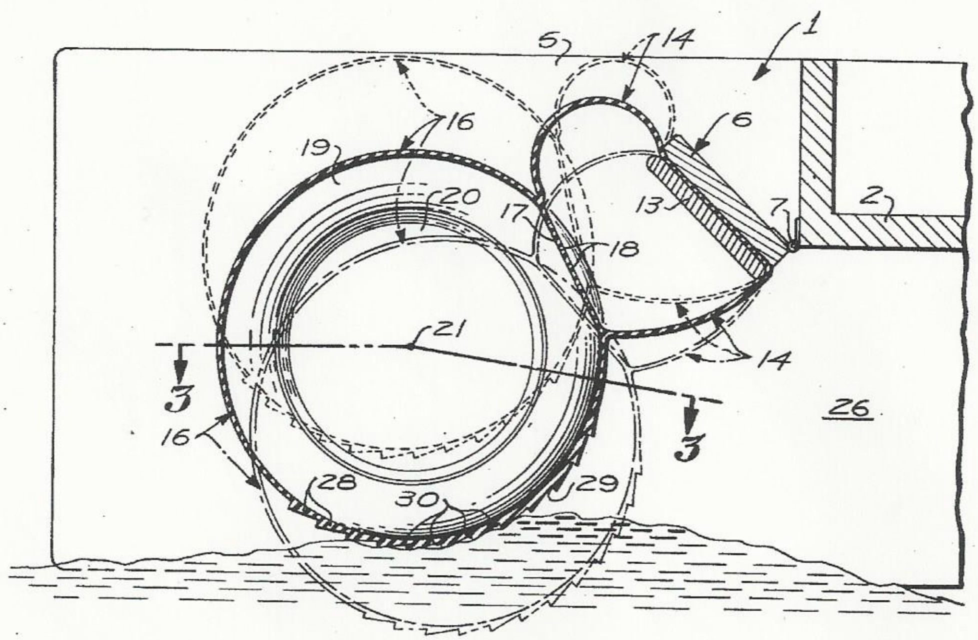
ABSTRACT: A seal structure for a hovercraft having spaced rigid sidewalls joined by a deck in which conjoined minor and major inflatable cylinders extend between the sidewalls of the hovercraft, the minor cylinder being transversely distortable and hinged as well as sealed to the stern or bow margins of the deck and the ends of the cylinders being in substantially sealing and sliding engagement with the sidewalls; the underside of the major cylinder being intended for water contact and having ribs arranged to permit controlled escape of air to minimize frictional contact.



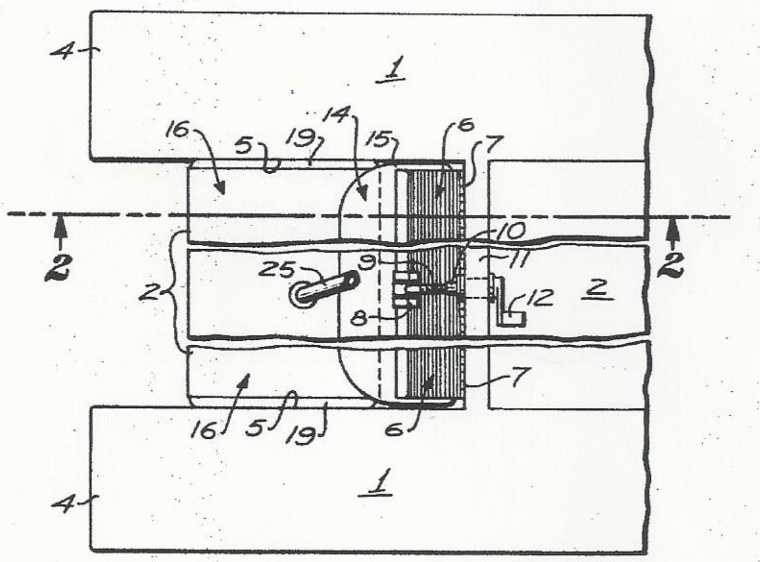


FIG. 1

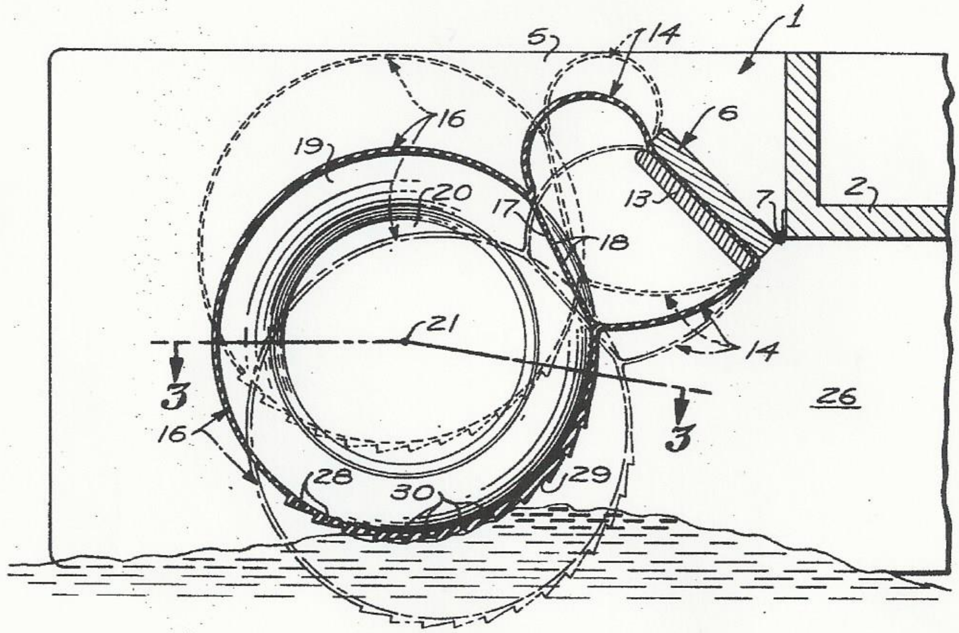


FIG. 2

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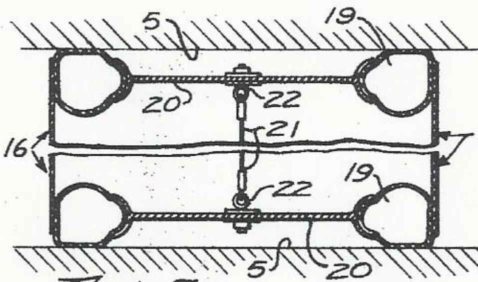

FIG. 3

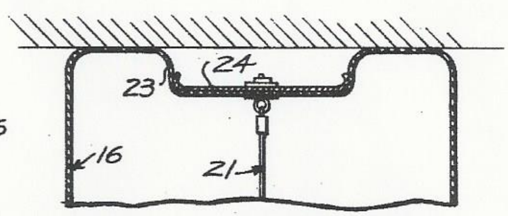

FIG. 4

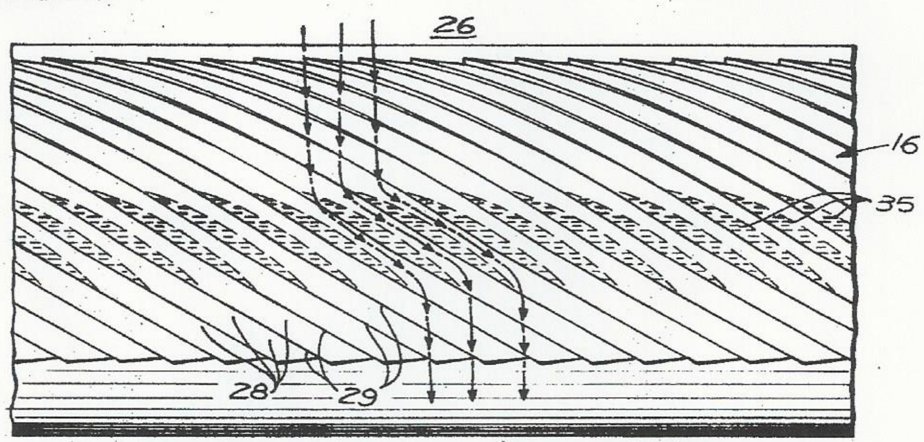

FIG. 5

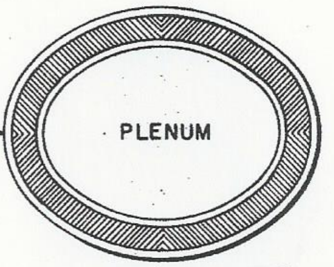

FIG. 7

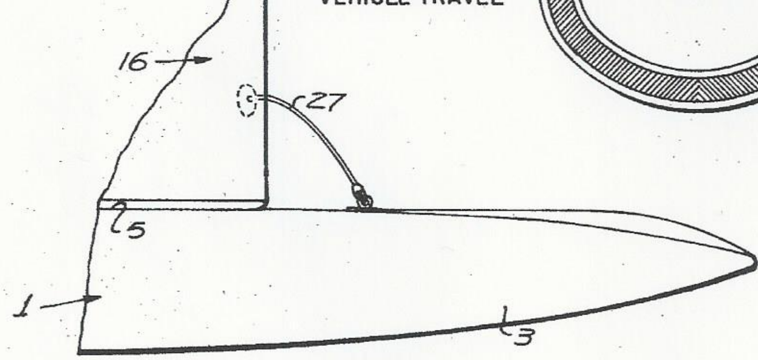

FIG. 6

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SEAL STRUCTURE FOR RIGID SIDEWALL HOVERCRAFT

BACKGROUND OF THE INVENTION

Rigid sidewall hovercraft has evolved as a marine specialization of the peripheral skirt hovercraft in which a flexible skirt encircles the entire craft, and air is supplied to a plenum formed within the peripheral skirt and is intended to leak around the entire skirt circumference while sustaining this type of hovercraft above water, or underlying surface. The sidewalls of the rigid sidewall hovercraft are intended to remain immersed in water while air is intended to escape only fore and aft under flexible seals extending between the sidewalls. While the immersed rigid sidewalls of this arrangement introduce a wetted drag, this is more than compensated by substantial reduction in lift power at cruise speed because leakage under the sidewalls is avoided. In fact, the lift power may be reduced from 40 percent of the total power, in the case of peripheral skirt hovercraft, to 10 percent, in the case of rigid sidewall hovercraft, providing that careful end sealing of the plenum air is maintained.

SUMMARY OF THE INVENTION

To accomplish this advantage requires minimal forward and rearward air leakage for the rigid sidewall hovercraft. The present invention is directed to a seal structure which is especially applicable for use at the stern of the rigid sidewall hovercraft, principally because the problem of air leakage control at the stern is more difficult than at the bow; however, the seal structure may be used advantageously at the bow of the hovercraft. More particularly, the present invention is applicable to the buoyant hull hovercraft disclosed in my copending application, Ser. No. 703,752, filed Feb. 7, 1968. The present invention is summarized in the following objects:

First, to provide a seal structure for rigid sidewall hovercraft wherein a minor diameter and major diameter inflatable parallel axis cylinders are joined longitudinally to each other, the smaller being hinged as well as sealed to the forward or rearward margin of a deck extending between the side hulls, and the ends of the cylinders being in sealing or semisealing engagement with the confronting sides of the hulls and capable of relatively free sliding movement; the underside of the larger cylinder being forced by inflation pressure into contact with the water.

Second, to provide a seal structure as indicated in the preceding object wherein the minor cylinder is readily distortable in response to wave action permitting the major cylinder to raise and lower readily in conformity to changing elevation of the water as waves pass from bow to stern.

Third, to provide a seal structure for hovercraft as indicated in the preceding objects which incorporates a novel seal means at the ends of the larger inflatable cylinder for engagement with the sidewalls of the hovercraft, the seal providing minimum resistance to sliding movement relative to the hull surfaces as the larger cylinder moves in conformance with the change in the surface of the water passing between the hulls.

Fourth, to provide a seal structure for hovercraft which has particularly low weight and inertia so that only a moderate elastic downforce resulting from distortion of the inflated minor cylinder need be applied to the major cylinder in order to maintain the major cylinder in effective contact with the underlying water even though the water level varies substantially and at a rapid rate as successive waves pass from bow to stern when the hovercraft is traveling at high speed.

Fifth, to provide a seal structure for hovercraft wherein the cross sections of the major and minor cylinders are determined by inflation pressure and the external mechanical forces applied thereto; that is, the cylinders are free of internal cords or other tension elements in order to maintain the external shape with the result that manufacturing costs are materially reduced and undesirable "quilting" of the surface is avoided.

Sixth, to provide a seal structure for hovercraft in which the water contacting portions are provided with novelly arranged planing steps permitting controlled escape of plenum air in such a manner that water contact drag is minimized and causing the seal to slide on the water in a highly stable condition.

Seventh, to provide a seal structure of the type indicated which is locally as well as generally yieldable to water impact minimizing the transfer of such impact to the structural parts of the hovercraft and to the seal structure.

DESCRIPTION OF THE FIGURES

FIG. 1 is a fragmentary plan view showing the stern portion of the hovercraft, and the seal structure mounted between the hulls of the hovercraft.

FIG. 2 is an enlarged fragmentary sectional view, taken through 2–2 of FIG. 1, with the seal structure shown by solid lines in the mid position, and indicating by broken and dotted lines, typical lower and upper positions of the seal structure.

FIG. 3 is a fragmentary sectional view, taken through 3–3 of FIG. 2, showing one form of end seal.

FIg. 4 is a similar fragmentary sectional view, showing a modified form of end seal.

FIG. 5 is a fragmentary bottom view of the major or buoyant inflatable cylinder to illustrate particularly that portion of which contacts the underlying water.

FIG. 6 is a fragmentary plan view showing a portion of the bow of a hovercraft, and illustrating the seal structure in relation thereto.

FIG. 7 is a diagrammatical bottom view of the toroidal inflated buoyant cell of a softwall or peripherally skirted hovercraft under which planing surfaces are provided.

The sealing structure is particularly adapted for use with a hovercraft comprising a pair of hulls **1**, connected by a deck **2**. The construction thereof may be similar to the aforementioned copending application, and thus may be buoyant; that is, the hulls have sufficient displacement as to support the hovercraft when the hovercraft is idle in the water. The bows **3** of the hulls project forwardly of the deck, whereas the stern portions **4** project rearwardly of the deck. In the region forwardly and rearwardly of the deck, the hulls include confronting walls **5** which are essentially parallel to each other.

Reference is first directed particularly to FIGS. **1** and **2** which show the seal structure as applied to the stern of a hovercraft. Extending between the confronting walls **5** is a hinge plate **6**, connected by a hinge **7** to the stern margin of the deck **2**. The hinge plate extends angularly upwardly and rearwardly from the hinge **7** and is intended to be angularly adjusted. For convenience of illustration, a hand operated adjustment means is illustrated, whereas in practice, an electric or hydraulic adjustment means suitable for remote control is utilized. More particularly, as illustrated, a fitting **8** is secured to the hinge plate **6** and pivotally supports one end of a screwshaft **9**, which is received in a screw sleeve **10** journaled in the rear wall **11** of the deck **2** and capable of rotation by a hand crank **12**.

Clamped to the hinge plate **6** by an internal clamp plate **13** is a minor inflatable cylinder or flexure cylinder **14** extending between the confronting walls **5**. The cylinder **14** includes closed ends **15** which may contact the confronting walls **5** or are closely adjacent thereto to minimize the leakage of air around the ends of the cylinder **14**.

The side of the flexure cylinder **14**, opposite from the clamp plate **13**, is joined to a major inflatable cylinder or buoyant cylinder **16** so that the two cylinders share a partition web **17**, having perforations **18**.

The ends of the major or buoyant cylinder **16** are joined to end seals **19** in the form of toroidal tubes which may be similar to the inner tubes of vehicle wheels. The tubes are intended to be pressurized independently of the buoyant cylinder and may be provided with conventional tire valves for this purpose. Each end seal **19** is mounted on the periphery of a closure disc **20**. The two closure discs **20** are joined together by a restraining or tension cable **21** and suitable anchor fittings **22**.

Alternatively, the major or buoyant cylinder **16** may have end closures **23**, in each of which is mounted a central disc **24** joined in the manner of the discs **20** by a restraining cable **21**. The central discs **24** are held away from the walls **5** by the restraining cable; however, the peripheral portion of the end closures **23** engage the walls **5** in the manner of the tubes **19**.

The conjoined cylinders **14** and **16** are inflated through a suitable inflation tube **25**, one tube being sufficient as the two cylinders are in communication through the perforations **18**. The inflation tube is connected to a suitable source of pressurized air. The pressure required is quite low, in the nature of approximately one pound per square inch above atmospheric pressure. The downward force exerted by the minor cylinder on the major cylinder may be varied by changing the inflation pressure; that is, the minor cylinder as it distorts acts as a downward loading spring forcing the major cylinder against the water, yet permitting ready compliance with the change in water level.

A conventional sealing means may be provided between the forward margin of the deck, the water below and the confronting sides **5** of the hulls so that a plenum **26** is formed under the deck. The plenum is supplied with air at relatively low pressure, but in high volume, from a conventional blower or the like, more fully disclosed in the aforementioned copending application. The plenum pressure is less than the inflation pressure of the cylinders **14** and **16**.

In place of a conventional seal at the forward end of the deck, the seal structure shown in FIGS. **1** and **2** may be employed; whereas in the structure shown in FIGS. **1** and **2**, the main or buoyant cylinder **16** trails behind the flexure cylinder **14**; if the seal structure is adapted for use at the forward end of the plenum, the buoyant cylinder **16** projects forwardly and downwardly from the flexure cylinder **14**. Inasmuch as the movement of water would tend to drive the buoyant cylinder **16** under the deck, restraining cables **27** are attached to the buoyant cylinder **16** and to the bow portions **3** of the hulls **1**.

Operation of the seal structure is as follows:

If both a forward and rearward seal structure of the type disclosed is employed, the seal structures close the ends of the plenum **26**. The seal is not intended to be perfect; instead, it is intended that plenum air flow under the buoyant cylinders. The downward force exerted by each buoyant cylinder is dependent upon the inflation pressure which determines the force required to flex or distort the cylinder **14**. Also, the downward force is dependent upon the angular adjustment of the hinge plate **6**. Both the cylinders **14** and **16** are formed of fabric material impregnated with a suitable elastomer and therefore have minimum weight, and consequently have minimum inertia. The construction of the end seals **19** or **23** is also such as to minimize weight and therefore minimize the inertia of the seal structure as a whole. As a consequence, the buoyant cylinders shift readily with change in the height of the underlying water and respond readily to wave action as the waves pass from the bow to the stern of the hovercraft.

It is highly desirable that the frictional contact between the buoyant cylinders **16** and the underlying water be minimized. This is accomplished by providing stepped planing surfaces **28** in the region of contact between the buoyant cylinder and the water. While some advantage is gained if such stepped planing surfaces extend axially with respect to the buoyant cylinder, the effect of the planing surfaces may be greatly increased by arranging the planing surfaces in a helical pattern, as shown particularly in FIG. **5**. Each planing surface increases gradually from its leading toward its trailing edge, terminating at its trailing edge in a shoulder **29**. When the buoyant cylinder is moving forwardly over the water, the water cavitates along each shoulder **29**, forming air passages **30**. By reason of the helical pattern provided by the planing surfaces, each air passage communicates between the plenum and the region outside the buoyant cylinder so that controlled outward flow of plenum air is provided while maintaining contact between the buoyant cylinder and the underlying water. This is graphically illustrated in FIG. **5** in which the shaded areas **31** represent the areas of contact between the buoyant cylinder and the water. It will be noted that FIG. **5** illustrates the condition with respect to the rear buoyant cylinder; that is, the direction of air flow and water flow with respect to the buoyant cylinder is the same, both flowing from the plenum side of the buoyant cylinder to the outboard side thereof. If FIG. **5** represented the condition with respect to a forward buoyant cylinder, the relative flow of water would be in the same direction, but the relative flow of air would be in the opposite direction from that illustrated.

By reason of the helical arrangement of the planing surfaces **28**, there is a slight lateral force imparted to the hovercraft. Tests have indicated, however, that this force is too low to require special correction. However, if the planing surfaces be arranged in herringbone fashion, these forces may be cancelled.

It will be observed that the end seals **19** or **23** bear only slightly against the confronting walls **5** so that the resulting friction is low. Also, with respect to the ends of the flexure cylinder **14**, it is not essential that a full seal be maintained, for any leakage here is but a small fraction of the total leakage of plenum air.

Reference is now directed to FIG. **7** which illustrates diagrammatically the toroidal buoyant cell **32** of a softwall hovercraft. Except for its toroidal curvature, the buoyant cell **32** appears essentially the same as that shown in FIG. **5**. That is, diagonal, angular, planing surfaces **28** with helical shoulders **29** provide the air passages **30**, all as illustrated in FIG. **5**, except that the angle is increased and may be fixed with respect to the direction of travel, as illustrated, or may be essentially constant with respect to the local axis of the inflated cell **32**. Also, fore and aft as well as at mid points at the sides of the cell, the planing surfaces form herring bone patterns. While at these areas the effectiveness of the planing surfaces are reduced, the areas involved constitute only a small percent of the total area.

The provision of the angularly extending planing surfaces under toroidal buoyant cells tends to alleviate a dangerous instability called "plough-in" observed in peripherally skirted hovercraft. That is, such hovercraft have on occasions experienced a dangerous loss of control initiated by a pitch down transient force causing the toroidal cell to make a high resistance contact. Just what occurs is not fully understood. One theory is that when complete water contact between the cell and the water occurs, the surface of the cell is flattened increasing the contact area of wetted skin friction. However, this does not seem to account for the observed drag. Another theory considers the effect of pressure drop in the water moving rapidly under the cell wall so that the wall is sucked into the water. Inasmuch as the wall is highly flexible, it may ripple or "flag" further increasing the drag load. Furthermore, the water flow, once attached to the surface of the cell, tends to cling and up the trailing or downstream surface of the cell adding to the force pulling the cell into the water.

In any case, the resulting sudden drag pulse decelerates the hovercraft while forming a couple with the inertial forward thrust of the center of gravity (plus the thrust of the air propeller if such is used) to amplify the pitch down further increasing the drag pulse sometimes to a sudden stop. Should this be combined with a sudden turn, the hovercraft may capsize.

The presence of the stepped planing surfaces **28** and shoulders **29** forming the passageways **30** reduces the possibility of high resistance water contact, thus avoiding the subsequent chain of events.

The rigid sidewall hovercraft illustrated in FIGS. **1** through **6** may be propelled by conventional means such as by an air propeller, by permitting increased rearward flow of plenum air or by motor driven water propellers at the sterns of the two hulls **1**.

While particular embodiments of this invention have been shown and described, it is not intended to limit the same to the details of the constructions set forth, but instead, the invention embraces such changes, modifications and equivalents of the various parts and their relationships as come within the purview of the appended claims.

I claim:

1. A seal structure forming a barrier between a plenum formed under a hovercraft and the region surrounding the hovercraft, wherein air above ambient pressure is delivered into the upper side of the plenum for controlled escape to the exterior of the hovercraft, said seal structure comprising:

a. a sealed flexible seal member containing air at a pressure above the pressure in the plenum adapted, at least intermittently, to contact the underlying water surface for controlled escape of air from the plenum;

b. a series of planing steps formed on the underside of said seal member and extending in angular relation to the flow of water under the seal member;

c. said planing steps forming imperforate cavitation shoulders along their trailing edges, which, with respect to the direction of water flow, overlap whereby air flowing from the plenum through the regions of cavitation is in angular relation to the direction of water flow.

2. A seal structure, as defined in claim 1, for hovercraft having a pair of confronting rigid sidewalls and a connecting deck, wherein:

a. at least one seal member extends between said sidewalls at an end of said deck;

b. means flexibly connects said seal member to said deck and forms a seal therewith;

c. and end seals are provided between said seal member and said confronting sidewalls.

3. A plenum air flow control means for marine hovercraft having confronting rigid sidewalls joined by a deck, the lower extremities of said sidewalls penetrating into an underlying water surface and said deck disposed above the water surface and forming with said sidewalls a plenum, said control means comprising:

a. a closure structure extending between said sidewalls at an end of said deck and resting on the underlying water surface;

b. said closure structure including a pair of longitudinally conjoined inflatable cylinders, the first cylinder being joined to said deck and distortable to produce an elastic download on said second cylinder against an underlying water surface;

c. and means at each end of said closure structure slidably and sealingly engaging a confronting sidewall.

4. A seal structure, as defined in claim 3, wherein:

a. a rigid hinge plate extends along the margin of said deck and is joined to said first cylinder;

b. and means are provided to adjust the angular position of said hinge plate to vary downward force applied to said second cylinder.

5. A seal structure, as defined in claim 3, wherein:

a. said closure structure includes a series of planing steps at its underside disposed in angular relation to the normal relative movement of the hovercraft over the water surface and tending to cause the water surface to cavitate along the trailing edge of each step thereby to cause water separation from said planing steps forming air channels across the underside of said closure structure.

6. A seal structure, as defined in claim 3, wherein:

a. said closure structure is disposed in trailing relation to said deck adjacent the stern of said hovercraft.

7. A seal structure, as defined in claim 3, wherein:

a. said closure structure is disposed forwardly of said deck adjacent the bow of said hovercraft;

b. and tension elements are connected to said closure structure and said hovercraft to limit downward displacement of said closure structure.

8. A seal structure, as defined in claim 3, wherein:

a. each end seal means includes an inflatable toroidal tube bonded to an end of at least said second cylinder for sealing and sliding engagement with a confronting sidewall;

b. seal discs closing said tubes to seal the ends of said second cylinder whereby said tubes are forced against said confronting sidewall by pressure within said second cylinder;

c. and a tension member joining said discs to limit relative outward movement in response to pressure in said second cylinder thereby to limit the force applied to said sidewalls by said tubes.

9. A seal structure, as defined in claim 3, wherein:

a. a flexible end member closes and seals each end of at least said second cylinder and is exposed to the pressure internally thereof for sealing and sliding engagement with the confronting sidewall;

b. and a tension member limits relative outward movement of said end members thereby to limit the force applied to said sidewalls by said end members.

PROPELLER WITH SPRING ACTUATED VARIABLE PITCH

Filed July 22, 1966

FIG. 1

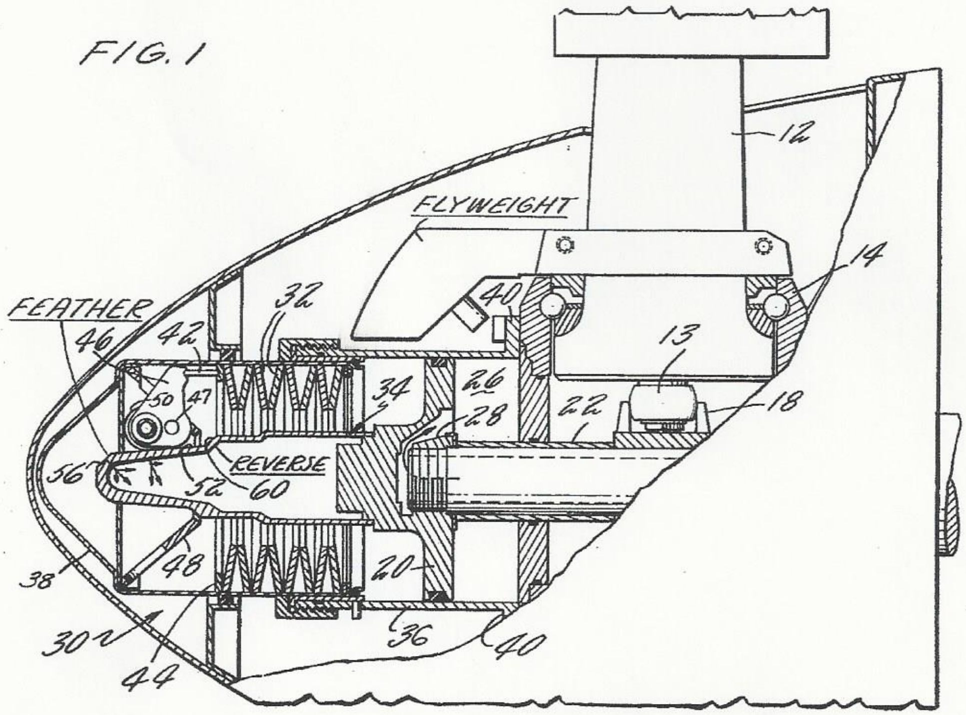


FIG. 2

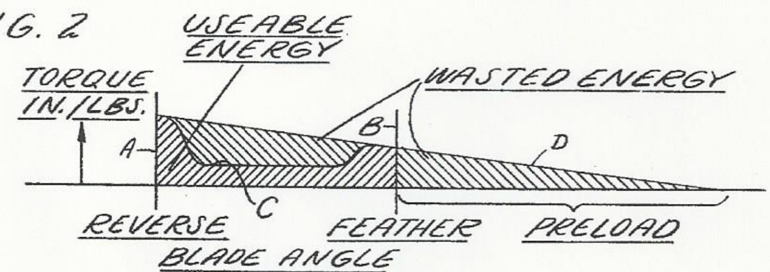
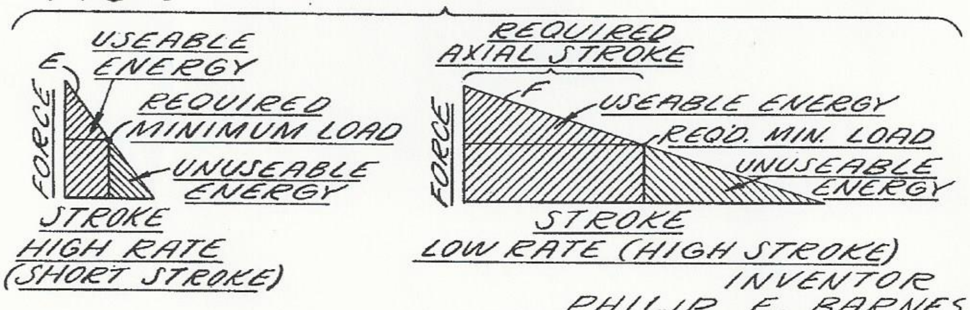


FIG. 3



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PROPELLER WITH SPRING ACTUATED VARIABLE PITCH

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8 Claims. (Cl. 170—160.32)

ABSTRACT OF THE DISCLOSURE

A propeller pitch actuating piston is loaded into and out of reverse and feather positions by a spring transmitting an axial load through a bellcrank and conically shaped cam extending axially along the axis of propeller rotation to give a different load for each axial position such that the load near reverse and feather is greater than the load intermediate thereof.

This invention relates to aeronautical variable pitch propellers of the type that are movable to feather and reverse positions.

In the field of lightweight, small, spring-actuated, pitch-changing propellers a problem existed where it was necessary to feather the propeller at a high specified flight velocity while the propeller lacked sufficient room to store enough spring energy. Additionally, maximum spring force was only required during two regimes of the blade angle range, namely, going out of reverse and approaching fully feather. Intermediate this range a relatively low energy spring device was sufficient. The use of a simple linear spring system was not possible since there was not sufficient room available to obtain the necessary energy in the limited area for the stroke of the spring. A dual spring system also was inadequate because of its complexity and additional weight.

Accordingly, I have found that I can obviate the problems noted above by providing a variable low stroke, high rate, high force, cam-actuated spring pack which provides the necessary force to urge the blades out of reverse and full feather while at the same time providing only the limited or minimum force necessary during the blade angle positions therebetween, thus providing an efficient use of the available energy.

Accordingly, this invention comprises a spring pack formed from a plurality of concentrically mounted disc type springs which axially load a spring seat and transmit this force through a flexible ring for producing a torque on a bellcrank which in turn loads a roller against a cam producing a variable axial load due to the cam slope. The cam, in turn, is connected to the pitch-changing piston connected to the propeller blades for varying blade angle. Thus, this system by being able to use the stored spring energy only where it is actually required results in a highly efficient spring system with considerable reduction in spring weight. This system also allows varying the output load with position over a wide range for varying propeller operating conditions by varying a cam contour. Additionally, the spring system provides this varying axial load from an axial spring system at a high efficient (ninety percent) cam-to-link system.

Other features and advantages will be apparent from the specification and claims and from the accompanying drawings which illustrate an embodiment of the invention.

FIGURE 1 is a view partly in elevation and partly in section illustrating the preferred embodiment of the present invention.

FIGURE 2 is a graphical illustration showing the desired usable energy necessary to position the blade to

feather and reverse position and comparing a simple linear spring system with the present invention.

FIGURE 3 is a graphical illustration comparing the force versus stroke of the present invention and heretofore known spring systems.

Referring now particularly to FIG. 1 illustrating the details of the present invention in its most preferred embodiment wherein numeral **10** generally illustrates the propeller assembly but excluding the controlling mechanism generally associated with a variable pitch propeller. The control for the propeller is not deemed a part of this invention and for the sake of convenience is being omitted. The propeller blades (only one being shown) are circumferentially mounted about the periphery of the propeller and retained in hub **14** for pitch change movement. The hub is attached to the engine drive shaft in the conventional manner for being rotated about the propeller axis. Eccentric arm **13** carried on the base of propeller blade **12** extends radially inward toward the center of rotation of the propeller assembly and is connected to suitable yoke mechanism **18** which is attached to pitch-changing piston **20** by hollow shaft **22**.

It is apparent from the foregoing that axial translation of piston **20** imparts rotary movement to propeller blade **14** about its longitudinal axis for varying the pitch thereof. Admission of high pressure fluid through hollow shaft **22** into chamber **26** via the drill passage **28** urges the piston to the left for advancing the propeller blades toward low pitch. Opposing this force is the force created by the counterweights and the spring pack assembly generally illustrated by numeral **30** which forms the important feature of this invention. While spring-loaded pitch actuators are in themselves old in the art, the specific spring assembly described hereinbelow is considered to be the advancement to the state of this art as will become apparent from the description to follow. It is pointed out here that the heretofore known spring assemblies are inadequate in this particular propeller because the space for retaining the customary spring is insufficient to provide the necessary energy required for the particular application of this propeller, namely high flight velocity aircraft. Hence according to this invention, suitable spring disc elements **32** are coaxially mounted within the dome assembly **36** extending forward of the hub **12** and suitably attached thereto by securing means mounted through flange **40** abutting the forward face of hub **12**. The spring disc elements **32** are stacked axially and are characterized by having high rate and low stroke. Disc elements (Belleville springs) **32** are generally toroidal in shape having a central opening surrounding the axial cam element **34** and are loaded in the axial direction and disposed coaxially relative to the propeller's axis of rotation. Other spring energy storage devices may be used as well. The free end of the spring pack engages spring seat **42** which in turn is connected to the flexible ring element **44** which bears against the upper arm of bellcrank **46**. Bellcrank **46** in turn is pivotally mounted on pivot **47** in fixed relation to the hub to suitable supporting bracket **48** mounted within dome casing **38**. Preferably three such bellcranks circumferentially disposed about cam **34** are utilized while the number employed does not affect the scope of the invention. The opposite end of bellcrank **46** carries roller **50** which bears against the cam surface **52** of cam **34**. It is apparent that when the load imposed by the spring-loaded roller **50** on cam **34** is resolved into its two component forces (horizontal and vertical), the magnitude and direction of the horizontal component will depend on the contour of the cam. If the tangent at the point of contact between roller and cam is parallel to the axis of the cam, there will be no horizontal component, and hence, no tendency to move cam **34** axially. Whenever the tangent through this point is angularly disposed to the centerline, then a horizontal component will be evident. Then the greater the angle, the larger the horizontal component force and hence the larger the resultant force in the axial direction.

Vectorially superimposed on FIG. 1 is the resultant and component forces showing the force behavior acting on cam **34** in the intermediate, feather and reverse ranges. This resultant force is then the force that is exerted against the hydraulic forces acting on the right-hand face of piston **20** by virtue of the pressure in chamber **26.** Thus, in the position shown in the drawing, only a slight force is exerted on piston **20** and hence, only a light force in this direction is exerted against the roller and yoke mechanism for actuating the pitch change movement. This is sufficient force for proper operation in this blade angle range. When it is necessary to actuate and move the blade into the feather position, the fluid in chamber **26** is drained by the independent pitch control means, not shown, and the spring urges the piston to the right where high aerodynamic forces created by the forward velocity is attempting to keep the propeller toward a low pitch position. When the roller contacts the slope portion **56** of cam **34**, a greater horizontal force will be evident and this force is sufficient to overcome the force generated by the blades and to advance them into feather position.

Similarly when the propeller is advanced toward the reverse position, the roller **50** engages slope **60** and imparts an additional load to piston **20** for overcoming the necessary forces which are generated by the loading on the propeller blades when advancing into or out of reverse.

The operating regime of spring energy required can best be seen by referring to FIG. 2 which is a plot of blade angle position with respect to torque in inch pounds. The vertical line A represents the reverse blade angle position and the vertical line B represents the feather position. Line C represents the forces necessary during the entire regime. Curve D illustrates the simple linear spring system. From the graph it can be seen that the usable energy necessary to operate the pitch movement is bounded between reverse and feather by curve C. All the energy shown under curve D is unusable and hence, wasted energy.

FIGURE 3 is a graphical comparison of a plot of force versus stroke in a simple linear system and the system described in the present invention. Curve E illustrates the force versus stroke of the spring pack of the present invention and curve F indicates the force per stroke of the spring used in the heretofore simple spring systems. It is obvious from the comparison of the two graphs that the stroke provided by the present invention is short while providing a high spring rate, and the stroke of the heretofore known spring systems is comparatively high and having a low spring rate. Thus, it followed that this system provides a varying axial load from an axial spring system through a high (approximately ninety percent) efficient cam-to-link system and additionally allowing the output load to vary with position over a wide range for varying propeller operating conditions merely by varying the cam's contour and also providing a high spring force but yet obtaining a low weight spring in a minimum space.

It should be understood that the invention is not limited to the particular embodiments shown and described herein, but that various changes and modifications may be made without departing from the spirit or scope of this novel concept as defined by the following claims.

I claim:

1. Means for adjusting the pitch of the blades of an aeronautical propeller including a servo piston having a fluid expansion chamber on one end, the pressure in said chamber adapted to move the servo piston in one direction and adjust the pitch of the blade in a corresponding direction, resilient means acting on the other end of the servo piston tending to urge the pitch of the blades in an opposite direction, and cam means extending axially relative to the propeller axis of rotation connected intermediate said resilient means and said servo piston varying the axial load in a relatively highly energy conservative manner such the the load output increases at proximity to the minimum and maximum compressed load of the resilient means.

2. Pitch adjusting means as claimed in claim 1 wherein the pitch of the blades are movable into reverse and feather position and said resilient means and cam means imparting a high force in said reverse and feather positions relative to the force intermediate these pitch positions.

3. Pitch adjusting means as claimed in claim 1 wherein said resilient means includes a relatively low stroke, high rate spring.

4. Pitch adjusting means as claimed in claim 3 wherein said spring includes a plurality of individual toroidal shaped elements disposed about the axial centerline of the propeller.

5. Pitch adjusting means as claimed in claim 3 wherein said cam means include a generally conically shaped cam surface having its base abut against the servo piston, a pivotally mounted bellcrank having one arm bearing against the wall of said cam and mounted in sliding relation and the other arm operatively connected to said spring.

6. Pitch actuating means as claimed in claim 5 including a spring retainer mounted adjacent the free end of said spring and a flexible element interconnecting the other arm of said bellcrank and said spring retainer.

7. For an aeronautical propeller having a plurality of blades circumferentially mounted for pitch change movement and movable to reversing and feathering pitch positions and having independent control means for controlling the pitch of said blades in one direction, means independent of said control means for controlling the pitch in the opposite direction, said last-mentioned means including spring means coaxially mounted with the center of rotation of said propeller, a pivotally mounted bellcrank having one end attached to the free end of said spring means, a cam extending axially relative the center of rotation of said propeller connected to said pitch changing means, a roller following said cam mounted on the other end of said bellcrank and adapted to impart a resultant force at predetermined points on said cam surface for urging said blades into and out of the desired position so that a higher force is exerted at the reverse and feather range of the propeller.

8. Means for imparting an axial load to a member, said means including a spring fixed at one end, a bellcrank having one arm connected to the free end of said spring, a generally frusto-conically shaped cam extending along the axial centerline of said member intended to be loaded, the other arm of said bellcrank bearing against the surface of said frusto-conically shaped cam for varying the load for each position of the cam so that a higher axial load is imparted to the member intended to be loaded at both extremities of the position of the cam.

References Cited

UNITED STATES PATENTS

Re. 25,096	12/1961	Biermann	170—160.32
2,492,653	12/1949	Reek	170—160.51 X
3,273,656	9/1966	Bird	170—160.51 X

FOREIGN PATENTS

452,625	8/1936	Great Britain.
534,529	3/1941	Great Britain.
340,848	5/1936	Italy.

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FEATHERING CONTROLLABLE PITCH PROPELLER

Filed Dec. 2, 1964 4 Sheets-Sheet 1

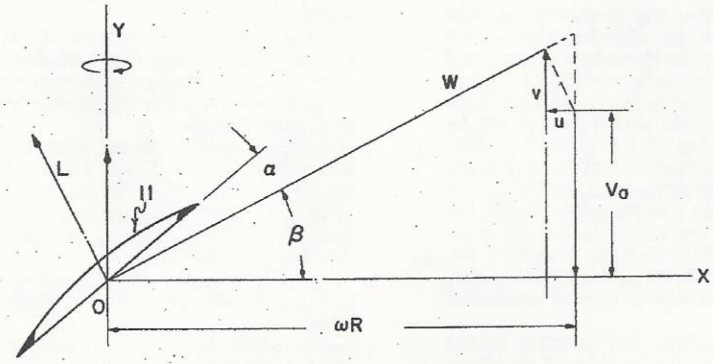

FIG. 1.

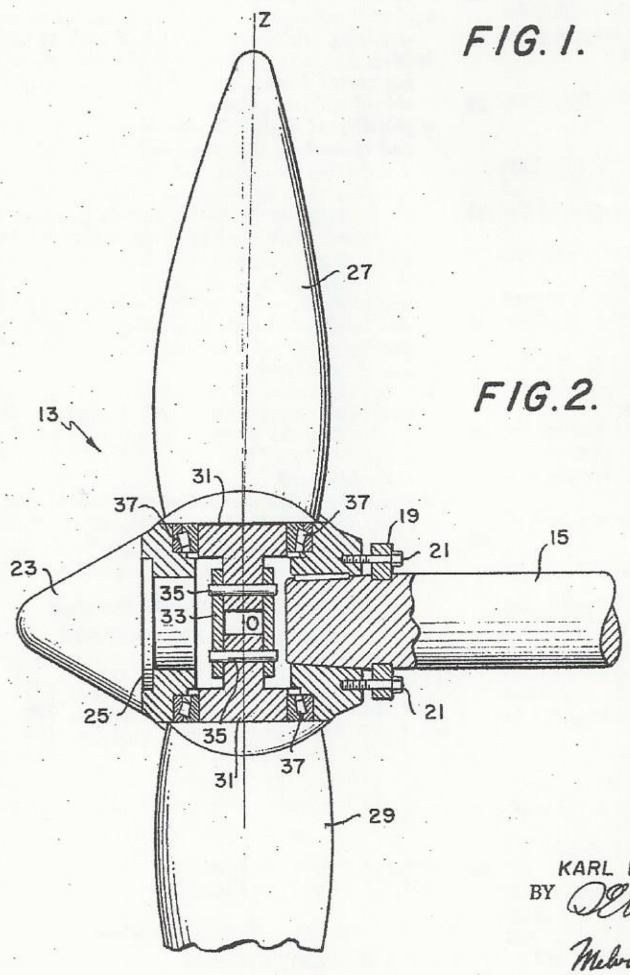

FIG. 2.

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FEATHERING CONTROLLABLE PITCH PROPELLER

Filed Dec. 2, 1964 4 Sheets-Sheet 2

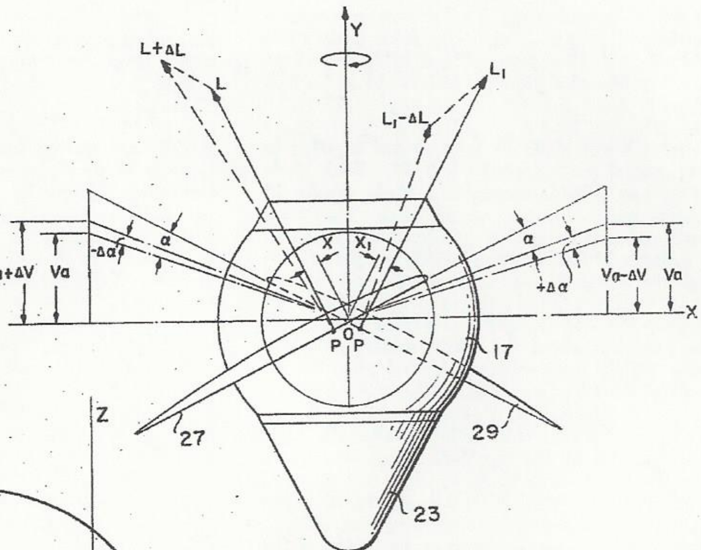

FIG. 4.

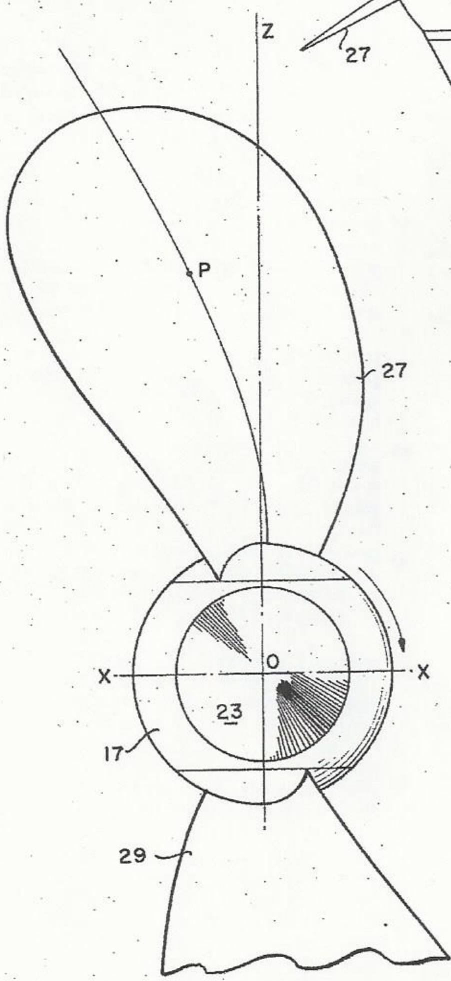

FIG. 3.

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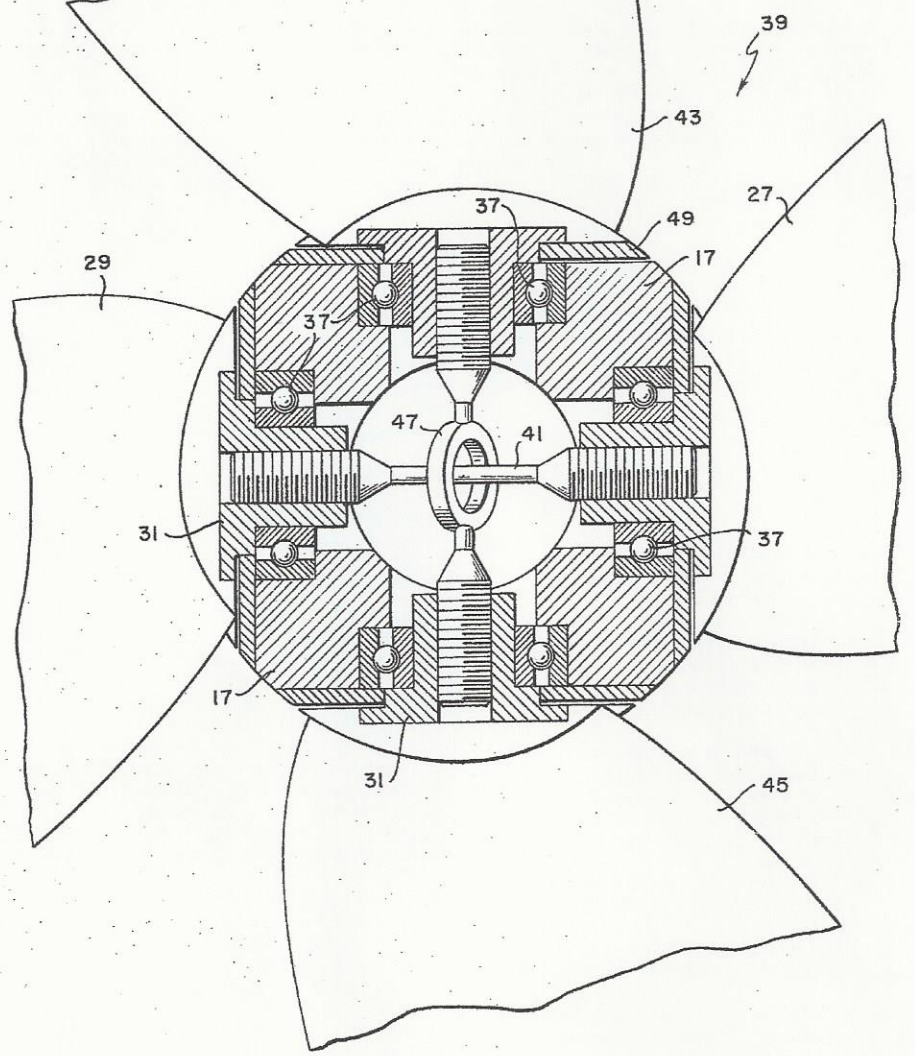

FIG. 5.

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FEATHERING CONTROLLABLE PITCH PROPELLER

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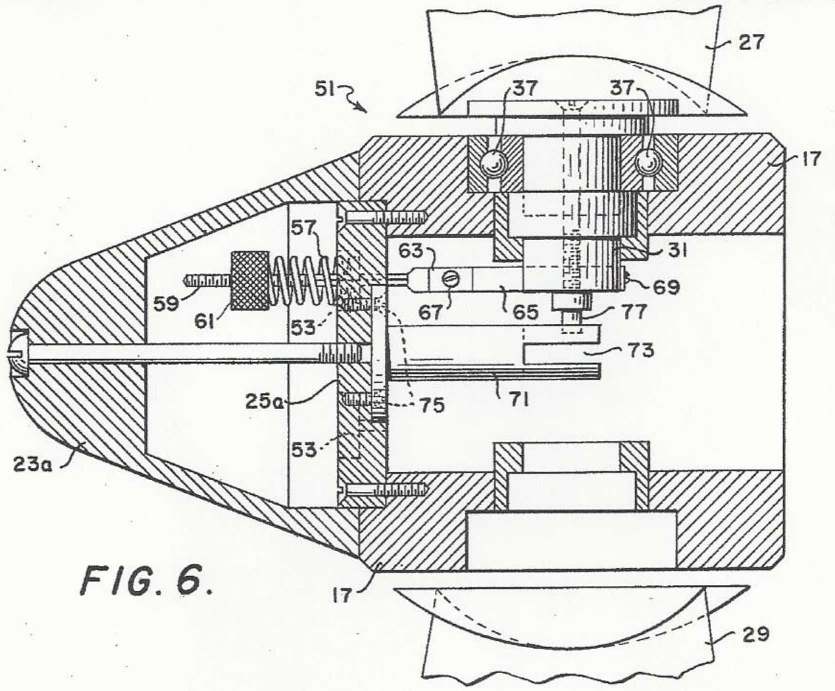

FIG. 6.

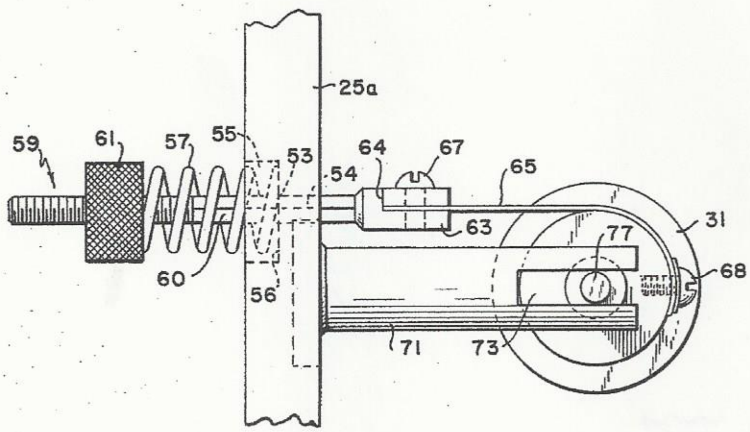

FIG. 7.

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3,249,161
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FEATHERING CONTROLLABLE PITCH PROPELLER

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Filed Dec. 2, 1964, Ser. No. 415,555
2 Claims. (Cl. 170—160.53)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

The present invention relates to marine propellers and more particularly to a propeller which will reduce the fluctuations of the propeller forces and thus minimize vibrations.

The propeller located behind the hull of a ship operates in the water disturbed by the hull, or the so-called wake of the ship. The velocity distribution in this wake is not uniform, but in general varies radially and circumferentially. Radial variation is not harmful as this can be allowed for in the design of the propeller. However, circumferential variation is harmful because this variation produces pressure fluctuations causing the angle of attack of the propeller blade to vary about a means value as the blade goes through one complete revolution. These pressure fluctuations are radiated into the surrounding water and are transmitted to the hull giving rise to the primary cause of vibration in the ship structure. Vibrations, in turn, are highly objectionable for marine vessels and must be avoided if possible.

Heretofore, attempts to reduce vibrations have resulted in arrangements of resiliently mounted propeller blades and standard controllable pitch propellers, wherein the pitch of the propellers are adjusted for varying loads and to reverse thrust without varying the direction of rotation of the shaft. The pitch adjustment, usually being effected by a bell crank arrangement in the interior of the hub activated by mechanical or hydraulic means. The prior art devices and arrangements have not proven satisfactory for the reduction of vibration due to the fluctuating wake forces.

The general purposes of this invention is to reduce the fluctuations of the propeller forces and thus minimize vibrations. To attain this, the present invention contemplates a self-adjusting feathering controllable pitch propeller arrangement whereby force fluctuations are reduced and vibrations are minimized.

An object of the present invention is the provision of a self-adjusting feathering controllable pitch propeller for minimizing ship vibrations.

Another object is to provide a rotatable blade propeller for efficient ship movement in the rearward direction.

A further object of the invention is the provision of a self-balancing propeller arrangement wherein an equilibrium of forces and moments is maintained.

Other objects and advantages of this invention will hereinafter become more fully apparent from the following description of the annexed drawings which illustrate preferred embodiments and wherein:

FIG. 1 is a representative section of a propeller blade showing the forces acting upon it;

FIG. 2 is a longitudinal sectional view along the lateral plane of a ship of a two-bladed propeller embodiment constructed according to the present invention;

FIG. 3 is a transverse view of the propeller of FIG. 2 projected on a plane transverse to the fore and aft axis of the ship;

FIG. 4 is a top view of a propeller of FIG. 3 showing the self-balancing feature of the present invention;

FIG. 5 is a transverse sectional view of a four-bladed propeller constructed according to the present invention showing the interior hub connections;

FIG. 6 is a transverse sectional view of a further embodiment of the present invention wherein resilient means control blade adjustments; and

FIG. 7 is a view of the resilient means of FIG. 6.

FIG. 1 discloses the action of a standard screw propeller with respect to a tri-rectangular system of coordinates wherein OY is the axis about which the propeller turns and along which it advances and OZ is the axis normal to the plane of the drawings. An ogive **11** represents a blade section at radius R from the center of the hub, having a linear tangential velocity of ωR and velocity of advance of the propeller being Va. From propeller theory it is then known that the resultant velocity W relative to the blade section is given by the expression:

$$W=\sqrt{(Va+v)^2+(\omega R-u)^2}$$

where,

u is the rotational slip velocity
v is the axial slip velocity.

The propeller is usually so designed that W meets the face of the blade section at an angle α, the so-called hydrodynamic angle of attack. This angle of attack causes a lift force L to be produced, the magnitude of which may be expressed by the equation:

$$L=\rho/2\ AW^2f(\alpha)$$

where,

ρ is the density of the medium
A is the area of the blade
W is the resultant velocity
$f(\alpha)$ is some function of α.

From this equation it is seen that when α increases, L increases and vice versa. For a given propeller, the angle of attack α varies when either the vector Va, the vector (ωR), or the ship velocity vectors u and v change. When the propeller is working behind a ship in the so-called wake of the ship, the wake which is not a uniform current but a highly irregular one causes the angle of attack α to vary about a mean value as the blade goes through one complete revolution. Therefore, the wake cause the angle α to vary and in turn causes the lift force L and the components of this force to fluctuate. These force fluctuations are the primary cause of vibrations in the ship structure.

The present invention minimizes force fluctuations caused by variable inflow into the propeller (variable wake) by feathering the propeller, that is, by reducing the angle of attack α when Va, the velocity of advance of the propeller, tends to decrease (region of high wake), and increasing α when Va tends to increase (region of low wake). Since the angle of attack is usually on the order of four to six degrees, angular adjustments ($\Delta\alpha$) required to smooth out these fluctuations need not be greater than about plus or minus 2°. To accomplish angular adjustments, each blade must of course be rotatable about the OZ axis as shown in FIG. 2. Control of the adjustments can be effected in several ways; (a) through a bell crank arrangement inside the hub actuated by mechanical or hydraulic means and programmed in suitable manner (b) through resilient means inside the hub or (c) through a special design of the blades and of the blade mounting on the hub as hereinafter described.

The essential features of a self-adjusting controllable pitch propeller are shown in FIG. 2. This figure shows a two-bladed screw propeller **13** for simplicity. Extension of the principle of this invention to a propeller with more than two blades is merely a matter of design. In this embodiment the multiple-bladed propeller has an even number of blades, that is two, four, six . . . blades. FIG. 2 is the longitudinal view of the propeller, that is, the propeller projected on the lateral plane of the ship. FIG. 3 is the transverse view, that is the propeller projected on a plane transverse to the fore and aft axis of the ship.

FIG. 2 shows in section the interior hub connections of the two-bladed propeller **13**. The drive shaft **15** is connected to the hub **17** at one end by suitable mountings shown as a ring **19** and a plurality of bolts **21** and a hub cap or fairwater **23** is placed over a cover plate **25** at the other end. The two-bladed propeller having an upper blade **27** and a lower blade **29** is connected together in the hollow, central portion of the hub **17**. Each blade is secured by any suitable means to a blade spindle **31** which extends into the center of the hub. The blade spindles are connected together by any suitable means shown as a sleeve **33** having two pins **35**, one pin extending through the end portion of each spindle and through the sleeve. The sleeve thereby forms a rigidly connected two-blade propeller and the spindles ride on bearings **37** which are provided about the blade spindles, thereby enabling the rigidly connected two-bladed propeller **13** to rotate about the OZ axis. The rigidly connected two-bladed propeller construction causes the rotational motion of each pair of blades to be such that when the angle of attack α increases for the top blade by an amount $\Delta\alpha$ it decreases for the bottom blade by the same amount.

The novel arrangement of FIG. 2 is self balancing in ahead operation as is shown in connection with FIG. 4. In this figure the OZ axis is normal to the plane of the drawing, the direction of rotation of the shaft is shown and the blade area is skewed aft as shown in FIG. 3 wherein the center of pressure P of the blade **27** lies rearward of the OZ axis. When the ship velocity (V_s), the velocity of advance (V_a), and the rotation velocity (ωr) are all uniform, the lift forces L and and L1 are equal. Since that the opposing blades **27** and **29** have the same shape, the moments of these forces about the OZ axis are also equal; that is

$$M=L\bar{X}=M1=L1\bar{X}1$$

where

M= the moment
L=lift force
$\bar{X}$=distance from the OZ axis to the pressure point on each blade

When there is some irregularity in the wake, the inflow angle of the upper blade is increased by the amount $\Delta\alpha$ but not for the lower blade, then the force L increases; this causes an inequality in moments, that is

$$L\bar{X}>L1\bar{X}1$$

And the system rotates about OZ in a clockwise direction. This rotation tends to diminish α for the upper blade **27** and tends to increase it for the lower blade **27**. The tendency therefore is to restore equilibrium in moments. Hence, there is a feathering action by the blades which tends to counteract the force of fluctuations reduced by wake or other flow regularities. The blades therefore exhibit an oscillatory motion in a variable wake, oscillating plus or minus two degrees about a mean value. In prior systems, the different pressures on the blades would be transmitted to the hub and the surrounding water due to the rigid connections of the hub and blade.

The system described is in stable equilibrium only for normal ahead operations. When the ship is backing, the equilibrium is unstable because the propeller is designed for forward operation. This invention provides sufficient room so that the blades can turn through 180 degrees so that, when the ship is backing and the blades have turned through the 180 degrees, operation is the same as for normal ahead operations. This reversal feature of the blades for backing operation is very useful because blade sections designed for best efficiency for ahead operation becomes very inefficient for backing. As a result of this decreased efficiency, the propulsive efficiency of a ship when backing is no more than ⅔ of the propulsive efficiency when moving forward. Therefore, the new propeller not only tends to smooth out force fluctuations but is also capable of improving the efficiency astern by as much as 30 percent which permits reducing the size of the astern turbine without imparing maneuverability.

FIG. 5 is an embodiment of a four-bladed propeller **39** constructed according to the present invention. One pair of blades **27** and **29** are connected together by a straight connecting rod **41** attached to the respective spindles **31** and a second pair of blades **45** and **43** are connected together by a forked connecting rod **47** with the straight connecting rod inserted through the fork. Mechanical limit stops **49** are provided about the blade to allow a rotation of the blade of approximately plus or minus 5 degrees, thereby insuring adequate rotational movement of the connecting rods without interference.

A second way to smooth out wake irregularities which may be used on a propeller having any number of blades, is to control the angle of incidence of the blade by resilient means. This embodiment is shown in FIGS. 6 and 7 wherein the same reference numerals are employed as in the previous figures. The hub **17** of the multi-bladed propeller **51** has a cover plate **25*a*** mounted on one end and a hub cap or fairwater **23*a*** mounted over the cover plate. A plurality of holes **53**, equal to the number of blades on the propeller are provided in the cover plate **25*a***. One part **54** of the hole in communicating relationship with the interior of the hub **17** is square in transverse cross-section and the other portion **55** of the hole in communicating relationship with the interior of the fairwater **23*a*** is circular in cross-section with a diameter greater than the greatest dimension of the square hole and abuts the square hole at a shoulder **56**. The circular hole and the shoulder form a seat for a resilient element such as a spring which rides on tension rod **59** having a middle portion **60** which is square in cross-section and is supported in sliding contact by the square hole **54**. The spring **57** is adjustably biased against the seat by a tension nut **61** located at one end of the tension rod **59**. The other end of the tension rod is provided with a cutaway portion which has a longitudinal flat portion **63** abutting a shoulder **64**. A flat, longitudinal flexible band **65** is placed upon the flat portion of the rod and is secured thereto by a clamp and screw **67**. The other end portion of the tension band is secured to the spindle **31** by any suitable means such as a clamp and screw **69** shown in the drawing. A longitudinal bar **71** having a plurality of apertures **73** at one end is secured at its other end to cover plate **25*a***, by a plurality of screws **75**. The apertures provide a bearing surface for the lower part **77** of the spindle **31** which is received by the aperture and is supported thereby. Mechanical stops may also be provided about the blade to limit rotation of the blade.

The operation of the spring biased propeller is essentially as follows. The spring **57** is selected to bias the propeller blades to a predetermined pitch for a desired flow condition. When the propeller revolves about its axis, the pressure on the blades due to the wake causes the spring **57** to be compressed and the tension bands **65** to wrap around the spindle **31** until the compression force on the spring and restoration force of the spring is in equilibrium and the predetermined pitch of the propeller is attained. When the propeller operates in a variable wake, the varying lifting forces on the blade **27** cause the blade **27** and spindle **31** to revolve in an attempt to relieve this varying pressure. The turning of the spindle causes the tension band **65** to wrap around the spindle and to compress the spring **57** more. The spring tends to counteract the compression force by its restoration force to obtain equilibrium of forces and return to its predetermined position, which it does when the excess pressure is removed from the blade. The returning of the spring **57** causes the tension band **65** to unwind and in turn the spindle and blade are returned to the desired operating pitch for the propeller. This spring biasing feature thus allows a propeller having any number of blades to be fabricated for operation according to the principles of the present invention.

As discussed before, another way to smooth out wake irregularities in addition to the aforedescribed passive systems is to alter the angle of incidence by a programmed mechanical force. Once the wake variation is known from model tests, the angle of incidence of each blade can be controlled as the propeller rotates through 360 degrees. By proper sequencing of the actuators, which could be hydraulic rams, the operation of the system can be made automatic. The advantage of controlled adjustment of the angle of incidence over the self-balancing system is that wake variations can be anticipated and thereby, force fluctuations can be completely smoothed out. Another advantage is that as in the spring biased system, an odd number of blades as well as an even number of blades, can be used.

Obviously many modifications and variation of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A feathering controllable pitch propeller for reducing ship vibrations comprising:
- a hub;
- a plurality of blade spindles spaced about said hub, each of said spindles rotatable in said hub about an axis perpendicular to the axis of rotation of the propeller;
- a plurality of propeller blades each of said blades being secured to one of said blade spindles;
- each of said blades having a blade area which is skewed aft and having a center of pressure lying aft of the blade axis of rotation;
- resilient means biasing each of said blade spindles for controlling the angle of attack of the propeller blades in response to wake force fluctuations;
- a cover plate mounted on one end of the hub having a plurality of circumferentially spaced apertures;
- a tension rod slidably mounted in each of the apertures of said cover plate;
- a spring mounted in overlying relation to one end of each of said rods;
- holding means forcing each of said springs against one side of said cover plate;
- a plurality of flexible tension bands each having one end secured to the other end of one of said rods and having its other end secured to one of said spindles;
- whereby said band winds around said spindle in response to an increase in pressure on the associated blade and unwinds under the force of said spring in response to a decrease in pressure;
- each of said apertures in said cover plate comprising two portions, with one of said portions being square in transverse cross-section, said square portion receiving a square middle portion of said tension rod thereby preventing rotational movement of said rod and twisting of said band;
- said other portion being circular in transverse cross-section and having a diameter greater than the greatest dimension of the square portion, whereby said circular portion forms a seat for said spring; and
- a longitudinal bar secured at one end to said cover plate, said bar having aperture means therein receiving a portion of said blade spindles for providing bearing surfaces for said blade spindles.

2. A feathering controllable pitch propeller for reducing ship vibrations comprising;
- a hub;
- a plurality of blade spindles spaced about said hub, each of said spindles rotatable in said hub about an axis perpendicular to the axis of rotation of the propeller;
- a plurality of propeller blades each of said blades being secured to one of said blade spindles;
- each of said blades having a blade area which is skewed aft and having a center of pressure lying aft of the blade axis of rotation;
- a plurality of resilient means, each of said resilient means biasing one of said blade spindles for independently controlling the angle of attack of the associated propeller blade in response to wake force fluctuations without affecting the angle of attack of the other propeller blades;
- a cover plate mounted on one end of the hub and having a plurality of circumferentially spaced apertures;
- a tension rod slidably mounted in each of the apertures of said cover plate;
- said resilient means comprising a spring mounted in overlying relation to one end of each of said rods;
- holding means on said one end of each rod, said holding means forcing each of said springs against one side of said cover plate;
- a plurality of flexible tension bands each having one end secured to the other end of one of said rods and having its other end secured to one of said spindles, whereby said band winds around said spindle in response to an increase in pressure on the associated blade and unwinds under the force of said spring in response to a decrease in pressure;
- each of said apertures in said cover plate comprising two portions, a first portion receiving a portion of said tension rod and cooperating therewith for preventing rotational movement of said rod and twisting of said band;
- the second portion of each aperture being circular in transverse cross-section and having a diameter greater than the greatest dimension of said first portion, whereby said circular portion forms a seat for said spring; and
- a longitudinal bar secured at one end to said cover plate, said bar having aperture means therein receiving a portion of said blade spindles for providing bearing surfaces for said blade spindles.

References Cited by the Examiner

UNITED STATES PATENTS

608,265	8/1898	Olsen	170—160.1
1,841,497	1/1932	Parham	170—160.51
1,919,586	7/1933	Dodge	170—160.51
2,231,464	2/1941	Dubbs	170—160.57
2,395,862	3/1946	Freeman et al.	170—160.51 X
2,483,913	10/1949	Lampton	170—160.52
2,583,369	1/1952	Fumagalli	170—13 X

FOREIGN PATENTS

563,529	9/1923	France.
888,497	9/1943	France.

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