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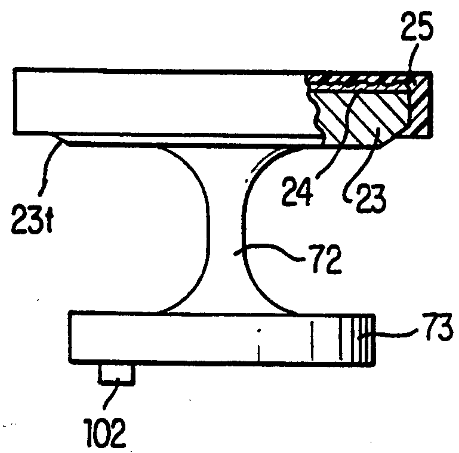

(57) Abstract

A hydrodynamic bearing which includes a carrier (10) and a plurality of bearing pads (23) circumferentially spaced about the carrier. The pads may have a modular construction whereby pad portions are secured to support portions (72). The pads may also be releasably secured to the carrier (10). Various bearing pad constructions are contemplated.

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PAD TYPE HYDRODYNAMIC THRUST BEARINGS HAVING A MODULAR CONSTRUCTION

Background of the Invention

The present invention relates to hydrodynamic bearings. In such bearings, a rotating object such as a shaft is supported by a stationary bearing pad via a pressurized fluid such as oil, air or water. Hydrodynamic bearings take advantage of the fact that when the rotating object moves, it does not slide along the top of the fluid. Instead the fluid in contact with the rotating object adheres tightly to the rotating object, and motion is accompanied by slip or shear between the fluid particles through the entire height of the fluid film. Thus, if the rotating object and the contacting layer of fluid move at a velocity which is known, the velocity at intermediate heights of the fluid thickness decreases at a known rate until the fluid in contact with the stationary bearing pad adheres to the bearing pad and is motionless. When, by virtue of the load resulting from its support of the rotating object, the bearing pad is deflected at a small angle to the rotating member, the fluid will be drawn into the wedge-shaped opening, and sufficient pressure will be generated in the fluid film to support the load. This fact is utilized in thrust bearings for hydraulic turbines and propeller shafts of ships as well as in the conventional hydrodynamic journal bearing.

Both thrust bearings and radial or journal bearings normally are characterized by shaft supporting pads spaced about an axis. The axis about which the pads are spaced generally corresponds to the longitudinal axis of the shaft to be supported for both thrust and journal bearings. This axis may be termed the major axis.

To a large extent, the problems associated with prior art hydrodynamic bearings have been solved by the bearing construction described in U.S. Patent No. 4,676,668 to Ide, the present inventor. This bearing construction includes a plurality of discrete bearing pads press fit into a support portion. The bearing pads may be spaced from the support member by at least one leg which provides flexibility in three directions. To provide flexibility in the plane of motion, the legs are angled inward to form a conical shape with the apex of the cone or point of intersection in front of the pad surface. Each leg has a section modulus that is relatively small in the direction of desired motion to permit compensation for misalignments. These teachings are applicable to both journal and thrust bearings.

While the construction described in the present inventor's previous patent represents a significant advance in the art, commercial production has shown that improvements are possible. For instance, the shape of the bearing pads is relatively complex; and consequently somewhat difficult to mass produce, use in radial or journal bearings, and dampen.

Additionally, since the bearing pads are unitary, the entire bearing pad must sometimes be constructed out of the most expensive material necessary in any part of the bearing. The unitary construction also makes it difficult to change the performance characteristics of any particular bearing pad. This necessitates a different bearing pad for each application thus limiting the ability to standardize bearing components (i.e., use standard components in different configurations for each application) and achieve the cost and other commercial advantages associated with standardization.

The press fitting of the pads into the carrier also complicates assembly of bearings. Moreover, by virtue of this press fit, the bearing pads cannot be easily removed from the carrier. This complicates reuse of the carrier (the most substantial portion of the bearing) in the event of a failure.

Summary of the Invention

The present invention relates to improvements in hydrodynamic thrust bearings of the type which includes a plurality of discrete bearing pads mounted in a carrier in a circumferentially spaced relation. Generally, the present invention relates to improvements in pad and carrier design.

Conceptually, the bearing pads and carriers of the present invention are designed by treating the pads and carriers as a solid piece of material and then selectively removing or adding material to the solid to cause it to deflect in a desired way under design loads. It can be readily appreciated that myriad designs are possible. Thus, it should be kept in mind that the structural features disclosed herein are generally applicable to any other bearing pad if structural conditions make this possible.

The inventor has discovered that in many specific applications such as in high speed applications, it is necessary to examine and evaluate the dynamic flexibility of the entire system consisting of the shaft or rotor, the hydrodynamic lubricating film and the bearing. This analysis should also involve consideration of other conditions which could impact wedge formation. For instance, it is know that shaft to pad contact can lead to thermal crowning which will, naturally, impact the shape of the space between the pad and the shaft surface. In computer analysis of this system using a finite element model, it has been determined that it is necessary to treat the entire bearing as a completely flexible member that changes shape under operating loads. By adding more or less flexibility via machining of the basic structure, bearing characteristics may be achieved that provide stable low friction operation over wide operating ranges. A number of variables have been found to substantially affect the bearing's performance characteristics. Among the most important variables are the shape, size, location and material characteristics (e.g.

modulus of elasticity etc.) of the pad and support members defined by the bores, slits or cuts and grooves formed in the bearing. The shape of the support members has been found to be particularly important.

In accordance with another important aspect of the bearings of the present invention, the bearing pads can be supported for deflection so as to retain the hydrodynamic fluid, thus obviating the problem of fluid leakage. With respect to radial or journal bearings, the support structure is designed such that, under load, the bearing pad deflects to form a fluid retaining pocket. Generally, such a support is achieved when the primary support portion is connected to the bearing pad proximate the axial edges of the bearing pad and the center of the bearing pad is not directly supported, i.e., is free to deflect radially outward. With respect to thrust bearings, the pad is supported so as to tilt toward the bearing's inner diameter under load so as to prevent centrifugal leakage. Generally, this is achieved when the pad support surface at which the primary support structure supports the bearing pad is located closer to the bearing outer diameter than to the bearing inner diameter. When the primary support structure includes two or more radially spaced beams, the overall support structure must be designed to cause deflection of the bearing pad at the inner end. Further, when the bearing pad is supported by a plurality of radially spaced beams and the region between the beams is not directly supported, the pad will tend to deflect so as to form a concave fluid retaining channel.

The pad surface bearing pad portion may also be coated with a separate material such as hardened rubber or the surface may have a separate pad insert of a high performance material such as silicon carbide.

The support portion preferably has a shape which conforms to the shape of the openings in the carrier. If this shape is non-cylindrical, the pad will be precisely positioned when it is fit into the carrier.

A wear surface may be molded onto the pad when the pad support is such that wear is expected during operation, e.g. at start-up. The wear surface is preferably formed from a material having a high PV limit such as CELEDYNE™. If necessary, a layer of surface roughness can be provided on the pad to better secure the wear surface to the pad. The edges of the pad may be tapered to improve inlet bending.

In some instances, the requirements for a particular application may be satisfied with a simple center post design which although quite rigid is shaped or positioned to favorably influence deflection. The center post may be double curved, cylindrical, oval or any other easily manufactured shape. The post may be offset with respect to the pad portion it supports.

Brief Description of the Drawings

FIG. 1A is a side cross-section of a thrust bearing construction according to the present invention.

FIG. 1B is a partial top view of the bearing construction of FIG.1A.

FIG. 2 is a perspective view of a sector shaped thrust pad with arrows indicating the side lines for the top side and edge views.

FIG. 3 is a perspective view of a circular thrust pad.

FIG. 4 is a side view of a thrust pad with tapered edges.

FIG. 5 is a top view showing an arrangement of bearing pads on a carrier according to the present invention.

FIG. 5A is a top view of another bearing pad according to the present invention.

FIG. 6A is a top view of a carrier member having a locator posts for positioning the bearing pads.

FIG. 6B is a cross-section of the carrier member of FIG. 6B along the lines indicated in FIG. 6A.

FIG. 6C is a top view of the carrier member of FIG 6D.

FIG. 6D is a cross-section of another carrier member having a locating protrusion.

FIG. 6E is a top view of a carrier member having locating openings formed therein.

FIG. 6F is a cross-section of the carrier of Fig. 6E.

FIG. 6G is a top view of a carrier formed with non-cylindrical openings.

FIG. 7 is a top view of another bearing pad according to the present invention.

FIG. 7A is a cross-section of the bearing pad of Fig. 7 along the lines indicated by arrows in Fig. 7.

FIG. 7B is a front view of the bearing pad of Fig. 7.

FIG. 7C is a cross-section of the bearing pad of Fig. 7 formed with a wear surface.

FIG. 8 is a partial front view of a bearing assembly showing one bearing pad and a part of a carrier in section.

FIG. 8A is a top view of the bearing pad of Fig. 8 with some obscured features in phantom.

FIG. 8B is a front view of the bearing pad of Fig. 8 having a surface roughening layer formed thereon.

FIG. 8C is a front view, partially in section, of the bearing pad of Fig. 8 with a wear surface formed thereon.

FIG. 9 is a top view of another bearing pad according to the present invention.

FIG. 9A is a front view of the bearing pad of Fig. 9.

FIG. 10 is a top view of another bearing pad according to the present invention.

FIG. 10A is a front view of the bearing pad of FIG. 10.

FIG. 10B is a front view of another bearing pad according to the present invention.

FIG. 11 is a front view of another bearing pad according to the present invention.

FIG. 12A is a front view of another bearing pad according to the present invention.

FIG. 12B is a front view of another bearing pad according to the present invention.

Detailed Description of the Drawings

FIGS. 1A and 1B illustrate the general environment of the present invention, namely hydrodynamic thrust bearings, which include a carrier member 10 having a plurality of openings such as bores formed therein and a plurality of bearing pad members 20 mounted in the openings. The bearing pads may be circumferentially spaced as indicated in, for example FIGS 1B.

In the past, the pad shape of hydrodynamic bearings has been primarily dictated by manufacturing convenience. For a thrust bearing, this has traditionally meant sector shaped pads to maximize the area of support or -- in the case of applicant's prior U.S. Patent No. 4,676,668 -- circular pads for low cost manufacture. In many cases, such conventional pad shapes can be supported to obtain optimum results. However, the present inventor has discovered that important performance characteristics can be achieved by modifying conventional pad shapes. Consequently, the support structure can be simplified, and in some cases, even eliminated.

Examples of typical thrust pad shapes are illustrated in FIGS. 2 and 3. FIG. 2 shows a sector shaped pad 132. The sight lines for a top view T, an edge view E and a side view S are indicated by arrows labeled T, E and S, respectively. FIG. 3 shows a circular pad 20. These pad shapes are characterized by uninterrupted planar surfaces and a uniform pad thickness. The arrangement of the pads on the carriers is illustrated in Figs. 5 and 5A.

Various modifications to traditional thrust pad shapes will be discussed hereinafter. In general, the effect of these modifications for any particular application can be determined through the use of finite element analysis. Such an analysis can also account for other factors which might impact wedge formation. For instance, if the support structure permits sustained shaft to pad contact, the pad will heat up. This temperature rise will result in thermal distortions or crowning of the pad. With finite element analysis these thermal effects can be used to enhance wedge formation. It should be kept in mind that any of these modifications to the shape of the pad may be used in combination or alone. Also, the modifications can be easily adapted to pads having shapes other than the specific pad shapes illustrated. Moreover, the pads may be symmetrically shaped to allow bidirectional operation or non-symmetrical to provide different operating conditions depending on the direction of rotation.

FIG. 4 illustrates another possible modification to the basic pad shape. Specifically, it has been learned that tapering the leading edge of the bearing pad results in increased inlet bending. This allows more lubricant to enter into the shaft-pad space which increases the load carrying capability of the pad. Complex finite element analysis using computers can predict the amount of bending needed to obtain optimum lubricant flow.

The drawings illustrate the use of tapered edges in thrust, radial, and combined radial/thrust bearings. Specifically, FIG. 4 is a side view along the S axis in FIG. 3 illustrating a thrust bearing pad 132 with a taper 132t formed at each edge. Again, the taper is provided at each end to allow for bidirectional operation. Of course, if unidirectional operation is sufficient, only one edge, the leading edge, should be tapered.

Figs. 7-7C illustrate a pad construction according to the present invention. In this construction, a pad includes a sector shaped pad 23 supported on a support post 70. As best shown in Fig. 7, the support post 70 has an oval cross-section a radial dimension which is larger than its circumferential dimension. Provision of an elongated post 70 of the type shown in Figs. 7-7C serves several functions. First, when a pad 20 of this type is mounted in a carrier 10 of the type shown in Fig. 6G (discussed below) having complimentary openings 101 for receiving the post 70, the pad 20 is automatically positioned in the precise location desired. In contrast, if the pad 20 were formed with a cylindrical support, it would have to be positioned in some other way.

In addition, the provision of an elongated oval post of the type shown in Figs. 7-7C affects the support of the pad portion 23. Specifically, since the support post 70 has a radial dimension greater than its circumferential dimension, the support of the pad 23 is more rigid in the radial direction than in the circumferential dimension. In the bearing pad 20 shown in Figs. 7-7C this effect is compounded since the sector shape of the pad portion 23 has a circumferential dimension greater than its radial dimension. Thus, as a result of both the shape of the pad portion 23 and the configuration of the support post 70, the circumferential ends of the pad portion 23 are relatively unsupported whereas the central region of the pad portion 23 is relatively rigidly supported.

An important aspect in the design of bearing pads such as those shown herein is to allow lubricant to circumferentially enter the pad region and to prevent circumferential leakage of the fluid lubricant. In the case of the bearing pads shown in Fig. 7-7C, this objective is achieved by designing the support such that under load, the radially inner edge (RIE) of the bearing pads deflect downward as viewed in Fig. 7B and the outer edge deflects upward. As best shown in Fig. 7, the support post 70 is connected to the pad portion 23 at a location which is closer to the radially outer edge (ROE) of the bearing pad than it is to the inner edge (RIE) of the bearing pad 20. Thus, the pad support surface, i.e., the surface at which post 70 contacts pad portion 23, is located radially outward of the radial dividing line. Considered another way, the geometric center of the pad PC is offset from the geometric center of the support post SC. Hence, the bearing is designed such that under load, the inner edge of the bearing deflects downward.

In operation, the downward deflection of the inner edge of the bearing pad corresponds to deflection away from the shaft supported and upward deflection of the outer edge of the bearing pad corresponds to deflection toward the shaft. The deflected orientation of the bearing pad permits lubricant to pass the radially inner edge RIE and enter the wedge region as a result of centrifugal forces and significantly inhibits the loss of fluid past the radially outer edge ROE which otherwise occurs as a result of the centrifugal forces acting on the fluid. While it is possible to optimize the design in this regard for any particular application, a general rule of thumb is that the geometric center of the support posts SC should be offset from the geometric center of the pad PC by about 10 percent.

As can be appreciated best from Fig. 7A, the support post 70 which supports the pad portion 23 is quite rigid. Indeed, this pad by itself would not permit movement of the pad portion 23 with six degrees of freedom. The present inventor has found that movement with six degrees of freedom is not always necessary to achieve adequate results. For example, in conventional tilt bearings, the individual pads need only tilt or pivot about an axis parallel to the rotor. A known rocker pivot pad has nearly zero rotational pivot stiffness. Such bearings are known to provide adequate performance, but they are more expensive and difficult to tailor to individual applications. Thus, for some applications, a pad having limited flexibility such as that shown in Figs. 7 and 7C is acceptable.

The pad shape can be modified along the lines discussed above to achieve the disclosed results. In the case of the bearing pad 20 shown in Fig. 7-7C, one particular modification employed is the tapering of the lower circumferential edges of the bearing pads to yield increased inlet bending. This allows more lubricant to enter into the shaft-pad space which increases the load carrying capability of the pad as discussed above in connection with Fig. 4. Specifically, as best shown in Fig. 7B the lower edge of the pad portion 23 is tapered. Since the particular bearing pad 20 shown is intended for bidirectional operation, (i.e., it is symmetrical and can support a shaft rotation at either direction), each of the two radially extending circumferential edges, (i.e., those edges extending between the radially inner edge (RIE) and the radially outer edge (ROE)) of the pad portion 23 are provided with tapers 23t to increase inlet bending. As best shown in Figs. 7 and 7B, the bearing pad further includes a chamfer on its top surface to permit easy entrance of lubricant.

As noted earlier, the pad construction shown in Figs. 7-7C has limited flexibility. In many cases, this flexibility, though limited, is sufficient to achieve hydrodynamic operation. In other instances, the carrier 10 in which the pad 20 is mounted can be provided with flexibility to allow increased deflection if this is called for. In some cases, however, the relatively rigid support structure is adequate in all cases except during start up. In these instances, the present invention allows for the possible provision of a wear surface so as to avoid damage to the pad during start-up as shown in the embodiment of Fig. 7C. The objective of such a wear surface is to allow the pad to withstand wear caused during start-up. Even with a relatively rigid support structure of the type shown in Figs. 7-7C, the pad can be designed to achieve hydrodynamic operation during steady state conditions, but the wear characteristics at start-up can cause a potential concern. By providing a wear surface the bearing is in effect designed to operate in two modes. First, at initial start-up, the bearing acts as a wear bearing wherein the shaft rubs against the pad surface. After start-up, the bearing pad operates hydrodynamically and there is little or no contact between the shaft and bearing pad surface.

While various materials can be used to provide the wear surface the preferred embodiment of the present invention comprises the use of a CELEDYNE™ resin molded around the pad as shown at 25 in Fig. 7C.

The bearing pad 20 may be formed of a wide variety of metal or plastic materials. In most common applications, however, the bearing is formed of metal typically either cast bronze or steel. Depending on the surface roughness of the pad 20, it may be desirable to add a layer of surface roughness 24 before molding the CELEDYNE™ wear surface 25 onto the pad 20. Several methods for doing this are described below.

Another bearing pad according to the present invention is disclosed in Figs. 8-8C. In this embodiment, the bearing pad 20 includes a circular pad portion 23 which is formed with a continuous taper 23t along its lower circumferential edge. The pad portion 23 is supported by a cylindrical support post 71 which, in this case, coaxially supports the pad portion 23. The pad 20 further includes a base 73 supporting the support post 71. In this particular case, the base 73 provides no additional flexibility to the bearing pad and functions merely to support the support post 71. Thus, if desired, the support post 71 could be mounted directly in a carrier and the base 73 could be eliminated without affecting the function of the pad 20.

Alternatively, the base 73 could be formed with a threaded opening for receiving a fastening screw 41 to secure the pad 20 to a carrier 10 as shown in Fig. 8. This type of fastening screw securement means could be used to secure most of the pads 20 disclosed herein to the carriers 10 disclosed herein, but is particularly well suited to pads having a solid base.

The pad shown in Figs. 8-8C is symmetrical. Thus, its position within a bore 101 in a carrier 20 does not affect its performance. Hence, there is no need for means for precisely positioning the pad within the bore.

The pad shown in Figs. 8-8C is, again, quite rigid. The support post 71 rigidly supports the central region of the pad portion 23, but does not directly support the outer periphery of the pad portion 23. Accordingly, the leading edge of the bearing pad portion 23 is less rigidly supported and likely to bend to permit formation of a hydrodynamic wedge. The inlet bending effect is further enhanced by the provision of the taper 23t which as described herein, improves wedge formation.

Because of the relative rigidity of the support post 71 which supports the pad portion 23, there is a possibility that wear will occur between the pad surface and the shaft in certain applications. In these applications, if such wear is particularly troublesome, the bearing pad 20 can be provided with a wear surface 25 as shown in Fig. 8C and previously discussed. Again, the wear surface 25 can be formed of any suitable wear material. However, the currently preferred material is CELEDYNE™ resin molded onto the surface of the pad portion 23.

Since the surface of the pad portion 23 is typically quite smooth, it is sometimes difficult to cause a wear material such as CELEDYNE™ to adhere to the pad surface. A currently preferred method of adhering a resin material such as CELEDYNE™ to a bearing pad in accordance with the present invention will be described hereinafter with reference to Figs. 8B and 8C.

To obtain proper adherence it is necessary to have a sufficiently rough surface onto which the resin is molded. This surface can be achieved by casting the part as a relatively rough surface. In the case of machined part, however, it is preferable to provide a layer of surface roughness 24 prior to molding the resin onto the pad. There are a number of ways in which this can be achieved. For example, small pieces of bronze can be melted onto the pad surface to form a rough surface. The preferred method, however, is to flame spray the pad with an aluminum/bronze (10% aluminum/90% bronze)alloy. By doing this, a relatively porus/rough surface can be achieved. This surface, during molding, allows the resin to flow into the surface craters and to lock into place. The pads are then heated slightly before they are inserted into the mold cavity, allowed to continue to heat in the mold, and then resin is injected onto the pad. The parts may then be annealed if desired. Tests have shown that the bonded surface shows good to excellent flow of material into the coating and adequate bond strength.

Fig. 8B shows a pad 20 having a surface roughening layer 24 provided thereon. Again, this surface roughened layer 24 is preferably formed by flame spraying an aluminum/bronze alloy onto the pad surface.

Fig. 8C shows a pad 20 in which the layer of resin 25 has been molded onto the pad 20 and is adhered to the pad by the surface roughening layer 24.

As previously noted, the support post 71 shown in Figs. 8 and 8A supports pad portion 23 at the geometric center of the pad portion 23. The advantage of such an arrangement is that the pad is symmetrical. This simplifies manufacture and assembly somewhat. In other instances, however, it is preferable to have the support post offset with respect to the pad portion 23. Figs. 9-10B depict bearing pads in which the support post 71 is offset to achieve the desired results.

In the embodiment shown in Figs. 9 and 9A, the support post 71 has a support center SC which is radially offset from the center PC of the pad portion 23 by an amount indicated as RO. Note, however, that the support is symmetrical about the circumferential center line CCL which is defined as a radial line passing through the center of the pad portion 23 and the axis of the carrier 10 (not shown). The radial center line indicated as RCL in Fig. 9 is defined as the circle center on the axis of the carrier and passing through the pad center PC.

There are several considerations involved with a non-symmetrical pad of the type shown in Figs. 9 and 9A. The first such consideration is that the pad 20 must be precisely positioned within the opening 101 in the carrier 10 because of its non-symmetrical construction. Various ways of achieving this are discussed herein, including use of locator posts and the like. In the embodiment shown in Figs. 9 and 9A, a locator post 102 is provided on the base 73. As discussed in regard to Figs. 6E and 6F, the carrier 10 is provided with a complimentary opening 103 for receiving the locator posts 102 so as to precisely position the bearing 20 in the carrier 10.

Because the support center SC of the support post 71 is located radially past the radial center line RCL, the pad portion 23 is supported such that the radially innermost edge RIE is supported for downward deflection under loading so as to increase bending to allow centrifugal entrance of oil. Conversely, the radially outermost edge ROE of the pad portion 23 is rigidly supported so that it forms a fluid dam to prevent centrifugal leakage of oil. Again, as a rule of thumb the point of attachment of the support post 71 to the pad portion 23 is normally shifted about 10 percent toward the outer diameter to increase bending.

The pad portion 23 is also provided with a continuous taper 23t to increase inlet bending as discussed above.

Finally, it is noted that the pad shown in Fig. 9 and 9A is suited for bidirectional operation since the pad is symmetrical about the circumferential centerline. In other words, the deflection characteristics of the pad will not change when rotation of the shaft is reversed.

Figs. 10-10B show another non-symmetrical pad construction. In this case, however, the pad 20 is designed for one-directional or unidirectional operation in the direction indicated by the arrows on the radial center line RCL. In the case of such one directional bearings, the point of attachment of the support post 71 to the pad portion 23 is typically offset. As a rule of thumb, the pad portion 23 should be shifted about 12% toward the trailing edge as shown best in Fig. 10. Thus, the support post has a support center SC which is offset from the center PC of the pad portion 23 circumferentially by a circumferential offset amount indicated as CO in Fig. 10 and radially by an amount indicated as RO in Fig. 10.

The radial offset serves essentially the same function as the radial offset in the bidirectional bearing shown in Figs. 9-9A and described above. The circumferential offset CO is provided to improve inlet bending by making the leading edge less rigidly supported. The pad portion 23 also includes a continuous taper 23t to improve inlet bending. Again, like the embodiment of Figs. 9 and 9A, the embodiment of Figs. 10-10B includes a locator post 102 to allow the pad 20 to be precisely positioned within the carrier 10.

Fig. 10B shows a slight modification to the bearing pad of Figs. 10 and 10A. Specifically , the pad 20 is provided with a wear surface 25. Again, the wear surface is preferably provided by molding a CELEDYNE™ resin onto the pad portion 23. In the embodiment shown in Fig. 10B, the support post 71 is also significantly thinner, and hence, more flexible than the support posts 71 shown in Figs. 10 and 10A.

It should be noted that, support posts described herein can have thin, thick or moderate diameters depending on viscosity, load, speed, envelope and general operating requirements. In addition, the operating requirements can be modelled using finite element analysis to determine the optimum dimensions for any particular application.

Fig. 11 shows another pad 20 according to the present invention. The pad 20 includes a pad portion 23, a support portion 72 and a base 73. Again, the base 73 is designed to be mounted in a bore 101 in one of the carrier constructions 10 disclosed herein. In this case, the base 73 is formed with a thread 40 as discussed above in connection with Figs. 11A and 11B, for example. The support 72 of the pad in this case is formed with a continuously curved surface which is thinnest at the central portion of the support 72 and flares out toward both the pad portion 23 and the base 73. Geometrically, this complex shape is roughly equivalent to the shape of the hole in a doughnut or, more technically, the shape enclosed within a torus or annulus which is a double-curved surface generated by revolving a circle about a straight line axis which does not contain the center of the circle. The purpose of the complex shape of the support portion 72 is to increase flexibility of the center region of the support post 72 and relieving stress from the end regions at which the post 72 joins the pad portion 23 and the base 73. These regions might otherwise be subject to stress concentrations. By virtue of this construction, the pad 20 has a tendency to tilt more easily about the center of the support portion 72 to improve deflection. The support portion 72 may be coaxial with the pad portion 23, to simplify manufacture and assembly. Alternatively, the support portion may be offset either radially or both radially and circumferentially to achieve the aforementioned functional advantages.

Figs. 12A-12B disclose another bearing pad according to the present invention. This bearing pad construction is similar to that shown in Fig. 11 and described above. Specifically, the bearing pad 20 includes a pad portion 23, a base portion 73 and a support portion 72. The support portion 72 again flares in a continuous curve toward both the pad portion 23 and the base 73. In this case, however, the center region of the support portion 72 is somewhat elongated such that the shape of the support 72 cannot, strictly speaking, be described as the shape defined as the void left in the center region of a torus. Nonetheless, the support portion 72 achieves the same effects of providing maximum flexibility in the center region of the support 72 and relieving stress and reducing flexibility at those portions of the support 72 nearest the pad portion 23 and the base 73.

The pad portion 23 is provided with a continuous annular taper 23t at the lower edge thereof. As noted earlier, the provision of such a taper improves inlet bending.

Further, the base 73 includes a locator projection 102 for precisely positioning the pad 20 with the bores 101 of a carrier. Of course, such a locator post is especially useful when the post center is offset from the pad center.

As shown in Fig. 12B, the bearing pad 20 may be provided with a wear surface 25. Again, the wear surface 25 is preferably formed by molding CELEDYNE™ to the pad portion 23 as shown in Fig. 12B. In addition, if necessary to assure proper adherence, a surface roughening layer 24 may be provided on the surface of the pad portion 23 prior to molding of the resin or other material onto the pad portion 23.

One particularly important aspect of the present invention is the disclosure of easily machinable pad shapes. Specifically, the circular pad shapes of the type disclosed in Figs. 8-12B can be readily formed from cylindrical bar stock using a lathe. Pad shapes which can be formed using a lathe provide a significant advantage over known constructions in which complex machining or casting must be performed both in terms of production cost and the cost and complexity of manufacturing prototypes. In regard to the offset constructions, it is noted that the pad would have to be lathed on more than axis to form such configurations.

Another important advantage of the present invention is the disclosure of bearing pads which are formed separately from the carrier. Such constructions make it possible to use standard carriers 10 to achieve a wide variety of results using a relatively limited number of pads. Although the base portions of a number of the pads shown herein are described as simple cylindrical bases which can be mounted in the bores, it should be understood that the base can be threaded, press fit, adhered with an adhesive or the like to the carrier.

FIGS. 6A, 6B, 6C, 6D, 6E, 6F and 6G illustrate another aspect of the present invention whereby the bearing pads 20 can be precisely located within the carrier 10. In FIGS. 6A and 6B, the carrier 10 is provided with locating pins 102 non-symmetrically disposed within the bores 101 provided for receiving the bearing pads 20. The locator pin 102 can be received in one of the non-symmetrically disposed openings in a bearing pad support structure (or a similar opening provided somewhere else in the bearing pad), to precisely position the bearing pad within the bore in the carrier 10. An alternative construction is illustrated in FIGS. 6C and 6D. In this construction locating protrusions 102 extending from the wall of the bore 101 and used instead of separate locating pins. The locating protrusion can be received in a complementary notch formed in the dog leg or tertiary support portion of any of the bearing pads of the present invention. By virtue of this locking pin or protrusion arrangement, the pre-biased bearing pads are forced into proper alignment when mounted in the bore.

Figs. 6E-6F illustrate a similar construction in which locator holes 103 are formed in each of the bores 101. The locator holes 103 are adapted to receive the locator pins 102 formed on bearing pads such as, for example, those shown in Figs. 9A and 10A. Since bearing pads formed with a locator pin 102 can only be positioned within the bore 101 such that the locator pin 102 is received in the locator hole 103, the pads must be precisely positioned if they are to be received in the openings 101. One advantage of the construction shown in Figs. 6E-6F is that the carrier 10 will receive pads which do not have a locator pin 102 just as it will receive pins that do have a locator pin 102. Thus, the carrier construction shown in Figs. 6E-6F can be more widely used.

Yet another form of carrier for precisely positioning the bearing pads within the carrier is shown in Fig. 6G. This carrier 10 is adapted for receiving pads having a oval base such as the pads shown in Figs. 7-7C. Thus, the openings 101 have a non-circular, in this case, oval shape. By virtue of the non-circular shape of the openings 101, the pads must be precisely positioned to fit in the opening.

I claim:

1. A modular hydrodynamic bearing adapted to support a rotating shaft, the bearing comprising: a carrier member, the carrier member having a plurality of openings formed therein, the openings being spaced about a predetermined axis; a plurality of bearing pads secured in the openings of the carrier, each of the bearing pads comprising a pad portion having a pad surface and a support portion supporting the pad portion; wherein each of the pad portions is formed in a sector shape and the support portion extends perpendicularly from the pad portion, the support portion having a shape which conforms to the shape of the openings formed in the carrier such that the support portion can be secured in the carrier so as to space the pad portion from the carrier; and the support portion of each of the bearing pads being designed such that, under load, the bearing pads deflect to form a wedge with respect to the shaft.

2. The bearing of claim 1, wherein the support portion of each of the bearing pads has a oblong shape and the openings formed in the carrier have a complementary oblong shape such that when the pad is secured in the openings formed in the carrier, the sector shaped pad is precisely positioned within the carrier.

3. The bearing of claim 1, further comprising a wear surface formed on the pad portion of each of the bearing pads, the wear surface being formed of a different material than the pad portion.

4. The bearing of claim 3, wherein the wear surface is a high performance resin with a high PV rating such as CELEDYNE™.

5. The bearing of claim 3, wherein the wear surface is a resin molded onto the pad portion.

6. The bearing of claim 1, wherein the sector shaped pad portion has two circumferential edges and at least one of these circumferential edges is tapered at its lower end.

7. A modular hydrodynamic bearing adapted to support a rotating shaft, the bearing comprising: a carrier member, the carrier member having a plurality of openings formed therein, the openings having a predetermined shape and being spaced about a predetermined axis; a plurality of bearing pads secured in the openings of the carrier, each of the bearing pads comprising a circular pad portion having a pad surface and a cylindrical support portion extending perpendicular from the pad portion and supporting the pad portion.

8. A bearing of claim 7, wherein the pad portion has a lower edge and the lower edge is continuously tapered.

9. The bearing of claim 7, wherein the pads further comprise a base on which the cylindrical support post is supported.

10. The bearing of claim 9, wherein a locator projection is provided on the base and carrier includes a projection receiving opening for receiving the projection so as to precisely position the bearing pad with respect to the support portion.

11. The bearing of claim 7, wherein the cylindrical support post has a support center and the pad portion has a pad center and the support center of the cylindrical post is radially offset from the pad center.

12. The bearing of claim 11, wherein the support center of the cylindrical post is circumferentially offset from the center of the pad portion.

13. The bearing of claim 7, further comprising a distinct wear surface formed on the pad surface of a different material than the pad portion.

14. The bearing of claim 13, wherein the wear surface is formed of a resin molded onto the pad portion.

15. The bearing of claim 1, wherein the bearing pad support portion is threadably connected to the carrier.

16. The bearing of claim 1, wherein the support portion of each bearing pad is connected to the carrier via a spline lock connection.

17. A modular hydrodynamic bearing adapted to support a rotating shaft, the bearing comprising: a carrier member, the carrier member having a plurality of openings formed therein, the openings being spaced about a predetermined axis; a plurality of bearing pads secured in the openings of the carrier, each of the bearing pads comprising a pad portion having a pad surface and a support portion having an axis which is perpendicular to the plane of the pad surface and the support portion supporting the pad portion, and a base supporting the support portion; the support portion having a first end attached to the pad portion and a second end attached to the base and a central region between the first and second ends wherein a support portion is curved so as to flare outward toward the first and second ends so that the support portion is wider proximate the first and second ends than it is in the central region.

18. The bearing of claim 17, wherein the pad portion has a lower edge which is tapered to improve inlet bending.

19. The bearing of claim 17, wherein a separate and distinct wear surface is formed on the pad surface of a different material than the pad portion.

20. The bearing of claim 19, wherein the wear surface is formed of a resin molded onto the pad portion.

21. The bearing of claim 17, wherein the bearing pad portion is circular and has a pad center and wherein the axis of the support portion is radially outward of the pad center such that the pads are supported for deflection of the radially innermost edge downward under load.

22. The bearing of claim 17, wherein a locating projection is provided on one of the base portion of the pad and the support portion of the carrier and the other of the pad portion and the support portion includes a projection receiving opening for receiving the projection so as to precisely position the non-circular bearing pad with respect to the support portion.

23. The bearing of claim 17, further comprising locating means for precisely orienting each of the non-symmetrical bearing pads in the carrier.

24. The bearing of claim 17 wherein the carrier includes a plurality of bores adapted to receive the bearing pads and wherein a locating projection is formed in each bore and each bearing pad includes an opening for receiving the locating projection such that when the bearing pad is received a bore in the carrier, the locating projection precisely orients the bearing pad with respect to the carrier.

25. A bearing for supporting a rotating shaft part, the bearing comprising:

a unitary carrier, the carrier having an axis, the carrier further comprising a plurality of openings spaced about the axis;

a plurality of bearing pads, each bearing pad being mounted in one of the openings formed in the carrier, each bearing pad comprising a pad portion and a support portion, the support portion including a double curved section having a large portion at each end and a narrow center region, one large end being secured to the pad portion.

26. The bearing of Claim 25, wherein the carrier is a flexible carrier formed with a plurality of openings in which the bearings pads are mounted are flexibly supported for deflection in a predetermined direction.

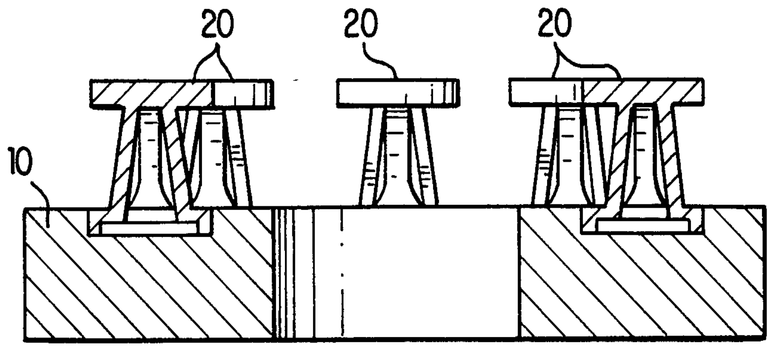

FIG. 1A

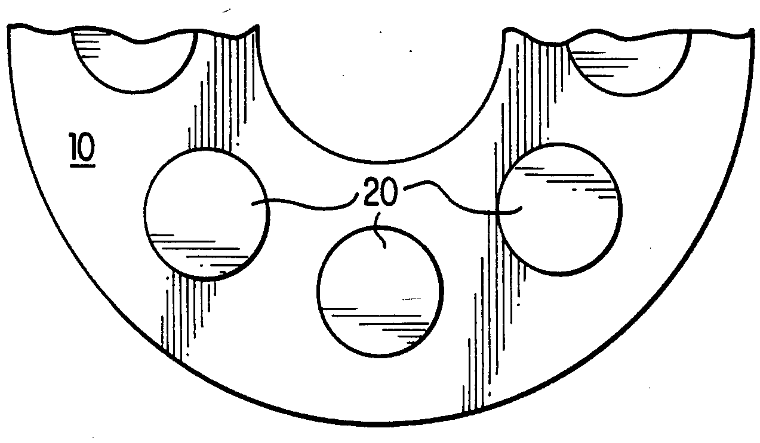

FIG. 1B

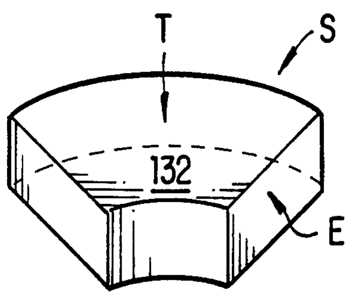

FIG. 2

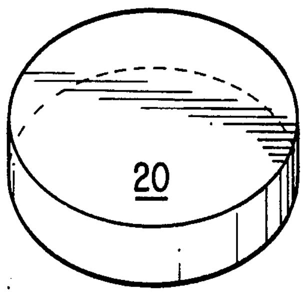

FIG. 3

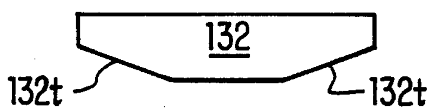

FIG. 4

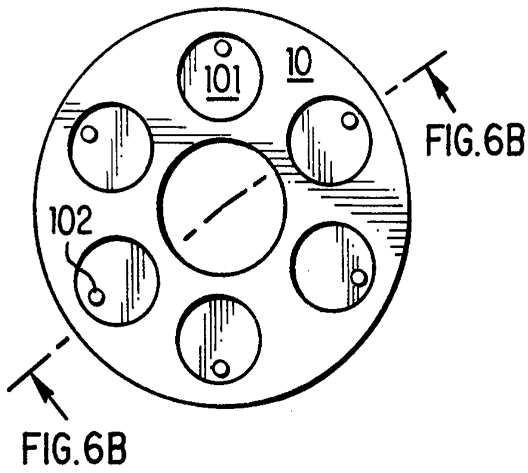

FIG. 6A

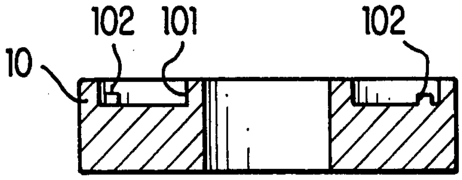

FIG. 6B

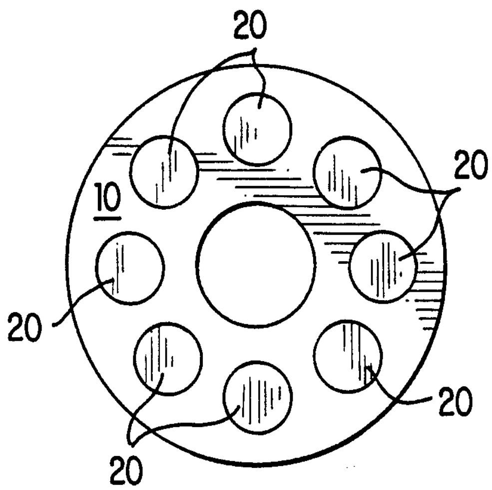

FIG. 5

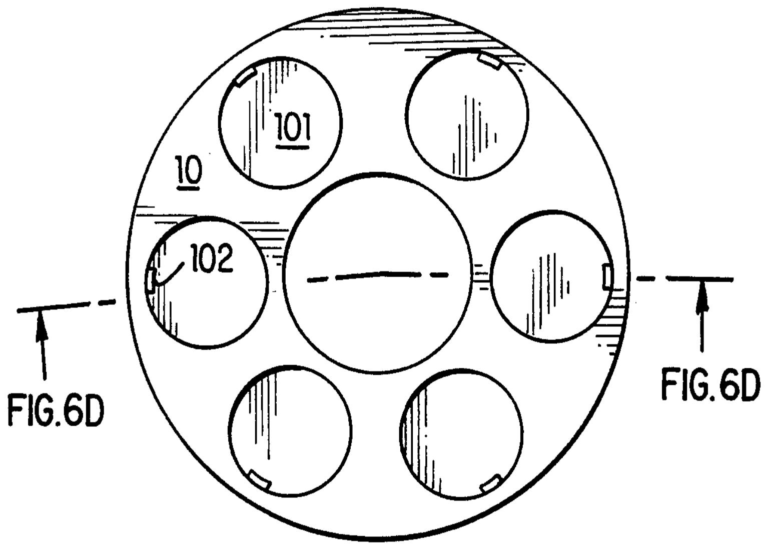

FIG. 6C

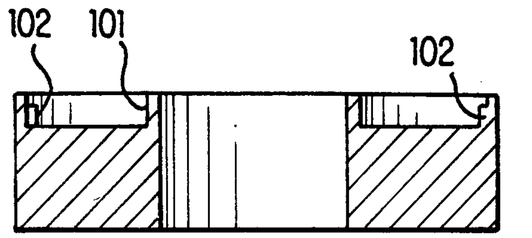

FIG. 6D

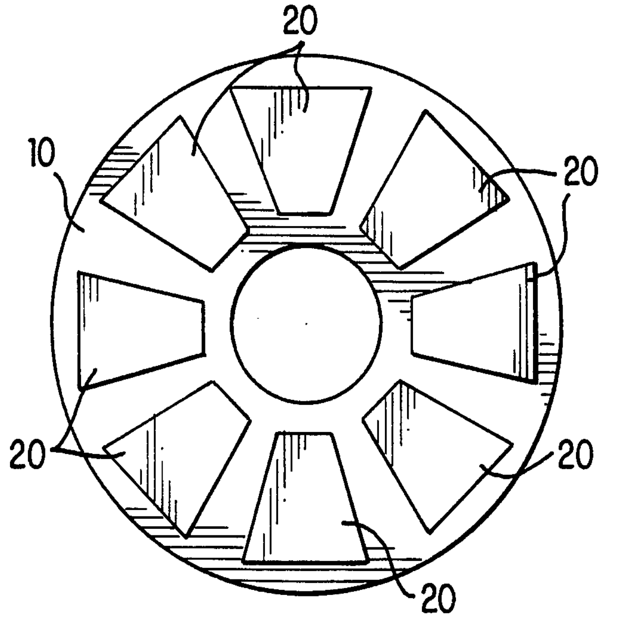

FIG. 5A

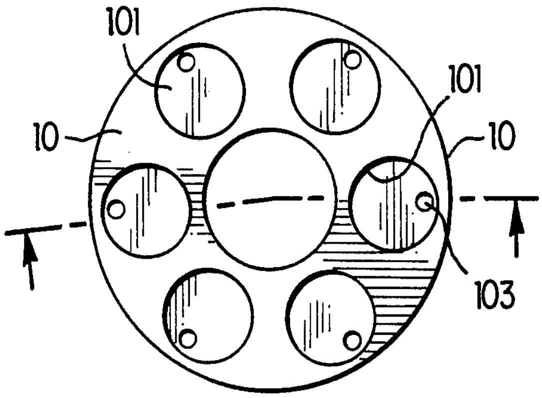

FIG.6E

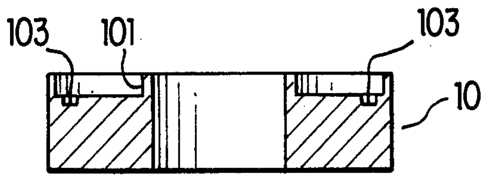

FIG.6F

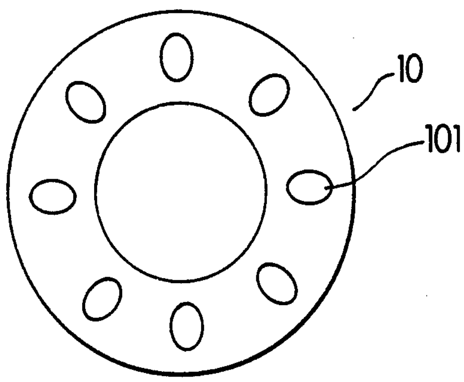

FIG.6G

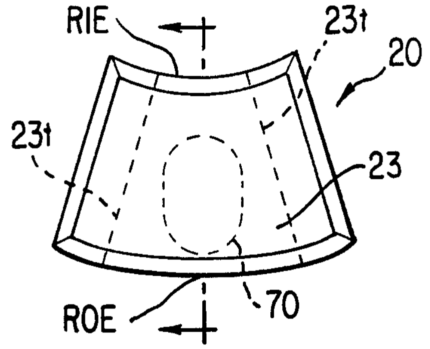

FIG. 7

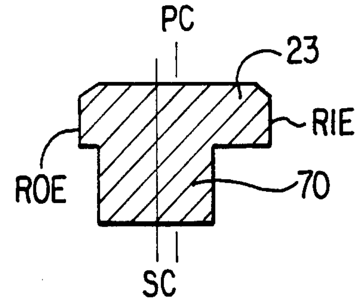

FIG. 7A

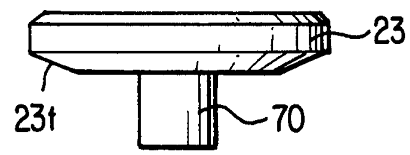

FIG. 7B

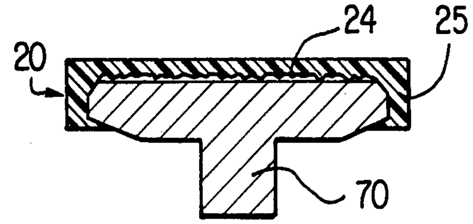

FIG. 7C

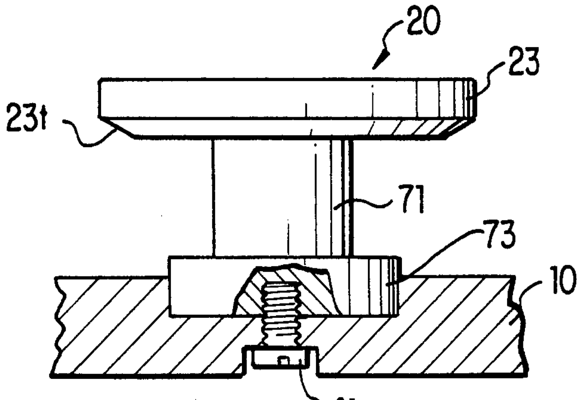

FIG. 8

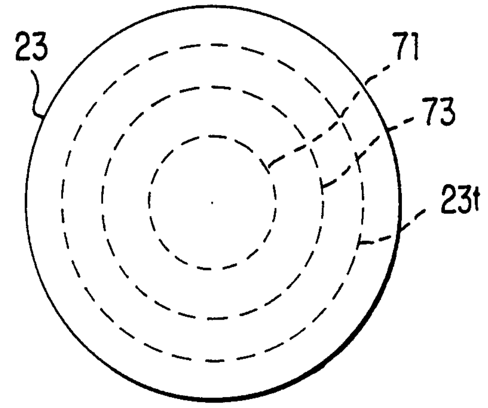

FIG. 8A

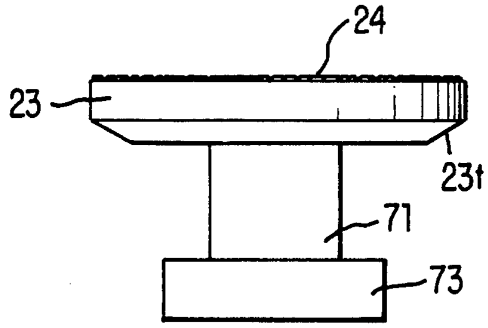

FIG. 8B

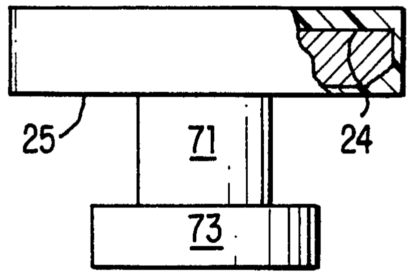

FIG. 8C

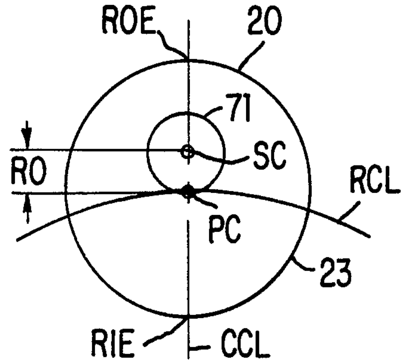

FIG. 9

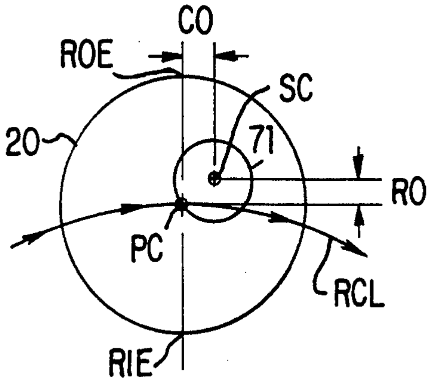

FIG. 10

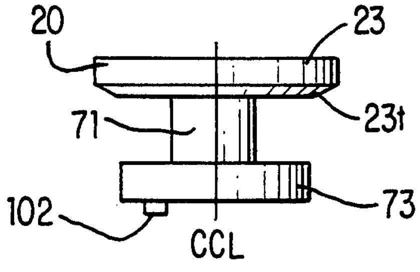

FIG. 9A

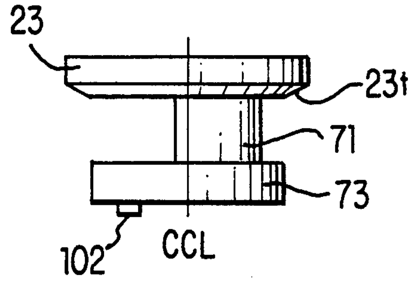

FIG. 10A

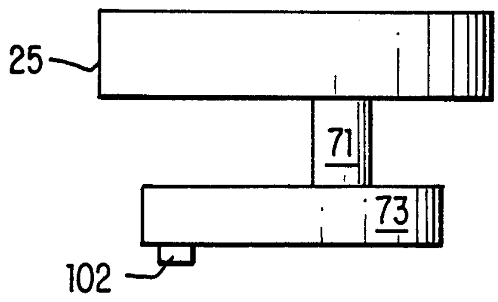

FIG. 10B

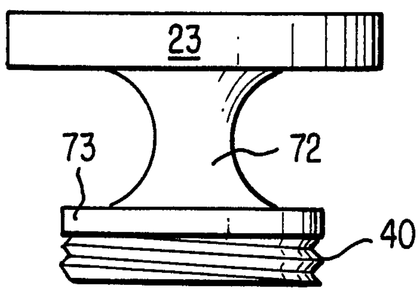

FIG. 11

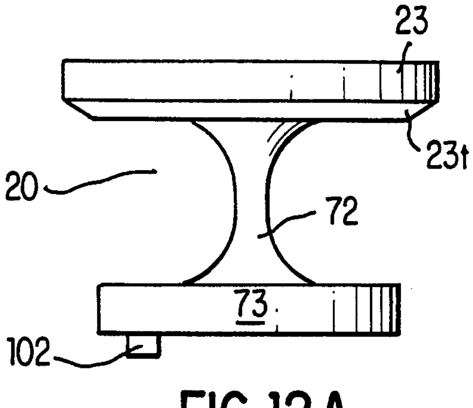

FIG. 12A

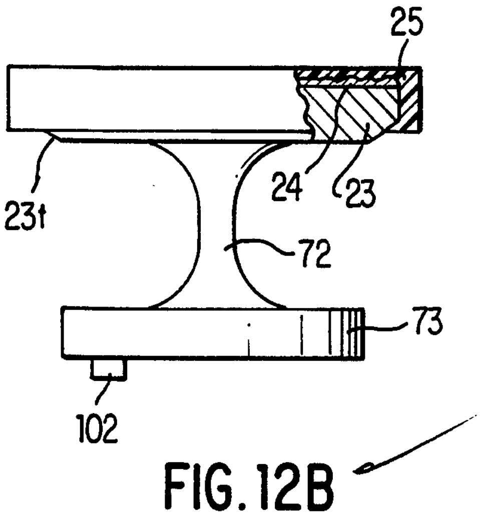

FIG. 12B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/08781

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) : F16C 17/06
US CL :384/122, 124
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 384/122, 124

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,676,668 (IDE) 30 JUNE 1987 (See Figs. 1-4.)	1-6, 17, 19-20, 15, 16, 22-25
Y	US, A, 2,424,028 (HAEBERLEIN) 15 July 1947 (See entire document.)	7-14, 17, 19-20, 22-25
Y	US, A, 1,991,461 (HOWARTH) 19 February 1935 (See Figs 5-6.)	1-6, 15-16

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 OCTOBER 1993	19 NOV 1993

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Sheila Veney for LENARD A. FOOTLAND
Facsimile No. NOT APPLICABLE	Telephone No. (703) 308-2683

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/08781

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Mutually exclusive claimed structure species:
Group I 1-6, 15-16, 26
Group II 7-14
Group III 17-25

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☒ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest
☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.