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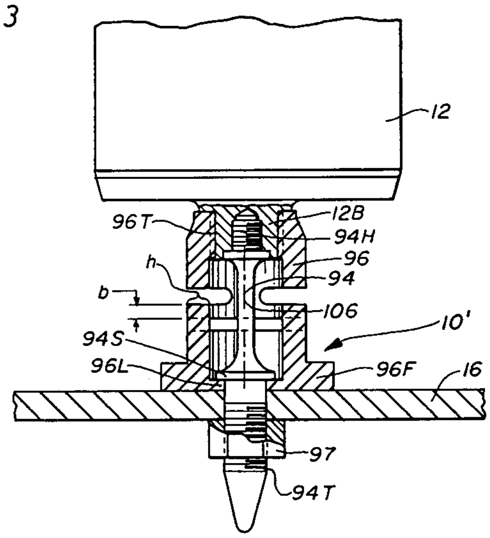
(54) Motor mount for a centrifuge.

(57) A mounting apparatus in which the vertical, lateral and torsional stiffness of the mounting apparatus are greater than the pivot stiffness. The greater stiffnesses are produced either by loading columns in tension or compression or by bending a rectangular column along its narrow, higher moment of inertia face.

Fig.3



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The present invention reiates to a mounting apparatus and in particular to a mounting apparatus for a motor used in a centrifuge instrument.

In a centrifuge instrument the rotating member, or rotor, forms part of a system that includes a motor or other source of motive energy, a drive shaft, and a rotor mounting device called a spud disposed at the upper end of the shaft on which the rotor is received. It is advantageous for a variety of reasons to cause the rotor to rotate with its center of gravity as close as possible to the axis of rotation. Initially, upon startup of the instrument the mass of the rotor has a tendency to spin on its geometric center. However. as rotor speed increases there occurs a shift in which the mass of the rotor spins about its center of gravity. The speed at which this shift occurs is known as the critical speed of the rotor. Violent motion and vibration are imparted to the rotor and the drive as it reaches the critical speed. However, once the critical speed is reached the vibration is significantly decreased. Typically the drive is provided with some form of compliance mechanism which accommodates the forces imposed on the system as the rotor approaches and passes through its critical speed.

Historically centrifuge drives have developed along two distinct paths related to the use of such drives in different centrifuge rotational speed regimes. The drives for so-called lower speed centrifuges (i.e., those having a speed less than twenty thousand revolutions per minute) typically use rigid shafts that are either directly coupled to a drive motor or are belt driven. Any compliance required for the stable operation of the instrument is achieved by the use of elastomeric "shock" mounts. Design of drives for higher speed instruments using such mounts is difficult since the dynamics of the system is influenced by the entire mass supported by the shock mounts, and not merely the rotor mass.

In higher speed centrifuges, such as those used in the so-called ultra speed range (i.e., above twenty thousand revolutions per minute) the compliance problem is solved, but at the expense of simplicity, ruggedness and cost, by reducing the dynamic mass and allowing compliance to take place through the flexure of a relatively long and delicate shaft on which the rotor is mounted.

Simple shock mounts cannot be used at higher speeds because of their low lateral and torsional stiffness compared to their pivot or moment stiffness. The moment stiffness is dependent on compression or extension of the elastic shock mount whereas the lateral and torsional stiffness are determined by shear of the elastic mount. For a given mount configuration the shear stiffness is usually only one third of the compressive stiffness. For this reason it is difficult to design critical speed out of the operating range from these three vibration modes.

United States Patent 4,511,350 (Romanauskas) relates to a suspension system for a centrifuge. Additionally, there is known a flexural pivot system sold by Bendix Aerospace in which springs are used to accommodate forces.

In view of the foregoing it is believed to be desirable to provide a centrifuge drive that is able to allow significantly higher operating speed with simpler, more rugged, rigid shaft design. It is also believed advantageous to provide a drive having a motor mount that exhibits a relatively high lateral, vertical and torsional stiffness relative to the moment stiffness.

The mounting apparatus of the present invention is defined by the features of claims 1, or 4, respectively.

The mount of the invention includes two members, one of which defines at least one column having an axis parallel to the axis of the mount while the other of the members defines a plurality of columns the axes of which extend perpendicular to the axis of the mount. The columns are arranged such that a moment and a lateral force imposed on the members are accommodated by bending of predetermined ones of the columns while vertical and torsional forces are accommodated by compression or tension in at least predetermined ones of the columns. In the preferred instance the inner member takes the form of an elongated pin that is arranged parallel to the axis of the mount while the outer member is generally cylindrical in shape and slotted to define a plurality of columns that lie in a plane that is generally perpendicular to the axis of the mount. A moment force is accommodated by bending of both the pin and the columns in the outer member. Lateral forces are accommodated primarily by bending of the columns in the outer member.

The invention will be more fully understood from the following detailed description thereof, taken in accordance with the accompanying drawings, which form a part of this application and in which:

Figure 1 is a definitional diagram showing the coordinate system to which the operation of the motor mount in accordance with the present invention will be referenced;

Figure 2 is a graphical representation of the relationship between the operating speed Of the instrument and the critical speeds controlled primarily by the various stiffness constants;

Figure 3 is a side elevational view entirely in section of an embodiment of the present invention;

Figure 4 is a developed view of the outer mounting member of the embodiment shown in Figure

3; and

Figure 5 is an elevational view of the inner mounting member of the invention shown in Figure 3.

Throughout the following detailed description similar reference numerals refer to similar elements in all figures of the drawings.

A typical centrifuge system includes a drive motor mounted to the superstructure of the instrument, a shaft extending from the drive motor into the chamber of the instrument, a rotor mounting device, also known as a "spud", disposed at the upper end of the shaft, and a rotor mounted to the spud. The system is acted upon by forces in the vertical direction z, lateral (or shear) direction r, the torsion direction Θ and the moment (or pivot) direction α, where these various directions are as indicated on the coordinate system shown in Figure 1. The vertical forces act on the system along the z axis, the lateral forces act along any axis r lying in a plane P perpendicular to the z axis, the torsional forces Θ act angularly about the z axis, and the moment forces αa act angularly about any axis r. For such a system the force equations can be written as follows:

$$F_z = m\ddot{z} + C_z\dot{z} + K_z z = 0 \quad (1)$$

$$F_r = m\ddot{r} + C_r\dot{r} + K_r r = 0 \quad (2)$$

$$F_\Theta = m\ddot{\Theta} + C_\Theta\dot{\Theta} + K_\Theta\Theta = 0 \quad (3)$$

$$F_\alpha = m\ddot{\alpha} + C_\alpha\dot{\alpha} + K_\alpha\alpha = 0 \quad (4)$$

where the character "C" represents the damping coefficient in the respective subscripted direction while the character "K" represents the stiffness coefficient in the respective subscripted direction.

It would be desirable, as shown in Figure 2, to structure the system in such a manner that the natural frequencies ω_z, ω_r, and ω_Θ of the system due primarily to the respective stiffness coefficient (K) in the z, r and Θ directions occur far from the normal operating speed range of the system, while the natural frequency ω_α of the system due primarily to the stiffness coefficient K_α occurs relatively early in the operating speed range. In this manner destructive critical speeds would be far removed from the range of system operation or would occur so early in the operation that the energy level at which the natural frequency occurs is not sufficient to cause significant vibration of the instrument.

In a motor mount 10' in accordance with an embodiment of the present invention the vertical (z) and torsional (Θ) forces are accommodated by placing columns in compression or tension, lateral (r) force is accommodated by placing columns with a relatively high moment of inertia inbending and moment force (α) is accommodated by placing columns with a reiatively low moment of inertia in bending. The stiffness coefficient K_α is relatively much less than the stiffness coefficient associated with the other directions.

Referring now to Figures 3 through 5, an embodiment of the motor mount 10' is shown. The mount 10' includes a first, central, member 94 and a second, outer, member 96. The central member 94 is an elongated, pin-like member having an integral head portion 94H, a body portion 94B, a shoulder 94S and a tail portion 94T. Both the head 94H and the tail 94T are threaded. The head 94H is threadedly secured to a boss 12B located on the lower end bell of the motor 12. The exterior of the boss 12B is also threaded. The tail 94T is secured to the support plate 16 which in this instance is disposed below the motor 12 of the centrifuge. A nut 97 engages the protruded threaded portion of the tail 94T. The body 94B exhibits a generally circular cross section and defines the main structural portion of the inner member 94. The member 94 has an axis 94A therethrough that aligns with the axis 10A of the mount (and with the z axis).

The outer member 96 is a hollow and generally cylindrical in shape. A flange 96F flares outwardly from one end of the member 96 and a lip 96L extends inwardly of the member 96 at the same end thereof. The interior surface at the opposite end of the member 96 is provided with threads 96T which engage the threads on the exterior of the boss 12B. The shoulder 96S of the inner member 94 clamps against the lip 96L of the outer member 96 to secure the same against the plate 16'.

As can best be seen in the developed view shown in Figure 5 the outer member 96 is provided with cooperating pairs of upper and lower slots that extend through the walls of the member. The upper pair of siots is indicated by reference characters 98A and 98B and the lower pair of slots is indicated by the characters 102A and 102B. The upper and lower slots cooperate to define horizontal (as defined above), semi-circular columns 104A, 104B, 104C, and 104D therebetween. The columns 104 are equiangularly spaced with the axes of the columns lying in a plane perpendicular to the axis 10A of the mount 10'. Each of the columns 104 is generally rectangular in cross section and has a width dimension b (measured along the axis of the member 96) and a depth dimension h (measured radially of the member 96). The width dimension b is relatively small when compared to the depth dimension h.

The axes of the semicircular columns lie on a common plane perpendicular to the axis of the mount. This plane intersects the axis 94A of the member 94 at the midpoint of the body portion 94B to define a pivot point 106 about which the mount

10' pivots.

In operation the second embodiment of the motor mount 10' in accordance with the present invention makes use of the well-known facts that a column in either compression or tension is inherently stiffer than the same column would be if loaded in bending and that a column with a rectangular cross section loaded in bending is stiffer when the load is imposed along its narrow dimension b as opposed to loading along the wider dimension h.

Thus, in directions where it is desired to exhibit a relatively high stiffness coefficient the forces imposed on the mount in these directions are accommodated either by placing predetermined the column or columns in either tension or compression or by positioning the columns such that loading is accommodated on the narrow, higher moment of inertia face b. In directions where a relatively lower stiffness coefficient is desired forces imposed on the mount in those directions are accommodated by the bending of the columns about the wider lower moment of inertia face h.

In accordance with this embodiment of the invention, when in its assembled relationship Figures 3 through 5, the vertical column defined by the body portion 94B of the inner member 94 accommodates forces in the vertical (z) direction by being placed in either tension or compression. Torsional (Θ) forces are accommodated by placing all of the horizontal columns 104A through 104D in the outer member 96 in compression. Lateral (r) forces are imposed upon the columns 104A through 104D along the narrow faces b thereof. However moment (α) forces are imposed on the columns along the relatively wider face h.

It should be appreciated from the foregoing that, in function, either embodiment of the present invention will accommodate any moment by pivoting about the pivot point 90, 106 (as the case may be) and as such will act as the kinematic equivalent of a ball joint. Although the above-described embodiments of the invention are set forth in the context of a mount of a motor for a centrifuge instrument it should be understood that the mounting apparatus in accordance with the present invention may be used in any other environment.

Claims

1. A mounting apparatus for a motor, the mounting apparatus having an axis therethrough, the mounting apparatus comprising:

a first (94) and a second (96) mounting member cooperating to define at least one column (94B) the axis of which is parallel to the axis (10A) of the mount and a plurality of columns (104) the axes of which extend perpendicular to the axis of the mount,

the columns (94B,104) being arranged such that a moment force and a lateral force imposed on the first and second members are accommodated by bending of predetermined ones (104) of the columns while vertical and torsional forces are accommodated by compression or tension in at least predetermined ones (94B) of the columns.

2. The mounting apparatus of claim 1 wherein the first member (94) is an elongated pin and the second member (96) is a generally cylindrical in shape and has an array of slots (98A,B;102A,B) formed therein, the slots cooperating to define the columns (104) therein.

3. The mounting apparatus of claim 2 wherein the columns (104) in the second member (96) are equiangularly disposed about the axis (10A) of the mount.

4. A mounting apparatus for a motor, the mounting apparatus having an axis therethrough, the mounting apparatus comprising:

a first, inner, column member (94) in the form of an elongated pin, the pin having an axis (94A) therethrough which lies parallel to the axis (10A) of the mounting apparatus,

a second, outer, member (96), the outer member being generally cylindrical in shape, the outer member having upper (98A,B) and lower (102A,B) pairs of slots therein, the slots cooperating to define a plurality of columns (104) therein, the columns having a width dimension (b) and a depth dimension (h), each column having an axis therethrough that lies perpendicular to the axis (10A) of the mounting apparatus,

the pin and the columns (104) being arranged such that forces imposed on the mounting apparatus along the axis (94A) of the first member (94) are accomodated by the pin being placed in either tension or compression, while torsional forces are accommodated by placing all of the columns (104) in the outer member in compression, lateral forces are accommodated by bending of the columns (104) along the width dimension (b) thereof and moment forces are accommodated by bending of the columns (104) along the depth dimension thereof (h).

5. The mounting apparatus of claim 4 wherein the columns (104) in the second member (94) are equiangularly disposed about the axis (10A) of the mount.

6. The mounting apparatus of claim 4 or 5 wherein the pin has a head (94H) and a tail (94T) thereon, and wherein each of the head and the tail are threaded.

Fig. 1

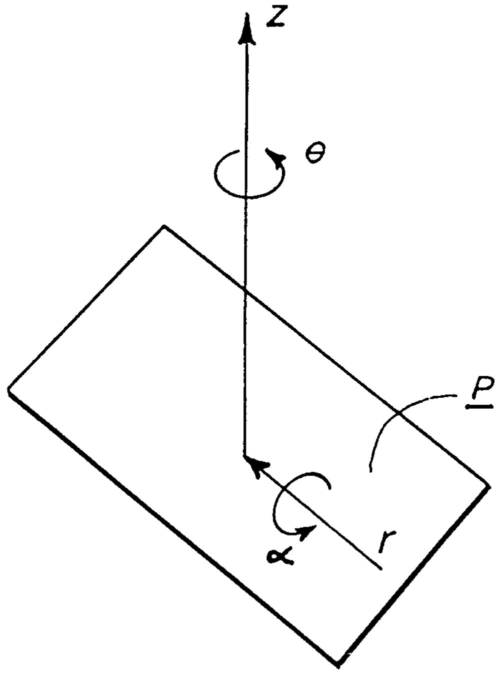
z
θ
P
r
α

Fig. 2

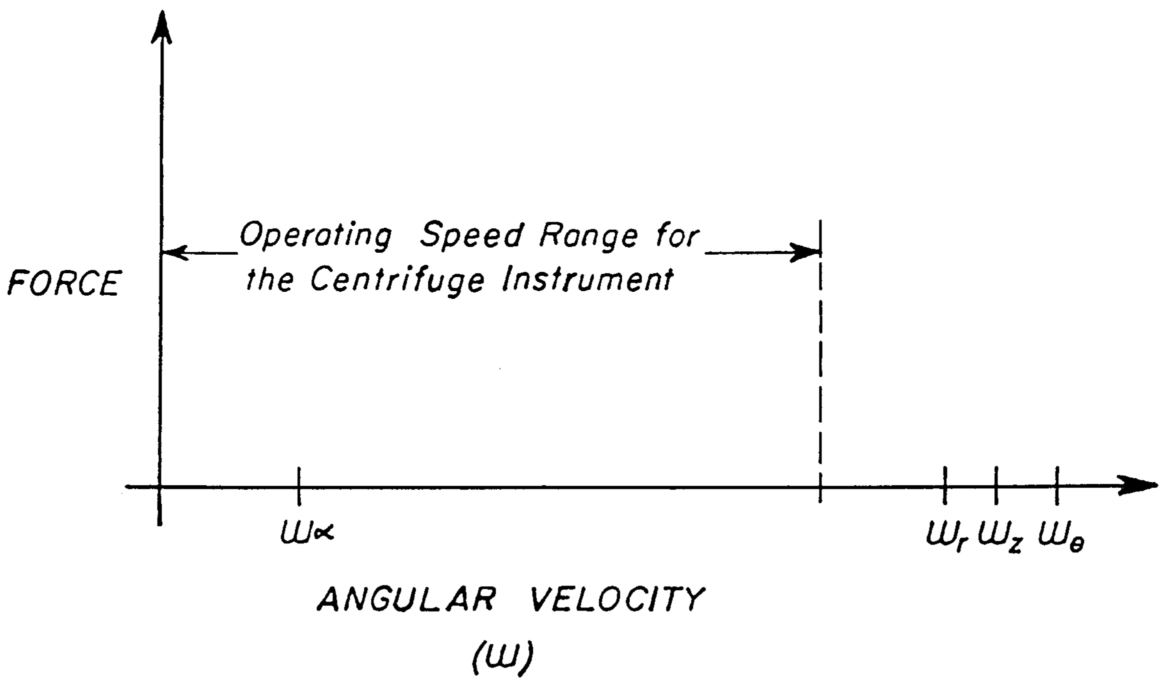
FORCE
Operating Speed Range for
the Centrifuge Instrument
ωα
ωr ωz ωθ
ANGULAR VELOCITY
(ω)

Fig.3

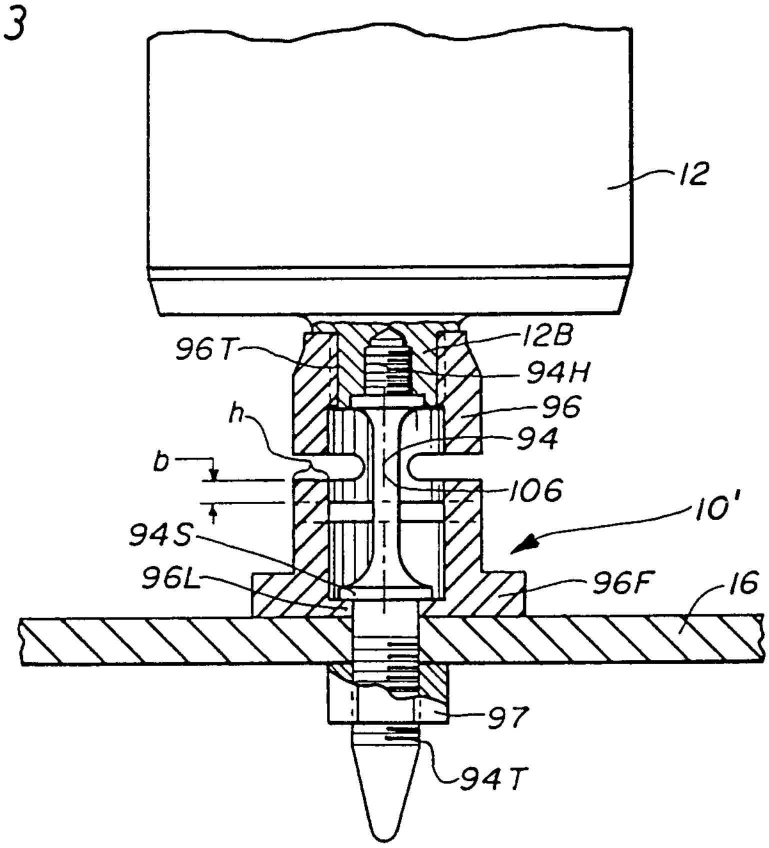
12
12B
96T
94H
96
h
94
b
106
10'
94S
96L
96F
16
97
94T

Fig.4

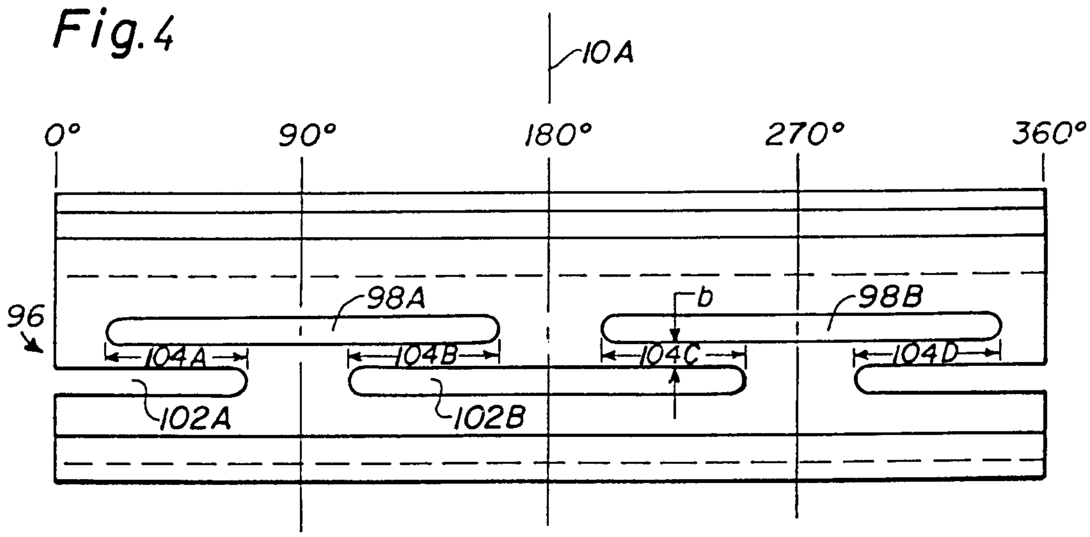
10A
0°
90°
180°
270°
360°
96
98A
b
98B
104A
104B
104C
104D
102A
102B

Fig. 5