ABSTRACT: An air bearing device capable of increased inflation height which consists of a load supporting member and an inflatable flexible diaphragm attached peripherally to the support, the attached diaphragm having a rigid center portion which operates in light contactual relationship with the operating surface, and spaces that portion of the diaphragm adjacent to the rigid center portion above the operating ground surface.
FREE BOTTOM AIR BEARING DEVICE

This invention relates to an air-bearing device capable of substantially frictionless movement on a film of low pressure air at increased heights and particularly to an improved air-bearing device or such air bearings.

Air-bearing devices are generally recognized as being highly effective means for carrying heavy loads over surfaces which cannot support devices having conventional casters or wheels or where features such as omnidirectional movement or a low moving force requirement are desirable. An air-bearing device which typifies those presently in use is disclosed in U.S. Patent No. 3,321,038. According to this patent, air bearings consist of a rigid annular support to which a flexible annular diaphragm is secured centrally and peripherally forming an annular torus-shaped chamber located between the support and the diaphragm. As the chamber is filled with air, the diaphragm is expanded downwardly forming a central plenum between the diaphragm and the ground surface. The diaphragm contains, in communication with the central plenum, one or more apertures through which air passes into the plenum. As the pressure of air in the chamber and in the plenum approaches equilibruim, the air within the plenum is forced into the atmosphere at a point between the surface of the ground and the lowermost portion of the diaphragm. The escaping air produces and film or an air cushion upon which the device is levitated in a substantially frictionless relationship with the ground surface.

With any of the prior art air-bearing devices which has as an essential part of its construction a flexible diaphragm secured both peripherally and centrally to a rigid support can be adapted to provide varying amounts of lifting capability. For example, when a diaphragm is employed having increasing amounts of fullness or sidewall height, the operating height of the rigid support above the surface increases accordingly. However this increase in height is limited to a certain maximum. Additional fullness beyond this point results in little or no additional operating height. Instead, the added material tends to form an excessive outward peripheral bulge at the point of attachment to the rigid support.

Tests have shown that the maximum operating height that is possible with a device having its diaphragm secured both peripherally and centrally to the load supporting member is limited to approximately 10 percent of the diaphragm radius (r). To a large degree this limitation is due to the angle θ formed between the ground surface and that portion of the diaphragm forming the plenum cavity. This section of the diaphragm exerts the tensile force needed to restrain the outer portion of the diaphragm against the internal pressure. The inner portion of the diaphragm exerts an upward component of the tension force which tends to lift the diaphragm and narrow the air film zone. When angle θ reaches approximately 7°, the air film zone (AFZ) becomes very narrow, and thus air can escape more readily and, depending on the operating ground surface, can escape at an uncontrolled rate. In addition, a relatively high air flow is required to obtain maximum operating heights.

Also, when operating at a constant air flow and with a very narrow air film zone, the operating height is greatly reduced by roughness, pits or projections in the operating ground surface.

When multiple air bearings are employed on a rigid load-carrying platform as described in U.S. Patent No. 3,392,800, the relatively low operating height severely limits the platform's ability to traverse ramps and surface undulations. Platforms with one or more air bearings are also often used for moving loads supported on blocks, skids or pallets. In these applications, the partially or fully deflated platform is inserted under the load, and then inflated, to lift the load and skids above the ground surface. Considerable lift may be required to take up the clearance, platform and load deflection, and yet result in adequate air clearance between the pallet skids and the floor surface. As earlier stated air-bearing devices having a diaphragm secured peripherally and centrally to the load platform may be incapable of providing lift sufficient for use in the above applications, particularly if near capacity loads are to be moved.

Accordingly, it is an object of this invention to provide an improved air-bearing device which exhibits a greater operating height. Another object of this invention is to provide an air-bearing device which provides a wide air film zone even at relatively high operating height. Still another object of this invention is to provide an air-bearing device which has high lift characteristics and is relatively insensitive to roughness or small defects in the operating surface.

Another object of this invention is to provide an air-bearing device capable of carrying heavy loads more efficiently and more economically, particularly over areas having ramps, uneven or irregular surfaces. Still another object of this invention is to provide an improved diaphragm for use on air-bearing devices which has overall generally improved operating characteristics. These and other objects as well as certain advantages of this invention will be more fully apparent by reference to the specification and drawings wherein:

FIG. 1 is a sectional elevational view of a device constructed in accordance with this invention, wherein the device has been inflated and is shown carrying a load.

FIG. 2 is a bottom view of FIG. 1.

FIG. 3 is a sectional view of a typical prior art device.

FIG. 4 is a magnified portion of the device shown in FIG. 3 emphasizing in exaggerated form angle θ.

FIG. 5 shows an inflated sectional elevational view of another embodiment of this invention.

FIG. 6 shows FIG. 5 in deflated condition.

FIG. 7 is a bottom view of FIG. 6.

It should be noted that the above views are all slightly exaggerated to more clearly show particular embodiments of this invention and of prior art devices.

Referring now to the drawings and particularly to FIG. 1, there is shown a circular load supporting platform designated generally by numeral 1. Extending beneath platform 1 is a flexible slightly expandable diaphragm 2. The outer 3 periphery of diaphragm 2 is secured to the edge of platform 1 by clamping ring 4. The securement of diaphragm 2 to platform 1 is such that air generated by a blower (not shown) enters annular chamber 5 formed between diaphragm 2 and the undersurface 6 of the platform 1 through conduit opening 7 of connectable air conduit 8. The central portion 9 of diaphragm 2 is clamped between lower disc 10 and upper disc 11 by screw 12. The intermediate central portion 18 of diaphragm 2 contains one or more apertures 13. The apertures 13 are in communication with plenum cavity 14 and annular chamber 5, thus permitting air from annular chamber 5 to enter into plenum cavity 14. In operation lower disc 10 is in light contact with ground surface 17 while the diaphragm 2 is floated on a thin film of air 30, separating the lowermost portion of diaphragm 2 from ground surface 17.

FIG. 2 shows a bottom view of FIG. 1. The distance from the center of the diaphragm to the edge of the diaphragm is the diaphragm's radius (r). Referring back to FIG. 1, air passes through conduit 8 and enters annular chamber 5 through opening 7. As diaphragm 2 begins to inflate, a portion of the air passes from the annular chamber 5 into plenum cavity 14 through apertures 13 located in the intermediate central portion 18 of diaphragm 2. As the pressure within the annular chamber 5 and the plenum cavity 14 reaches equilibrium, the diaphragm 2 will be fully inflated and platform 1 will have load 15 will be elevated to its operating level.

When the pressure in annular chamber 5 exerts a force over its effective lift area greater than total force exerted downward, the diaphragm 2 and its load is levitated and cushioned on a thin film of air 30 escaping from plenum cavity 14 into the surrounding atmosphere. The diaphragm's effective lift area is the area circumscribed within the outer diameter of the lowermost portion 20 of diaphragm 2. The distance between the lowermost portions 20 is referred to as the effective lift area or as the effective lift diameter (ELD), while the height that the diaphragm raises the rigid support above the ground surface 17 is known as the diaphragm's effective lift height (L).
The thin film of air 30 which is produced between the lowermost portion 20 of diaphragm 2 and ground 17 functions as a substantially frictionless bearing permitting omnidirectional displacement by the application of a minimum of external force. The area covered by this film of air is referred to as the air film zone (AFZ). The distance between the inner and outer peripheral edge of the air film zone is known as the air film zone width. In FIG. 4, the diaphragm's air film zone, the diaphragm's effective lift diameter, and the diaphragm's effective lift capacity are identified by the abbreviations AFZ, ELD, and L, respectively. In FIG. 2, the diaphragm's radius is identified as r.

As can be seen in FIG. 1, the function of lower disc 10, which is preferably convexed in shape, is to keep the intermedicate central portion 18 of diaphragm 2 spaced vertically above ground 17, to provide and maintain plenum cavity 14 and to allow free communication between annular chamber 5 and plenum cavity 14. If lower disc 10 were absent, the intermediate central portion 18 of diaphragm 2 would come in direct contact with ground 17, resulting in no plenum cavity 14 being formed. Further apertures 13 would be sealed off by being in direct proximal contact with ground 17, preventing the escape of air from chamber 5 into the plenum cavity 14 and thus preventing the formation of lubricating air film 30. FIG. 1 also shows that lower disc 10 contacts ground 17 with a downward force which is the resultant of the weight of lower disc 10, upper disc 11, and the central portion 9 and intermediate central portion 18 of diaphragm 2. This relatively small downward force results in a practically insignificant frictional force resisting motion of the loaded air bearing. However, it is important that pressure P1 in annular chamber 5 be essentially equal to pressure P2 in plenum cavity 14. This can be assured by making apertures 13 sufficiently large and numerous that essentially no pressure drop is caused by air flowing through apertures 13. If P1, substantially exceeds P2, the upper disc 11 and lower disc 10 will be forced down against ground 17 by an additional force caused by the pressure difference and area of the discs. This can create an undesirably high amount of drag.

Uninterrupted communicative flow between annular chamber 5 and diaphragm 2 through communicating holes 13 is an essential part of this invention and can be achieved by any means that establishes and maintains a plenum cavity 14 between the centermost undersurface portion 28 of central portion 18 of diaphragm 2 and operating ground surface 17. This can be best achieved for example, by having a central di-cylindrical surface preferably having a convexed bottom attached to the underside of the diaphragm. However, the diaphragm itself can be shaped to give the desired effect, such as by molding it with a rigid insert, or attaching a shaped member to the upper side of the diaphragm, which causes the center of the diaphragm to project downward. The downward projecting member or portion should be so shaped to pass easily over small projections, cracks or ridges in the operating surface.

An alternate construction, FIGS. 5-7, employs and annular ring 24 attached to the central periphery 26 of the diaphragm 2. This construction permits incorporation of a support foot 22 beneath the rigid support platform 1, which supports the air bearing. This is off, and prevents pinching of the diaphragm when in the deflated or off-condition.

In this invention as compared to prior art devices, the center portion of the diaphragm is not in any way supported or connected with the load supporting member. Thus the center portion of the diaphragm is not drawn upward with the support platform as the platform is raised by inflation. In fact, the device of this invention is in direct contradistinction to the teachings found in the prior art, e.g., U.S. Pat. No. 3,321,038 and 3,414,076. The teachings found in the above patents in essence emphasize that the centermost portion of the diaphragm be free of any contact whatsoever with the ground surface. The many advantages and particularly the increased operating height which is possible with a device having an unsecured center portion is neither disclosed nor suggested by the prior art teachings.

As is shown by the prior art devices of FIGS. 3 and 4, the effective lift of these devices is limited by the angle formed by the undersurface 32 of diaphragm 34 and ground surface 36. This angle is referred to as angle &theta;. This is clearly depicted in FIG. 4, which shows the maximum angle &theta; possible. Although FIGS. 3 and 4 are exaggerated to more clearly show this angle &theta;, angle &theta; will not in most all cases exceed about 7°. If the angle does exceed 7° the diaphragm's air film zone (AFZ) becomes so small that the diaphragm's floating capabilities and lifting capabilities are jeopardized particularly over a ground surface which is uneven or irregular. However with the device of this invention, angle &theta; is not nearly as critical and in most cases is very small and does not tend to pull up on the portion of the diaphragm defining the inner edge of the AFZ. As a result, the AFZ remains fairly wide even at high lift height. With this type of construction, a lift height of approximately 20 percent of the diaphragm's radius can be readily achieved. With the devices shown in FIGS. 3 and 4, a maximum height of only about 10 percent of the diaphragm's radius is possible. As previously indicated, the importance of establishing and maintaining a large AFZ along with a high effective lift cannot be overemphasized particularly if the device is to be operated over an irregular surface such as one containing crevices, depressions or offsets.

A wide air film zone is also important for best performance on a smooth surface. Escape of air from underneath the air bearing is controlled by the air film zone, which acts as a throttling gap, where the degree of restriction is proportional to the length of the gap and inversely proportional to its thickness. Thus at a given rate of air flow to the air bearing, a wide air film zone means a long throttling gap, which means the thickness of the gap, or air film, can be relatively great. If the AFZ is short, as in prior art devices which are operated at near maximum inflation heights, then the air film gap must be thin to cause the same back pressure.

In summary therefore, a device adapted with a diaphragm having an unsecured center portion has numerous advantages over devices which are secured both peripherally and centrally to a rigid platform. These are:

1. Substantially higher lift capabilities approximately double that heretofore possible.
2. Relatively large air film zones, even when being operated at or near maximum lift.
3. Substantially longer throttling gaps permitting for a more efficient operation over surfaces which are uneven or irregular.

When the air-bearing device such as the type shown in FIG. 1 is used in a load-carrying application, air is introduced into air conduit 8 from an air supply means, such as an air-blowing means, by means of a hose or other suitable type of connecting means. If desired, the air-bearing device can be designed and constructed to carry its own air supply means. In any case, the air is introduced into the annular chamber of the diaphragm and into the plenum cavity in amounts sufficient to produce plenum pressure sufficient to overcome the force exerted by a load and cause levitation. The amount of air supplied will, of course, vary depending on the weight on the load, the size and capacity of the air bearing, the diaphragm's effective lift area, quality of the ground surface, etc. For example, an air bearing having an effective lift area of 350 square inches can levitate loads between 700 to 10,000 pounds by the corresponding application of from about 2–20 p.s.i. of air to a height of 2 inches and even higher. Once levitation is achieved, omnidirectionally substantially frictionless movement is achieved by the air film formed by air escaping from the plenum to the atmosphere. With the air bearing of this invention a relatively high lifting height is achieved which as earlier pointed out reduces the possibility of grounding of rigid portions of the bearing or associated structure on undulating or sloping surfaces, while maintaining a wide air film zone, which improves operation over rough or pitted surfaces. Omnidirectional movement can easily be obtained by the application of a slight external force upon the load.
While therefore various embodiments of the invention have been shown and described, it will be apparent that other changes and modifications may be made therein. It is to be understood, therefore, that still it is not intended to limit the invention to the embodiment shown but only by the scope of the claims that follow.

I claim:

1. An air-bearing device operable over a ground surface comprising a flexible diaphragm having an unsecured center portion, a load-carrying member to which said diaphragm is secured to provide a gas-receiving chamber, a cavity-forming support means having a convex shaped or upwardly directed bottom carried by the unsecured center portion of the diaphragm for turning the unsecured center portion upward and to thereby form a ground proximate plenum cavity beneath said diaphragm, said diaphragm being characterized by having openings adjacent to said support means which are maintained in communication with said gas-receiving chamber and said ground proximate plenum cavity by means of said cavity-forming support means.

2. The air-bearing device of claim 1, wherein the cavity-forming support means is an outer plate having its ground proximate outer surface generally convex and its inner or upper surface concave.

3. The air-bearing device of claim 2, including a second plate conforming to and mounted on top of the outer plate with the unsecured center portion of the diaphragm held therebetween.

4. The air-bearing device of claim 1, wherein the cavity-forming support means comprises a rigid cavity-forming insert to which the diaphragm's center portion is attached.

5. An air-bearing device operable over a ground surface comprising a flexible diaphragm having an unsecured center portion, a load-carrying member to which said diaphragm is secured to provide a gas-receiving chamber therebetween, a cavity-forming support means having a convexed shaped bottom portion carried by the unsecured center portion of the diaphragm for turning the unsecured center portion upward and to thereby form a ground proximate plenum cavity beneath said diaphragm, said diaphragm being characterized by having openings adjacent to said support means which are maintained in communication with said gas-receiving chamber and said ground proximate plenum cavity by means of said cavity-forming support means.

6. The air-bearing device of claim 5, wherein said gas inlet means passes through said load-carrying member at a point offcenter thereof.