

Removable Disk Cartridge

Field of the invention

The present invention relates to a disk cartridge made up of a data storage disk enclosed within a casing. The cartridge is removably insertable into a disk drive to have data read from or written to it. In particular, the disk may be
5 a magnetic disk, such as a floppy disk, or an optical disk particularly of the kind having a small thickness and a large form factor.

Background to the invention

Many prior removable disk cartridges and associated disk drive mechanisms
10 fall into one of two categories. In the first category, the cartridges contain a rigid magnetic media disk. Flying-type heads are usually used to achieve high recording density with little or no wear on the media disk. The removable hard disk cartridges typically have capacities of several gigabytes. Hard disk media are relatively expensive and the cost is relatively high. In the second
15 category, the cartridges contain a flexible magnetic media disk (floppy disk or plastic disk) enclosed in a casing. They are generally cheaper to make than the first category of hard disk cartridges. High density flexible disk drives, whose recording capacity may be over 360 MBb, usually use a pair of flying-type heads attached to arms with a suspension-gimbal-flexure assembly. The
20 disk rotates at a much higher speed than a standard 1.44 MBb floppy disk drive which uses contact heads.

One common problem for the aforementioned removable disks is vertical vibrations of the rotating disk. There are several sources for this vibration, but it is especially a problem for disk drives for portable use. The vertical
25 vibrations of the media disk are coupled with the vibrations of the head-gimbal-assembly, and produce turbulent air flow within the cartridge and disk drive cavity. The turbulent flow generated by the rotating disk surface interacts

with the structure of the cartridge and introduces random vibrations-disk flutter. Disk flutter may cause the position error for read/write heads, as shown by the authors of all the references cited here.

5 A special problem for a floppy disk is the vertical deflection due to the stationary transverse load exerted by the heads. A conventional floppy disk is so thin that it alone is basically unable to withstand any external transverse point load.

10 Since disk drives for removable disks are often used as portable data recording tools in the consumer product market, it is essential that a removable disk cartridge can survive a shock impact test. It is known that the shock load with a pulse with a width of the order of a few milliseconds will excite several vibration modes of the disk. The vibrations may lift the read/write (R/W) head off the disk surface, and it may slap on the disk surface when it comes back or when the disk moves towards to it. The vibrations of
15 the head-gimbal-assembly and disk are modulated with each other. It would therefore be of great value to limit the amplitude of the vertical vibration of the disk, especially at during operation, in order to reduce the damage under shock load.

20 One method of reducing vibrations is to form the disk with high specific stiffness. This requires high performance disk substrates such as ceramics and glasses.

Another method to suppress disk flutter is to control the air flow within the cartridge. Changing the design of air paths inside the cartridge or placing stationary obstructions may reduce the intensity of the turbulence and
25 vibrations excited by the flow, as disclosed in US 6097568.

Another method to suppress disk flutter is to place a stationary smooth plate close to the a rotating disk. Air bearing is formed between the moving surface

of the disk and the plate. The damping effect of the squeeze air film helps to suppress the disk vibration. One shortcoming of this method is that there is a danger of disk-plate contact. The use of a Bernoulli plate has been suggested by several authors (see for example US 5293287), but the presence of a
5 Bernoulli plate makes two-sided recording extremely difficult. Furthermore, very tight manufacturing tolerances are required which increase the cost of the cartridge.

A centred disk stabilisation method was described in Briggs, J.C., 1996, "Enabling technologies for a 100MB 3.5" floppy (ZIP™) disk drive", SPIE
10 (International Society for Optical Engineering), Vol 2604, pp220-227. The disk was stable under operating speed at least 3000 rpm. This method only provided gross stabilisation, however, and the disk had vertical run-out from 50 to 100 μ m.

A standing wave stabilisation method is disclosed in US 5537281. A number
15 of radially extending stabilizers were arranged on the inner surfaces of the housing to maintain a standing wave pattern. This method may encounter problems when the access window is relatively large.

Another concern for removable cartridges is contamination of the disk. There are two openings associated with a disk cartridge: one is for the R/W head to
20 access the disk, and another is for the motor engaging and rotating the disk inside the cartridge. The contaminant particles may be brought into the cartridge through either of these openings. Conventional floppy disk cartridges use a liner on the inner surfaces of casing to capture the particles.

Summary of the Invention

25 The present invention seeks to provide a new and useful magnetic disk cartridge, and particularly one which addresses at least one of the above problems.

In general terms, the present invention proposes that pairs of mirror-image air bearing surfaces are provided within the cartridge to either side of the disk, for developing a positive pressure between themselves and the disk, so as to maintain the disk at a desired distance from each of the surfaces and/or act
5 as a dynamic seal to reduce the risk of contamination.

Specifically, the present invention proposes a disk cartridge for removable insertion into a disk drive, the cartridge including a data recordal disk enclosed within a casing and arranged for rotation within the casing about an axis;

10 the casing including one or more pairs of air bearing surfaces, the or each pair of air bearing surfaces facing respective sides of the disk at oppositely disposed positions on the disk;

each air bearing surface being formed with grooves, the grooves having a pattern for developing a positive pressure between that surface and
15 the disk upon rotation of the disk within the cartridge.

Preferably, the grooves on each air bearing surface are a mirror image of the grooves on the other air bearing surface of the pair. The mirror plane is transverse to the axis of the disk, and defines the desired position to which the disk is urged by the pressures developed by the air bearing surfaces.

20 As in conventional cartridges, the cartridge of the present invention generally includes a window which may be opened (e.g. when the disk is inserted into the disk drive) to allow a R/W head of the disk drive to access the disk. Preferably, one pair of air bearing surfaces is radially inward of the window, i.e. at location which is radially inward of the location on the disk closest to the
25 axis at which data is stored. The inner air bearing surfaces may be substantially ring-shaped and centred on the axis of the cartridge, so as to encircle the axis of the cartridge. This pair of air bearing surfaces, in addition

to providing a degree of stabilisation to the disk, provide a dynamic seal to prevent contamination particles from entering the cartridge, e.g. through an aperture provided at the axis of the cartridge through which the motor of the disk drive drives a hub on which the disk is mounted.

- 5 Separately from these inner air bearing surfaces, an outer pair of air bearing surfaces may be provided radially outwardly of the radially innermost part of the window (i.e. radially outward of the most radially inward position on the disk at which data is stored). The outer pair of air bearing surfaces may in fact be proximate the radially outermost portion of the disk, so that they can apply
10 stabilising force to the parts of the disk which are least adequately supported by the hub.

In a particularly efficient arrangement, these outer air bearing surfaces are disposed in arcs centred on the axis, the arcs having a gap extending across said window.

- 15 To reduce the risk of the air bearing surfaces causing damage to the disk in the case that they come into contact with it, the air bearing surfaces are preferably formed by a material having lower hardness than the surface of the disk. Preferably the hardness is lower than $H_v=800$.

- To further reduce the chance of damage being caused to the disk, at least
20 one pair of air bearing surfaces is covered with or contains a lubricant. One suitable lubricant is MYB1070.

- As noted above, in addition to the support function, the air bearing may reduce the risk of contamination by reducing air flow into the disk. To achieve this, the grooves, both of the inner and outer air bearing surfaces, are formed
25 to inhibit net radial air flow across the air bearing surfaces upon rotation of the disk within the cartridge. They may do this by generating a pressure profile

which is highest the centres of the air bearing surfaces, and which opposes net radial air flow.

To ensure that the air film is strong enough to provide a worthwhile urging force to the disks at conventional rotation speeds, the pairs of air bearing surfaces are preferably mutually separated by no more than about 0.1mm (plus the thickness of the disk). To set this in context, the grooves, to be capable of generating adequate pressure, are normally deeper than the spacing between the air bearing surfaces, e.g. each groove may be about 3 times as deep as the space between the surface and the disk.

Creation of the air films provides a frictional resistance to rotation of the disk. Accordingly, the air bearing surfaces cover no more than 25% of the surface of the disk. For the same reason, each of the air bearing surfaces has a radial extent which is between 10% and 20% of the radius of the disk.

As in conventional cartridges, the casing of a cartridge according to the present invention may be formed of two shells, the disk being sandwiched by the shells. In this case, each pair of air-bearing surfaces is preferably provided on elements adhered to, or integral with, the respective shells.

The invention is particularly suitable to the case that the data storage disk is a magnetic recording disk, such as a magnetic disk having a plastic substrate, and thus a high flexibility. However, the invention is not limited in this respect, and the disk may alternatively be an optical disk, such as one having high flexibility.

Brief description of the drawings

An embodiment of the invention will now be described, for the sake of example only, with reference to the following drawings, in which:

Fig. 1, which is composed of Figs. 1(a), 1(b) and 1(c), shows the construction of the embodiment;

Fig. 2, which is composed of Figs 2(a) and 2(b), shows the groove pattern of Fig. 1 and how it is implemented;

Fig. 3 shows the pressure profile produced by the grooves of Fig. 2;

Fig. 4 shows the relationship between the clearance between the disk and air bearing surfaces of Fig 1 and the load-bearing capacity and stiffness of the air films; and

Fig. 5 shows the relationship between the clearance between the disk and air bearing surfaces of Fig. 1 and the natural frequency of the resultant vibration of the disk.

Detailed Description of Invention

The preferred embodiment of this invention, a removable disk cartridge using herringbone-grooved air bearing surfaces as a stabilizer, is now described in detail with reference to Fig. 1. The embodiment consists of a casing 1, comprising two "shells" 3, 5 enclosing a data storage disk 7. The cartridge has an axis 9. Fig. 1(a) shows a first ("lower") shell 3 of the cartridge, viewed in use looking along the axis from the direction of the other shell. Fig. 1(b) shows the second ("upper") shell 5 viewed in use looking along the axis from the direction of the shell 5. Thus, the casing is formed by turning the shell 5 of Fig. 1(b) over, and placing it "over" the shell 2 of Fig. 1(a). In this case, the outer profiles 2, 4 of the shells 3, 5 are in register. Fig. 1(c) shows a cross-section of the embodiment in a plane perpendicular to the axis 9.

In Fig. 1(a) the lower shell 3 and disk 7 are illustrated as if they were partially transparent, so that one can see through them the cover 11a which is provided on the underside of the shell 3, and is rotatable about the axis 9 of the shell to expose a window subtending a sector S_1 of the disk 7. The cover is opened automatically on insertion of the cartridge into a disk drive. An arm unit 12 of the disk drive (also on the far side of the shell 3 and disk 7 and only visible in Fig. 1(a) because those elements are treated as transparent) pivots

to move a R/W head 13 (in the case that the disk 7 is a magnetic disk, the head is an electromagnetic transducer of a known type mounted on the arm 12 by a known construction) in an arc over the exposed surface of the disk 7. The shell 3 includes a circular aperture 17 of known construction so that a
 5 motor mechanism 18 (shown only in Fig. 1(c)) can contact a central hub 15 which supports the disk 7.

Similarly, Fig. 1(b) illustrates the shell 5 as being partially transparent, so that a cover 11b is shown in an open configuration, exposing a window in the shell 5.

10 The shells 3, 5 are provided with respective outer air bearing surfaces 19a, 19b and inner air bearing surfaces 21a, 21b. The annular bearing surfaces 19a, 19b have a radial width B_{out} and extend in a band almost in a full circle, except that they include a gap subtending a sector S_2 , which includes the respective window for the R/W head. The air bearing surfaces 19a, 19b are
 15 mirror symmetric about a nominal central plane of the disk, which is the plane in which the disk 7 is shown as lying in Fig. 1(c). A lubricant may be applied on the bearing surfaces 19a, 19b. The dimensions and groove patterns will be explained below.

The inner annular bearing surfaces 21a, 21b have radial width of B_{in} and
 20 extend in a full circle. The air bearing surfaces 21a, 21b are mirror symmetric about the central plane of the disk. Dimensions and groove patterns can be determined by the same formula as the outer air bearing surfaces (discussed below). B_{in} is much smaller than B_{out} since the inner air bearing mainly works as a dynamic seal to prevent the contamination particles from entering the
 25 cartridge. The lubricant may be applied on the bearing surfaces 21a, 21b.

Although the opening window is illustrated in Fig 1(a) and 1(b) as having a fan shape, the invention is not limited in this respect and the window may have a rectangular shape for head access driven by a linear actuator.

Pivot 23 protrudes from the upper shell 5 . It limits the axial movement of the hub 15 and aligns it to the axis 9. It reduces the risk that the disk contacts the bearing surfaces when the cartridge is inserted into the disk drive. There is an appropriate amount of grease between pivot 25 and a hole 28 in the upper surface of hub into which the pivot 23 is inserted, to provide for lubrication and thus damping of shocks.

The aperture 17 has a sliding door (not shown) which is opened when the disk is introduced into the disk drive, to allow the hub 15 to engage the motor 18. There are several protrusions 25 placed along the opening 17 to limit the axial movement of the hub 15 so that the disk 7 does not contact the air bearing surfaces 19a, 19b, 21a, 21b before the cartridge is inserted into the disk drive.

A further hole 26 is provided on the hub to receive a protrusion 27 on the motor 18. Pivot 23, protrusions 27 and holes 26, 28 allow the disk 7 and hub 15 to move along the axial direction within a certain range to supply tolerance for the motor 18 to engage the hub. These two holes 26, 28 are for alignment when the cartridge is inserted in and the motor is engaged.

The protrusion 27 is supported by a spring and is on the connection surface of the motor 18. It pushes the hub upward slightly and facilitates sliding the cartridge into the disk drive. Magnetic force is used to pull the hub 15 down to engage the motor 18 after the cartridge is fully inserted. The protrusion 27 makes the hub 15 align to the rotating axis 9 of the motor. There is a mechanism to push the covers 11a, 11b of the openings on the casing open. There is another mechanism to push them back to closing position when the cartridge is rejected by the drive. A conventional seal 29 is provided on the shell 3, between the shell 3 and the hub 15.

The air bearing surfaces 19a, 19b are provided on elements 31a, 31b adhered to the shells 3, 5 by adhesive layers 32a, 32b. The air bearing

surfaces 21a, 21b are provided on elements 33a, 33b adhered to the shells 3, 5 by adhesive layers 34a, 34b.

The groove patterns on the shell 3 are shown in Fig. 2(a). The groove pattern of shell 5 is substantially identical (after a mirror reflection). The patterns are composed of lands 37 constituting the surfaces, and grooves 39 shown hashed. One function of the groove patterns is to build up air pressure while providing damping to the change of the gap. Another function is to generate a special flow pattern. Another is to reduce the potential contact area.

The maximum radial extent of the outer air bearing surface 19a is r_{out} , and its minimum radial extent is r_{in} . The maximum radial extent of the inner air bearing surface 19a is r'_{out} , and its minimum radial extent is r'_{in} .

One example of a suitable groove pattern is a known herringbone groove pattern, as illustrated. One choice is that the centre of the groove is a logarithmic spiral. The pump-in groove (i.e. the radially inner one) has the following formula in the polar co-ordinates:

$$r = r_{out} e^{-(\tan \beta)\phi} \quad (1)$$

The pump-out groove has the following formula:

$$r = r_{in} e^{(\tan \beta)\phi} \quad (2)$$

The air bearing surfaces 19a, 19b have inner radius r_{in} and outer radius r_{out} , and the width B_{out} of the outer air bearings is

$$B_{out} = r_{out} - r_{in} \quad (3)$$

The radial value r_h of the circular line in the surface 19a at which the grooves change from formula (1) to formula (2), is that at which the inner and outer

portions of the surface develop equal pressures. This value is known to be given by:

$$r_h^2 = \frac{1}{2}(r_{in}^2 + r_{out}^2) \quad (4)$$

The pressure distribution is shown in Fig. 3. The radial flow across the air bearing area is suppressed due to the pumping effect of the grooves and the special pressure distribution.

As shown in Fig. 2(b), which is an enlarged view of part of the cross-section of Fig. 1(c) such that the configuration of the grooves is visible, the depth of the grooves is . The thickness of the backing part of the elements 31a, 31b is t . The thickness of the disk is T . The air film thicknesses are h_1 and h_2 for the upper and lower air bearing surface respectively. The total clearance for the air film is h_0 , given by:

$$h_0 = h_1 + h_2, \quad (5)$$

which is preferably less than 0.1mm. The spacing H between the upper and lower bearing surfaces is then determined by:

$$H = h_1 + h_2 + T \quad (6)$$

Each pair of upper and lower air bearings works in series, therefore the total stiffness K is the summation of the stiffnesses K_1 and K_2 of each individual air bearing:

$$K = K_1 + K_2$$

Another choice of groove pattern is that each groove is an Archimedian spiral. In this case, the pump-in groove has the following formula in the polar coordinates:

$$r = -\frac{a}{2\pi}\phi, \quad (8)$$

where a is the radial distance the groove advances in a complete turn. The pump-out groove has the following formula:

$$r = \frac{a}{2\pi}\phi, \quad (9)$$

- 5 We value of r_h at which the pump-in and pump out groove generate equal pressures is given for this type of spiral by:

$$r_h^3 = \frac{1}{2}(r_{in}^3 + r_{out}^3) \quad (10)$$

- All of the above discussion is in terms of the outer air bearing surfaces 19a, 19b, but exactly the same applies to the inner air bearing surfaces 21a, 21b
10 in the case, with B_{out} , r_{in} , r_{out} and r_h replaced by B_{in} , r'_{in} , r'_{out} and r'_h respectively.

- We will now state the preferable parameters for the groove pattern in the case of the logarithmic spiral explained above. For the outer air bearing, it is preferable that r_{out} is equal to the outer radius of the disk and B_{out} is equal to 0.25 r_{out} . For 3.5" disk, the outer air bearing is located at $r_{out}=47\text{mm}$ and thus
15 $B_{out}=12\text{mm}$. For the inner air bearing, it is preferable that r'_{out} is equal to the inner radius of the disk and B_{in} is equal to 0.25 r_{in} . For 3.5" disk, the inner air bearing is located at $r'_{out}=12.5\text{mm}$ with $B_{in}=4\text{mm}$.

- The groove width is a_1 and the land width between grooves is a_2 . The position angle between two successive grooves is θ . The preferred values are
20 $\theta=20^\circ$ (hence the number of grooves is $360/20=18$ as shown in Fig. 2(a)), $a_1=2a_2$, and $\delta=0.125\text{ mm}$ respectively.

It is recommended that $h_0=0.100\text{ m}$ or less, so the average value for h_1 or h_2 is about 0.050 mm. The total stiffness can be greater than 1 N/ μm when h_1 or

h_2 is around 10 μm . The air bearing urges the disk to its balanced position if the disk deviates to either side, and it also provides damping.

Bearing force and stiffness increase greatly with the decreasing of air film thickness, as shown in Fig. 4, so that contact is avoided. Fig. 5 shows the relationship between the natural frequency of the umbrella mode (the oscillation mode of lowest frequency, in which the outer circumference of the disk remains circular but oscillates perpendicular to the plane of the disk) and the minimal air film thickness for a flexible disk (ignoring the bending effects). Therefore, this technique provides a quick response to shock load with a narrow pulse width.

The grooves also reduce the possible contact area between the disk and the air bearing plate. The ridge area only accounts for about 25% of the total bearing surface.

The groove pattern with a logarithmic spiral expands rapidly so that the groove density becomes small when the outer diameter of the disk is relatively large. Low groove density will result in leakage and lower the pressure. An Archimedian spiral may be used instead of a logarithmic one to make the groove density higher.

The elements 31a, 31b, 33a, 33b having the herringbone groove pattern may be cut portions of a thin plate made of plastics, or some porous material including lubricant within it. Alternatively, the herringbone pattern may be formed (e.g. by moulding) on elements which are integral with the shells 3, 5.

The clearance between each bearing surface and the disk may be about 50 μm and the groove depth may be about 3 times of the clearance. The groove pattern is designed to have a pump-in portion and a pump-out portion and equal pressure is built up when they meet. The pattern is arranged uniformly in the circumferential direction with spacing of about 20 degrees (e.g 15 to 20

degrees). Lubricant is preferably applied to the top surfaces of the ridges. The radial width of the pattern may be in the range of 10% to 20% of the outer radius of the disk.

5 The inner grooved air bearing surfaces near the hub is mainly (though not exclusively) provided for seal and flow control purposes, and the outer grooved air bearing surfaces near the rim of the disk are provided for stabilization and flow control purposes. There are sliding doors to cover any necessary openings for head access or motor engagement.

10 It is recommended that a disk driver including a HGA limiter or an arm-based disk limiter be used to read/write data to this proposed cartridge to prevent head-disk impact.



CLAIMS

1. A disk cartridge for removable insertion into a disk drive, the cartridge including a data recordal disk enclosed within a casing and arranged for rotation within the casing about an axis;
- 5 the casing including one or more pairs of air bearing surfaces, the or each pair of air bearing surfaces facing respective sides of the disk at oppositely disposed positions on the disk;

each air bearing surface being formed with grooves, the grooves having a pattern for developing a positive pressure between that surface and
10 the disk upon rotation of the disk within the cartridge.
2. A cartridge according to claim 1 in which the grooves on each air bearing surface are a mirror image of the grooves on the other air bearing surface of the pair in a mirror plane transverse to the axis.
3. A cartridge according to claim 1 or claim 2 in which the cartridge
15 includes a window for accessing the disk, and said one or more pairs of air bearing surfaces include an inner pair of air bearing surfaces radially inward of the window.
4. A cartridge according to claim 3 in which the inner air bearing surfaces are substantially ring-shaped and centred on the axis of the cartridge.
- 20 5. A cartridge according to any preceding claim in which the casing comprises a window for accessing the disk, and said one or more pairs of air bearing surfaces include an outer pair of air bearing surfaces extending radially outwardly of the radially innermost part of the window.



6. A cartridge according to claim 5 in which the outer air bearing surfaces are disposed in arcs centred on the axis, the arcs having a gap extending across said window.
7. A cartridge according to claim 5 or 6 in which said outer pair of air bearing surfaces are proximate a radially outermost portion of the disk.
8. A cartridge according to any preceding claim in which the air bearing surfaces are formed by a material having lower hardness than the surface of the disk.
9. A cartridge according to any preceding claim in which at least one pair of air bearing surfaces is covered with or contains a lubricant.
10. A cartridge according to any preceding claim in which the grooves are formed to inhibit net radial air flow across the air bearing surfaces upon rotation of the disk within the cartridge.
11. A cartridge according to any preceding claim in which at least one pair of air bearing surfaces are mutually separated by no more than 0.10mm plus the thickness of the disk.
12. A cartridge according to any preceding claim in which the disk is connected to and surrounds a hub having (i) a first surface for engaging a motor for rotating the hub and (ii) a second surface facing away from the first surface, the hub being provided with protrusions on the first surface and a pivot connection to the casing at the centre of the second surface, the protrusions and pivot limiting the motions of the hub to prevent the disk from contacting the air bearing surface when the hub is not engaged with the spindle.



13. A cartridge according to any preceding claim in which the grooves on at least one pair of air bearing surfaces are deeper than the spacing between those air bearing surfaces.
14. A cartridge according to any preceding claim in which the grooves on
5 at least one pair of air bearing surfaces account for about 75% of the total area of the air bearing zone.
15. A cartridge according to any preceding claim in which the air bearing surfaces cover no more than 25% of the surface of the disk.
16. A cartridge according to any preceding claim in which each of the air
10 bearing surfaces has a radial extent which is between 10% and 20% of the radius of the disk.
17. A cartridge according to any preceding claim in which the casing is formed of two shells, the disk being sandwiched by the shells, each pair of air-bearing surfaces being provided on elements adhered to, or integral with, the
15 respective shells.
18. A cartridge according to any preceding claim in which the disk is a magnetic recording disk.
19. A cartridge according to any preceding claim in which the disk has a plastic substrate.