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29 OCT 2002

Composite Ramp Structure for Data Storage Devices

FIELD OF THE INVENTION

This invention relates generally to computer hard drives and other data storage devices utilizing rotating disks. More particularly, it relates to a load/unload ramp structure for holding the magnetic heads away from the data storage disks when the disks are not spinning.

BACKGROUND OF THE INVENTION

Computer hard drives typically employ a number of rapidly rotating disks having a coating of magnetic data storage material. Each disk is matched with a magnetic read/write head which is held very close to the disk surface. The magnetic read/write head can thereby read and write data on the magnetic disk as it moves.

The magnetic head is prevented from contacting the disk surface by an air cushion of moving air which is moving with the disk. Typically, the magnetic head rests about 0.02 microns above the disk while the disk is moving.

It is very important that the magnetic head and disk surface not come in contact for any extended period of time, since this can result in damage to both the disk surface and the magnetic head. For example, data can be permanently destroyed if excessive contact should occur. In an operating hard drive, contact is prevented by the fact that the disks are rapidly moving

29 OCT 2002

It is also important for the magnetic head and disk surface not to come in contact when the disks are not rotating (i.e., when the hard drive is not powered). If a disk and magnetic head are at rest and in contact for a period of time, the head and disk surface can stick together, resulting in damage to the disk surface when the disks start to rotate. Also, the disk must start from rest, and a certain minimum velocity is required for the magnetic head to float over the disk surface. Therefore, each startup of the hard drive results in the magnetic head and disk surface rubbing for a distance until the disk achieves sufficient speed to form the air cushion.

For these reasons, load/unload ramp structures have been used in some hard drives to hold the magnetic heads away from the disk surfaces while the hard drive is not operating. The magnetic heads are released from the ramp structure when the disks have achieved the minimum speed for causing the magnetic heads to float above the disk surfaces.

It is noted that some hard drives have disks with nonstick portions that will not cause damage to the magnetic heads even if the heads remain in contact with the nonstick portion for an extended period of time. Such hard drives are known as contact start/stop (CSS) hard drives. CSS hard drives do not utilize load/unload ramp structures.

Fig. 1 shows a typical prior art hard drive with three disks **2**. An actuator arm **3** supports a suspension **4**, a slider **5** and a lifting feature **6**. A magnetic read/write head (not shown) is located on a bottom surface of the slider **5**. The actuator arm **3** pivots about a pivot post **9**. The lifting feature **6** is positioned on the suspension **4** so that it engages with a ramp **8** on a ramp structure **10**. The ramp **8** imparts an upward force on the lifting feature **6** which lifts the slider **5** and magnetic head away from the disk **2**. The magnetic head is thereby not in contact with the disk **2** whenever the lifting feature **6** is moved onto the ramp **8**.

29 OCT 2002

It is desirable to make the ramp structure **10** from low friction polymer materials. Low friction ramps **8** reduce the amount of energy required to unload the magnetic heads (a concern during unpowered unloading), and also reduce the amount of debris particles generated when the lifting feature rubs over the surface of the ramp. It is also desirable to rigidly fix the location of the ramp structure with respect to the disk surface.

Ramp structures **10** made of polymer materials have thermal expansion coefficients which are often quite different from the thermal expansion coefficients of surrounding metal components which are usually made of aluminum or stainless steel. Therefore, during temperature changes, the plastic ramp structure expands and contracts at a different rate than surrounding components, resulting in misalignment of the ramp structure **10** relative to the disks **2**.

Thermal expansion induced misalignment results in decreased usable disk surface area for data storage.

Thermal expansion induced misalignment also necessitates looser alignment tolerances between the ramps **8** and disks **2**, which requires that more vertical space be provided between disks. An undesirable consequence of this is that fewer disks fit into a hard drive of a given size.

U.S. Patent no. 4,933,785 to Morehouse et. al. discloses a ramp structure having a cam structure for holding magnetic heads in an unloaded position. Morehouse does not disclose means for preventing thermal expansion induced misalignment.

U.S. Patent no. 5,034,837 to Schmitz discloses a ramp structure comprising a single piece of plastic. Schmitz does not disclose means for preventing thermal expansion induced misalignment.

29 OCT 2002

U.S. Patent no. 5,241,438 to Matsushima discloses a ramp structure comprising a plastic ramp and rigid metal ramp support member for supporting the plastic ramps. Matsushima does not disclose means for preventing thermal expansion induced misalignment.

It would be an advance in the art of hard drive design to provide a ramp structure which provides constant ramp alignment over a wide range of temperatures.

OBJECTS AND ADVANTAGES OF THE INVENTION

Accordingly, it is a primary object of the present invention to provide a ramp structure that:

1) reduces thermal expansion induced misalignment of load/unload ramps;

2) retains the advantages of using ramps made of polymer materials;

3) tightens the mechanical tolerances achievable in ramp-disk alignment;

4) is easily and accurately mounted to the base of a hard drive.

These and other objects and advantages will be apparent upon reading the following description and accompanying drawings.

SUMMARY OF THE INVENTION

The objects and advantages of the invention are attained by a ramp structure for providing load/unload ramps in a data storage device. The data storage device has a disk mounted on a spindle. The ramp structure has a rigid support structure and a ramp unit attached to the rigid support structure. The ramp unit has load/unload ramps. The rigid support structure has a thermal expansion coefficient selected such that a ramp-disk spacing remains constant during changes in temperature.

29 OCT 2002

It is noted that the movement of the disks caused by thermal expansion can also be affected by thermal expansion of a motor, spacer rings between the disks or the disks themselves. The spindle, motor, spacer rings, disks, and any other parts affecting disk movement are considered in sum to be a total drive assembly. Preferably, the rigid support structure has a thermal expansion coefficient selected to match the thermal expansion coefficient of the total drive assembly.

Preferably, the rigid support structure has a thermal expansion coefficient that matches the thermal expansion coefficient of the spindle, disk, and spacer rings. Also preferably, the rigid support structure is made of the same material as the spindle, disk and spacer ring. For example, the rigid support structure can be made of aluminum, steel, stainless steel, ceramic, plastic, glass-filled plastic, and carbon filled plastic.

Preferably, each ramp unit has two load/unload ramps. Alternatively, each ramp unit can have a single ramp.

Preferably, the ramp units are made of a polymer material, e.g. liquid crystalline polymer such as copolyesters of 4-hydroxybenzoic acid and 6-hydroxy-2-naphthoic acid (HAHN), polyacetals, or polyetheretherketone (PEEK). The ramp unit material can have filler materials such as PTFE internal lubricants.

Also preferably, the ramp units and the rigid support structure are mechanically interlocked. In one embodiment, holes in the rigid support structure into which the ramp units extend facilitate interlocking of the ramp units and rigid support structure.

Preferably, the ramp structure is made by molding the ramp units onto the rigid support structure. Molding of the ramp units onto the

29 OCT 2002

rigid support structure can be performed by insert molding, for example.

Preferably, each ramp unit comprises a separate piece of material (i.e., the ramp units are not contiguous). This means that the ramp units are mechanically connected only by means of the rigid support structure.

In a particularly preferred embodiment, the rigid support structure has a foot with a step in the bottom surfaces of the foot. The foot extends perpendicularly to the rigid support structure. The step in the foot is designed so that a tilting torque results when the foot is pressed against a flat surface. This enables the ramp structure to be aligned by registration against a sidewall acting as a mechanical fiduciary.

DESCRIPTION OF THE FIGURES

Fig. **1** shows a perspective view of a typical prior art hard drive and load/unload ramp structure.

Fig. **2A** shows a side view of a typical prior art hard drive and load/unload ramp structure.

Fig. **2B** shows a closeup view of how a load/unload ramp operates.

Fig. **2C** illustrates thermal expansion induced misalignment problems in a typical prior art load/unload ramp structure.

Fig. **3** shows a side view of a hard drive with a ramp structure according to a preferred embodiment of the present invention.

Fig. **4** shows a perspective view of the ramp structure according to the preferred embodiment of the present invention.

Fig. **5** shows a perspective view of a rigid support structure which is a component of the ramp structure of the present invention.

Figs. **6A**, **6B** show cross sectional views of the ramp structure illustrating how the rigid support structure and ramp units are attached in the preferred embodiment.

Fig. **7** shows a vertical cross sectional view of the ramp structure.

29 OCT 2002

Fig. 8 shows a perspective view of the back side of the rigid support structure.

Fig. 9 shows a side view of the ramp structure according to the present invention and how the ramp structure is preferably mounted to a base.

Fig. 10 shows a reverse perspective view of the rigid support structure according to a preferred embodiment.

Fig. 11 shows a vertical cross sectional view of the ramp structure bolted to a base. The ramp structure has a foot with a step to cause a clockwise tilting torque.

Fig. 12 shows an alternative embodiment in which each ramp unit has a single ramp.

DETAILED DESCRIPTION

Figs. 2A, 2B, and 2C illustrate problems inherent in prior art ramp structures made of polymer materials. **Fig. 2A** shows a ramp structure **10** attached to a base **11**. A spindle **12** having an axis of rotation **13** is connected to a motor **14**, and the motor is bonded to the base **11**. The motor **14** rotates the spindle **12** about its axis of rotation **13**. Data storage disks **2** are mounted on the spindle **12**. Each disk **2** has a top disk surface **15A** and a bottom disk surface **15B**. The ramp structure **10** provides one load/unload ramp **8** for each disk surface **15**. Each disk surface **15** and ramp **8** define a ramp-disk spacing **16**. Spacer rings **17** are positioned between disks **2** and so help to define a disk spacing **37** between disks **2**.

Fig. 2B shows a closeup of the ramp **8** and a lifting feature **6**. The lifting feature **6** is designed to be lifted by the ramp **8** when moved in a radial direction away from the spindle **12**. A ramp tip **19** is located closer to the disk surface **15** than the lifting feature **6** so that the lifting feature **6** contacts the top surface of the ramp **8**. This arrangement must take into account the position uncertainties of the ramp **8** and lifting feature **6**. A magnetic head **20** is attached to

29 OCT 2002

the lifting feature 6 so that the magnetic head is lifted away from the disk surface 15 when the lifting feature contacts the ramp 8.

The ramp 8 is located above the disk surface 15. The distance between the ramp and the disk surface defines the ramp-disk spacing 16. Ramps 8 typically have a slope 36 of about 1/4 or 15 degrees with respect to the disk surface 15. The ramp-disk spacing 16, slope 36, and radial location of the ramp 8 determine a landing radius 40 location. A landing radius 40 is the outermost radius at which the magnetic head 20 and disk surface 15 are close enough to interact. The location of the landing radius determines the outermost radius at which data can be stored. No data can be stored at a radial position outside the landing radius 40.

The location of the landing radius 40 will change when the ramp-disk spacing 16 changes. The landing radius 40 will move towards the spindle axis 13 if the ramp-disk spacing 16 increases, and away from the spindle axis 13 if the ramp-disk spacing 16 decreases. For ramps having a slope of 1/4, the radial movement in landing radius location 40 will be four times the change in ramp-disk spacing 16. Changes in the ramp-disk spacing will change the outermost radius at which data can be stored. Data must always be stored closer to the spindle 12 than the minimum possible radius of the landing radius 40. Consequently, large radial uncertainty of the landing radius location 40 reduces the surface area available for storing data. For maximum data capacity and reliable hard drive operation, it is important that the ramp-disk spacing 16 be fixed and well defined. For example, the ramp-disk spacing 16 must not change significantly during changes in temperature.

Temperature change induced variations in ramp-disk spacing 16 require that the disk spacing 37 be larger. This is because the ramp 8 must be large enough to ensure that it intercepts the lifting feature 6. A larger disk spacing 37 results in fewer disks being able to fit into a given volume, and hence, lower data capacity per unit volume.

29 OCT 2002

Table 1 shows thermal expansion coefficients for aluminum and steel, which are commonly used in the spindle **12**, motor **14**, spacer rings **17** and disks **2** and other components that are mechanically connected to the disks **2**.

Table 1

Material	Thermal Expansion Coefficient ($x10^{-6}$/degree Celsius)
Aluminum	22-23
Glass	7-7.5
Stainless Steel	11-12

Table 2 shows thermal expansion coefficients for plastics used for ramp structures. Copolyesters of 4-hydroxybenzoic acid and 6-hydroxy-2-naphthoic acid (HAHN) is sold by Hoechst-Celanese, Inc. under the tradename VECTRA A430. HAHN is a liquid crystalline material that has a low coefficient of friction and good wear properties. It is noted that HAHN has a highly anisotropic thermal expansion coefficient and so has two coefficients.

Table 2

Material	Thermal Expansion Coefficient ($x10^{-6}$/degree Celsius)
HAHN	-2 to 5 (longitudinal) or 65 to 80 (transverse)
Polyacetal	75-85
Polyetheretherketone (PEEK)	40-50
Polyimide	31-50
Polyetherimide	40-50

Fig. 2C shows the effect of a temperature increase on a prior art ramp structure. The spindle **12**, motor **14**, spacer rings **17** and data storage disks **2** are made of metals (or ceramics or glass) and so have

29 OCT 2002

a relatively low thermal expansion coefficient. The ramp structure **10** is made of plastic and so has a relatively high or variable thermal expansion coefficient. Consequently, the ramps **8** move upwards relative to the disks **2** during an increase in temperature, and thereby become misaligned. The change in relative height is due mostly to the low expansion of the spindle **12** compared to the high expansion of the ramp structure **10**. The change in relative heights is greatest for the disks furthest from the base **11**. The ramp-disk spacing **16A** between a top load/unload ramp **8A** and a top disk surface **15A** is increased. The ramp-disk spacing **16B** between a bottom load/unload ramp **8B** and a bottom disk surface **15B** is decreased. This results in the landing radius on the top disk surface **15A** moving closer to the spindle **12**. The landing radius on the bottom disk surface **15B** will move further from the spindle **12**. The locations of the landing zones on all the disk surfaces will be moved by the relative change in height between the disk surfaces **15** and load/unload ramps **8**.

Fig. 3 shows a preferred embodiment of a ramp structure **51** according to the present invention. Ramp units **50**, each having a pair of load/unload ramps **32**, are attached to a rigid support structure **52** which is mounted to a base **22**. The ramp units **50** and the rigid support structure **52** comprise the ramp structure according to the present invention. Preferably, each ramp unit **50** is a separate piece of material (i.e., the ramp units **50** are not contiguous). Also preferably, the ramp units **50** have a minimal vertical extent **55**. In one embodiment, the material of the rigid support structure **52** is selected to have a coefficient of thermal expansion which closely matches the coefficient of thermal expansion of a spindle **26**. Preferably, the spindle **26**, spacer rings **29**, disks **30** and rigid support structure **52** are made of the same material. Alternatively, the spindle **26**, spacer rings **29**, disks **30** and rigid support structure are made of different materials with approximately equal thermal expansion coefficients. Since the ramp units are not connected by plastic material, during temperature changes the ramp units **50** will

29 OCT 2002

move with the expansion and contraction of the rigid support structure **52**. Also, because the ramp units have a small vertical extent **55**, the thermal expansion motion of the ramps **32** is dominated by the thermal expansion motion of the rigid support structure **52**.

Since the spindle **26** and the rigid support structure **52** expand and contract at the same rate, the ramp-disk spacing **38** will be substantially constant for all disk surface/ramp pairs over a wide range of temperatures. The ramp-disk spacing **38** will remain constant during temperature changes even for disks far from the base **22**.

More generally, the rigid support structure **50** can be made of a material selected to have a coefficient of thermal expansion that results in the ramp-disk spacing **38** being constant during changes in temperature. In most drives this is accomplished by matching the thermal expansion coefficients of the rigid support structure **50** with the spindle **26** (to which the disks **30** are mounted). However, thermal expansion of other parts such as the motor **28**, spacer rings **29**, and the disks themselves can also influence the displacement of the disks **30** during changes in temperature. Therefore, the thermal expansion coefficient of the rigid support structure **52** may not be exactly equal to the thermal expansion coefficient of the spindle **26**. Instead, the thermal expansion coefficient of the rigid support structure **52** can be matched to the thermal expansion coefficient of the combined spindle **26**, spacer rings **29**, disks **30** and motor **28**. The spindle **26**, motor **28**, spacer rings **29**, and disks **30** and related components that affect the thermal expansion movement of the disks **30** can be considered to be part of a total drive assembly. It is noted that the total drive assembly comprises any components that affect the thermal expansion displacement of the disks **30** and hence the ramp-disk spacing **38**. A particular data storage device may have components other than the spindle, spacer rings, disk, and motor that affect the thermal expansion displacement of the disks **30**.

29 OCT 2002

Disks **30** which are used in hard drives comprise a plate of material (typically aluminum) coated with a thin film of magnetic data storage material. Other coatings may also be used. The thermal expansion coefficient of such a coated disk **30** is almost wholly determined by the material of the plate and not of the coatings disposed on the plate.

It is noted that the thermal expansion change in ramp-disk spacing **38** can also be affected by the base **22** if the base does not have a uniform thickness. For example, if the base **22** is thicker beneath the spindle **26** and motor **28** than beneath the ramp structure **51**, then the thermal expansion of the base **22** will have an effect upon the ramp-disk spacing **38**.

Data storage devices such as hard drives typically are constructed to operate at temperatures in the range of 0°C to 70°C. Therefore, the ramp-disk spacing **38** should be relatively constant over this temperature range. A relatively constant ramp-disk spacing over this temperature range can be accomplished by the ramp structure **51** of the present invention.

In a particularly preferred embodiment, the rigid support structure **52** is made of aluminum and the spindle **26** is made of aluminum. Alternatively, the spindle **26** and rigid support structure **52** are made of stainless steel.

In some drives, disks **30** made of glass may be used. Glass has a thermal expansion coefficient that approximately matches that of stainless steel. Therefore, in the case of using glass disks, the spindle **26**, spacer rings **29** and rigid support structure **52** may be made of stainless steel.

The spindle **26** and spacer rings **29**, however, have by far the greatest effect upon the thermal expansion movement of the disks **30**. Therefore, matching the thermal expansion coefficients of the spindle

29 OCT 2002

26, and spacer rings 29 with the thermal expansion coefficient of the rigid support structure 52 will provide substantial reduction of thermal expansion induced changes in ramp-disk spacing 38 compared to conventional ramp structures.

Fig. 4 shows a closeup view of the ramp structure of the present invention. Three ramp units 50 are attached to the side of the rigid support structure 52. The ramp structure shown in **Fig. 4** has six load/unload ramps 32 (two on each ramp unit 50), and so is appropriate to use in a drive with three disks. However, almost any number of ramp units 50 can be bonded to the rigid support structure 52.

Preferably, the ramp units 50 have parking well surfaces 54 which are sloped such that the lifting feature 34 is held in a parked position. The use of parking well surfaces 54 in ramp structures is known in the art of hard drive construction.

The ramp units 50 are made of a plastic which has a low coefficient of friction and good wear properties (low particulate production). Examples of such materials include liquid crystalline polymers such as copolyesters of 4-hydroxybenzoic acid and 6-hydroxy-2-naphthoic acid (HAHN), polyetheretherketone (PEEK), polyimide, and polyacetals. To reduce friction and wear, PTFE-filled plastics can be used. In a particular preferred embodiment, the ramp units 50 are made of injection molded liquid crystalline polymer such as HAHN, which is sold by Hoechst-Celanese, Inc. under the tradename VECTRA A430.

The rigid support structure 52 preferably has flanges 60, 62 to help increase the rigidity of the rigid support structure 52. High rigidity is beneficial for maintaining accurate positioning of the ramp units 50 with respect to the disks 30.

29 OCT 2002

Fig. 5 shows a preferred embodiment of the rigid support structure **52**. The rigid support structure **52** preferably has holes **64** with which the ramp units **50** mechanically interlock.

Fig. 6A shows a cross sectional view of the rigid support structure **52** and ramp unit **50**. The ramp unit extends through the hole **64** and so mechanically interlocks with the rigid support structure **52**. This is the preferred means of attaching the ramp units to the rigid support structure **52**.

Alternatively, as in **Fig. 6B**, the ramp unit **50** can wrap around the flange **60** to provide added mechanical stability. It is noted that more than one hole **64** can be provided for each ramp unit **50**. For example, each ramp unit **50** can also be mechanically interlocked with a second hole **65** in the flange **60**.

Otherwise, the ramp units **50** can be attached to the rigid support structure **52** with screws. This is not preferred as screws can cause plastic deformation of the ramp units **50** and eventual misalignment.

Another alternative is to attach the ramp units **50** by snap-fit structures which snap into the holes **64**, **65**. Yet another alternative is to attach the ramp units to the rigid support structure **52** by means of a heat staking process.

Fig. 7 shows a cross sectional view of the ramp structure in which the cross section cuts vertically through the ramp units **50** and holes **64**. Preferably, the rigid support structure **52** has a foot **66** to facilitate mounting the ramp structure to the base **22**. The foot **66** extends perpendicularly to the rigid support structure **52**. A thin layer **68** of plastic ramp unit material may be present between the ramp units **50**. The thin layer **68** should be thin compared to a thickness **70** of the ramp units **50** and a thickness **71** of the rigid support structure **52**. Restricting the layer **68** to be thin renders the ramp units **50** mechanically connected predominantly by means of

29 OCT 2002

the rigid support structure **52**. Consequently, the ramp units **50** move during changes in temperature according to the thermal expansion coefficient of the rigid support structure **52**.

Fig. 8 shows a back view of the rigid support structure **52** according to the preferred embodiment of the present invention. The foot **66** can be clearly seen. Preferably, the foot **66** has a threaded hole **72** for accepting a screw or bolt.

The ramp structure according to the present invention can be made by stamping and forming the rigid support structure **52**. In a typical embodiment, the rigid support structure is about 15 mm tall and 0.8 mm thick. The rigid support structure is placed inside an injection molding machine and the plastic ramp unit material is flowed around the rigid support structure. The ramp unit material is flowed through the holes **64**, **65** to provide mechanical interlocking of the rigid support structure and ramp units. Placing a part such as the rigid support structure inside an injection mold is well known in the art of injection molding as 'insert molding'. Insert molding can form ramp units **50** having accurate dimensions and dimensional stability.

Alternatively, the rigid support structure can be made by die-casting, extruding, molding or machining. The rigid support structure can also be made of plastics or ceramic materials, provided that the rigid support structure has an appropriate thermal expansion coefficient. In the case where the rigid support structure is made of plastic material, the plastic material composition can be adjusted to provide the rigid support structure with a predetermined thermal expansion coefficient. For example, glass-filled plastics and carbon-filled plastics can be used.

Although the rigid support structure has been shown to have a flat, planar shape, it is possible to use a rigid support structure with

29 OCT 2002

other shapes. For example, rigid support structures with block shapes or cylinder shapes can be used.

Fig. 9 shows a cross sectional side view of the ramp structure of the present invention attached to the base **22** with a screw **74**.

Fig. 10 shows the preferred embodiment of the present invention in which the foot **66** has a step **76** on the bottom. Preferably, the step **76** intersects the threaded hole **72** as shown. An outer bottom surface **78** of the foot is raised compared to an inner bottom surface **79** of the foot **66**.

The step **76** shown in **Fig. 10** serves to simplify the task of mounting and positioning the ramp structure to the base. **Fig. 11** shows a preferred method of mounting and aligning the ramp structure. A screw **80** attaches to the foot **66** through the base **22**. A sidewall **82** is positioned adjacent to the ramp structure. The sidewall **82** has a raised portion **84** which is positioned to contact the flange **60**. When the screw **80** is tightened, the step **76** in the bottom of the foot **66** is pressed against the base **22**. This pressing action causes a tilting torque **86** about the point of screw-foot contact. The tilting torque **86** acts in a clockwise direction in the view of **Fig. 11**. The tilting torque causes the flange **60** and raised sidewall portion **84** to be pressed together. This pressing together of the raised portion **84** and flange **60** results in accurate positioning of the ramp structure. The raised portion **84** acts as an alignment fiduciary and so provides accurate registration of the rigid support structure **52**. Alternatively, the flange **60** has a raised portion and the sidewall **82** is flat.

Fig. 12 shows an embodiment in which each ramp unit **50** has a single ramp **32**. In this case, each ramp unit **50** having a single ramp **32** is individually attached to the rigid support structure **52**. Attaching each ramp individually to the rigid support structure **52** will further reduce the thermal expansion induced changes in ramp-disk spacing **38**.

29 OCT 2002

However, this embodiment is not preferred because individually attaching the ramps renders the ramp structure more costly to manufacture.

Although the present invention has been illustrated with three ramp units and six ramps, it is appreciated that almost any number of ramp units or ramps can be attached to the rigid support structure.

It will be clear to one skilled in the art that the above embodiment may be altered in many ways without departing from the scope of the invention. Accordingly, the scope of the invention should be determined by the following claims and their legal equivalents.

29 OCT 2002

What is claimed is

1. A data storage device comprising:

a) a total drive assembly comprising:

1) a spindle having a thermal expansion coefficient,

2) a motor for rotating the spindle,

3) a data storage disk attached to the spindle;

b) at least one ramp unit having a load/unload ramp, the load/unload ramp and the data storage disk defining a ramp-disk spacing therebetween, wherein the ramp unit has a thermal expansion coefficient;

c) a rigid support structure to which the ramp units are attached, wherein the rigid support structure has a thermal expansion coefficient equal to the spindle thermal expansion coefficient to within $19x10^{-6}$ per degree Celsius.

2. The data storage device of claim 1 wherein the rigid support structure has a thermal expansion coefficient equal to the spindle thermal expansion coefficient to within $8x10^{-6}$ per degree Celsius.

3. The data storage device of claim 1 wherein the total drive assembly has a thermal expansion coefficient, and wherein the rigid support structure has a thermal expansion coefficient equal to the total drive assembly thermal expansion coefficient to within $19x10^{-6}$ per degree Celsius.

4. The data storage device of claim 1 wherein the rigid support structure and the spindle are made of the same material.

29 OCT 2002

5. The data storage device of claim 1 wherein the rigid support structure and the disk are made of the same material.

6. The data storage device of claim 1 wherein the data storage device further comprises a spacer ring and wherein the rigid support structure and the spacer ring are made of the same material.

7. The data storage device of claim 1 wherein the rigid support structure has a thermal expansion coefficient equal to the spindle thermal expansion coefficient to within $8x10^{-6}$ per degree Celsius.

8. The data storage device of claim 1 wherein the ramp units are made of a material selected from the group consisting of polyimide, polyacetals, PEEK, HAHN, liquid crystalline polymers, and PTFE-filled plastics.

9. The data storage device of claim 1 wherein the rigid support structure is made of a material selected from the group consisting of aluminum, steel, stainless steel, ceramic, plastic, glass-filled plastic, and carbon-filled plastic.

10. The data storage device of claim 1 wherein the ramp units and the rigid support structure are mechanically interlocked.

11. The data storage device of claim 10 wherein the ramp units and rigid support structure are mechanically interlocked by holes in the rigid support structure with the ramp units extending into the holes.

12. The data storage device of claim 1 wherein the ramp units are injection molded ramp units.

13. The data storage device of claim 1 wherein each ramp unit comprises a separate piece of material.

14. The data storage device of claim 1 wherein the rigid support structure further comprises a foot for mounting to a flat surface.

29 OCT 2002

15. The data storage device of claim 14 wherein the foot comprises a step such that a tilting torque is exerted on the rigid support structure when the foot is pressed against the flat surface.