SUSPENSION DESIGN FOR SUPPORTING A LOW MASS READ/WRITE HEAD

Field of the Invention

This invention relates generally to a suspension for supporting a read/write head adjacent to a relatively moving recording medium in a disk drive. More particularly, it relates to a suspension that is especially well suited for supporting low-mass heads at the end of a load beam, wherein the suspension has a modified geometry to reduce the mass of the load beam and to improve the resonant mode characteristics of the head and suspension combination.

Background

With the advent of more powerful central processor units (CPU's) and higher bandwidth bus structures, disk drive performance has become a significant limiting factor in overall computer system performance. Specifically, disk drives tend to impose data access delays on the order of several milliseconds, as opposed to the nanoseconds required to access data from electronic storage, hence there is a need to reduce actuator access times in order to enable more rapid retrieval of data from the tracks of a recording surface in a disk drive.

Contemporary disk drives typically include a rotating rigid storage disk and a head positioner for positioning a data transducer at different radial locations relative to the axis of rotation of the disk, thereby defining numerous concentric data storage tracks on each recording surface of the disk. The head positioner is typically referred to as an actuator. Although numerous actuator structures are known in the art, in-line rotary actuators are now most frequently employed due to their simplicity, high performance, and their ability to be mass balanced about their axis of rotation, the latter being important for making the actuator less sensitive to perturbations. A closed-loop servo system is employed to

operate the actuator and thereby position the heads with respect to the disk surface. The dynamic characteristics of hard disk drive actuator servo systems are such that higher servo system performance may be achieved when the natural mechanical vibration modes of the head and suspension structures do not occur at or near the servo sampling frequency or its aliased variants.

The read/write transducer, which may be of a single or dual element design, is typically mounted upon a ceramic slider structure having an air bearing surface for supporting the transducer at a small distance away from the surface of the moving medium. The combination of an air bearing slider and a read/write transducer is also known as a recording head. By utilizing an air bearing slider to support the head away from the disk surface, the head operates in a hydrodynamically lubricated regime at the head/disk interface rather than in a boundary lubricated regime. The former regime creates additional spacing between the transducer and the medium which reduces transducer efficiency, however, the avoidance of direct contact vastly improves the reliability of the head and disk components. The disk drive industry has been progressively decreasing the size and mass of the slider structures in order to reduce the moving mass of the actuator assembly and to permit closer operation of the transducer to the disk surface, the latter giving rise to improved transducer efficiency that can then be traded for additional track density.

In order to realize improved actuator access times, it becomes important, inter alia, to reduce undesirable levels of vibrations of components within the disk drive, because such vibrations can cause instability of the disk drive's servo system. Specifically, the resonant frequency of the first torsional mode of oscillation of a suspension's load beam structure is typically the first encountered (i.e., lowest frequency) resonant mode that limits actuator seek performance. The first torsional mode of oscillation can significantly limit

the achievable access time because the torsional oscillations result in off-track motion of the supported data transducer relative to the data tracks on the storage disk. This off-track motion constrains servo system performance and leads to delays in the transfer of data because of the settling time that is incurred to allow the amplitude of torsional vibrations to decay so as not to cause erroneous reading or writing of a data track.

Seek performance may also be improved by reducing the mass of the moving structures, e.g., the suspension. As is known in the prior art, reductions in suspension mass tend to lower the stiffness of the mass-reduced structure, which then leads to undesirable reductions in the resonant frequencies of the structure. As was noted hereinabove, the reduced resonant frequencies typically have deleterious consequences on the servo performance. Accordingly, there exists a need for a mass reduced suspension structure having improved resonant frequency characteristics, particularly with respect to the first torsional (1T) mode of oscillation.

The invention to be described provides a mass-reduced suspension for an in-line rotary actuator having a load beam that exhibits improved modal performance, particularly with respect to the first torsional resonant mode, thereby making it particularly suitable for use in high performance disk drive applications.

Summary of the Invention

A suspension assembly in accordance with this invention incorporates a tapered spring section supporting a significantly narrowed load beam structure. This invention shows a substantial performance advantage over prior art suspension designs. While the mass of the suspension is significantly reduced, the first torsional mode resonant frequency is almost doubled without causing material performance sacrifices in other modes, such as the first lateral and first bending oscillation modes.

A general object of the present invention is to provide a low-profile suspension with an improved load beam structure for supporting a read/write head in a disk drive which overcomes limitations and drawbacks of the prior art.

A more specific object of the present invention is to provide a suspension for supporting subminiature sliders in an inline rotary actuator that exhibits a higher first torsional resonant frequency than prior art suspensions.

Yet another object of the present invention is to provide a mass reduced suspension.

An additional object of the present invention is to provide an in-line, mass balanced, rotary voice coil actuator assembly which includes a reduced width, vented load beam having improved dynamic properties.

These and other objects, advantages, aspects, and features of the present invention will be more fully appreciated and understood upon consideration of the following detailed descriptions of a preferred embodiment presented in conjunction with the accompanying drawings.

Brief Description of the Drawings

In the Drawings:

Fig. 1A is diagrammatic, plan view of a prior art picoslider suspension.

Fig. 1B is a section view of the suspension of Fig. 3A taken along section line 1B-1B in Fig. 1A.

Fig. 2 is a diagrammatic, side elevation of a prior art picoslider suspension.

Fig. 3A is a diagrammatic, plan view of an upswept rail picoslider suspension in accordance with a preferred embodiment of the present invention.

Fig. 3B is a section view of the suspension of Fig. 3A taken along section line 3B-3B in Fig. 3A.

Fig. 4A is a diagrammatic, plan view of a reversed rail picoslider suspension in accordance with an alternative preferred embodiment of the present invention.

Fig. 4B is a section view of the suspension of Fig. 3A taken along section line 4B-4B in Fig. 4A.

Fig. 5A is a graphical representation of the frequency response characteristic of the prior art picoslider suspension of Fig. 1.

Fig. 5B is a graphical representation of the frequency response characteristic of the prior picoslider suspension of Figs. 3A and 3B.

Fig. 6 is a graphical representation of [...], i.e., Negative Offset and Bump plots.

Detailed Description

Fig 1A shows a prior art upswept rail suspension 10 for supporting a 30-percent slider (15) (also known as a "picoslider") adjacent to a disk surface (not shown). The illustrated suspension 10 is generically known as a "Type 8" suspension which has been adapted for use with a picoslider. Suspension 10 includes a baseplate 20 conventionally attached to mounting section 21 of the suspension (at the cantilevered end). Baseplate 20 is ultimately used for rigidly mounting suspension 10 to an actuator arm (not shown); typically, the baseplate is swaged onto the actuator arm. Spring (or hinge) section 22 which is fixed to mounting section 21 and interconnects the mounting section 21 with load beam 24. Spring section 22 includes one or more voids 26 for adjusting the spring constant of spring section 22. The thickness of spring section 22 may also be varied to adjust the spring constant. Suspension 20 has a small tooling hole 27 which is used to facilitate the accurate fabrication and assembly of the suspension.

Load beam 24 incorporates a pair of upswept rails 28 along the sides in order to stiffen the load beam. The configuration of rails 28 influences the resonant frequencies of beam 24, hence rails 28 can be designed to improve servo system performance by moving the resonant frequencies of suspension 20 away from the servo sampling frequency. Significantly, the load beam is specifically designed, consistent with prior art teachings, to widen near the spring section in order to improve resonance characteristics. The proximal end of load beam 24 is about ___ mm wide. Fig 1B shows a cross sectional view of the upswept rails 28 (taken along section line 1B-1B of Fig. 1A).

Turning now to Fig. 2, suspension 10 includes a flexure 29 which implements a gimbal and which is attached to the distal end of load beam 24 for interconnecting and pivotably supporting head 15 relative to the load beam. The spring section 22 may optionally be prebent so that during operation, suspension 10

remains relatively straight while still applying a load force on head 15 in the direction of the disk surface, thereby reducing the z-axis (height) clearance required for the in situ suspension structure.

In a preferred embodiment of the present invention, as illustrated in Fig. 3A, the suspension 40 has an overall length (in the longitudinal direction) of about 20-30 millimeters and a transverse width on the order of about __ millimeters at the widest region of the suspension, which is preferably located at or near the junction of mounting section 41 and spring section 42. The proximal end of load beam 44 has a width of about __ mm. [criticality discussion re: dimensions]

The main suspension body member is chemically etched from flat stainless steel sheet having a thickness on the order of about 60-75 microns. The etching operation defines the regions that will ultimately comprise the mounting section 41, spring section 42 (including void 46), load beam 44 (including tooling hole 27), and rails 48. After the suspension 40 is etched, mechanical forming operations are employed to impart features generally perpendicular to the flat regions of load beam structure 44, in this case, a laterally spaced apart pair of upswept rails 48. Typical rail dimensions are 0.2-0.3 millimeters in height and approximately 0.2-0.5 millimeters in width. A separate baseplate 20 is conventionally fabricated (e.g., turned or formed in a progressive die operation) and is attached to suspension 40 via conventional means, e.g., bonding or spot welding. In operative condition, the average height of the top surface of load beam 44 is not more than about 0.__ millimeters from the disk surface.

Conventional gimbal means, e.g. a flexure (not shown), are fixed to the distal end of load beam 44, although a gimbal may optionally be formed as an integral part of load beam 44 via, e.g., a chemical etch process. A suitable flexure typically has planar dimensions on the order of 1.5x10.0 millimeters and a

thickness on the order of 25-30 microns. The flexure is commonly etch formed and is affixed to the underside of load beam 44 using conventional prior art means, such as adhesives or spot welding, for example. A load button (not shown) may optionally be formed on the flexure or near the end of load beam 44, to establish a point about which head 15 is gimbaled. Finally, prior to attaching read/write head 15 to the underside of the flexure, suspension 40 is plastically deformed or prebent in spring area 42 so that when resultant suspension 40 is installed in a drive, load beam 44 will remain essentially flat and generally parallel to the disk surface (not shown) in order to maintain a low profile while still imparting a restoring force on head 15 in the direction of the disk surface. In the preferred embodiment show in Fig. 3A, the load beam also includes an optional pressure equalizing vent 49 between load beam rails 48 which further reduces the mass of the load beam structure.

In contrast to the teachings of the prior art, which indicate that widened suspension structures should be employed to improve the resonant mode characteristics of the suspension, the instant invention employs a much narrower load beam that has a maximum width less than the baseplate width and which includes spaced apart rail structures along at least a portion of the lateral edges of the load beam. Surprisingly, the significant narrowing of the load beam does not appear to deleteriously alter the modal resonant frequencies of the beam, but significantly increases the torsional mode resonant frequencies. Table 1 shows results of finite element modeling that indicate the respective modal resonant frequencies of picosliders 10 and 40 of Figs. 1A and 3A, respectively.

Table 1

MODE DESCRIPTION	PICOSLIDER SUSPENSION (PRIOR ART)	PICOSLIDER SUSPENSION WITH NARROW LOAD BEAM
First Torsion	2.5 KHz	3.8 KHz

First Bending	1.9 KHz	1.9 KHz
Second Torsion	8.5 KHz	9.0 KHz
Second Bending	_._ KHz	_._ KHz
Third Torsion	_._ KHz	_._ KHz
First Lateral	10.0 KHz	9.5 KHz
Heave	__._ KHz	__._ KHz

Additionally, the tapered spring and the narrow load beam configuration results in a significant decrease in the mass of the suspension and hence the polar moment of inertia of the resultant actuator structure, which decreases seek time. The masses of picosliders 10 and 40 of Figs. 1A and 3A, respectively, are shown in Table 2.

Table 2

[Table 2]

In disk drive applications where high volumetric efficiency is a dominant design goal, reverse rail load beams and prebent spring sections may be employed in a suspension to reduce the requisite z-axis clearance relative to a conventional upswept rail suspension design, which allows for closer disk-to-disk spacing. In such situations, the mechanical suspension structure should remain relatively unmodified in rail depth to maintain suitable modal performance. Fig. 4A shows an alternative preferred embodiment of the present invention for use in drives requiring very close disk-to-disk spacing. Suspension 50 includes reverse rails 58 and a prebent hinge section 42, both of which contribute to improved disk-to-disk spacing. Although the downswept rail embodiment of the present invention requires additional width (and therefore mass) at the distal end in order to ensure that rails 58 do not interfere with the gimbaling of supported slider 15, significant improvements in modal performance and mass reduction are still achieved relative to prior art reverse rail picoslider designs. In this downswept rail embodiment, the dimensions of void 49 are critical and must be carefully controlled to reduce both mass

and radial-air-flow induced oscillation. The vent area 49 is not less than __% of the load beam area.

[Bode Plot discussion re: Fig. 5]

[NOB Plot discussion re: Fig. 6]

In summary, the instant invention provides a mass reduced suspension design having improved modal performance for use with low mass sliders operating in an in-line rotary actuator assembly. A suspension in accordance with the teachings of the present invention provides better actuator servo system performance through improved modal performance. The combination of lower overall mass and improved servo system performance provides improved seek performance relative to a drive which incorporates prior art picoslider designs. Thus the present invention facilitates the design and fabrication of higher performance disk drives.

Although the present invention has been described in terms of the presently preferred embodiment, i.e., a suspension optimized for use with picosliders or sub-picosliders, it should be clear to those skilled in the art that the present invention may also be applicable to suspensions designed for use with somewhat larger sliders, such as nanosliders. It should therefore be understood that the instant disclosure is not to be interpreted as limiting. Various alterations and modifications will no doubt become apparent to those skilled in the art after having read the above disclosure. Accordingly, it is intended that the appended claims be interpreted as covering all alterations and modifications as fall within the true spirit and scope of the invention.

* C L M S *

What is claimed is:

1. A suspension for supporting a magnetic read/write head on an actuator assembly, the suspension comprising:

a baseplate for mounting the suspension to the actuator assembly, the baseplate defining a baseplate width;

a mounting region fixed to the baseplate and located at a proximal end of the suspension;

a spring section fixed to the mounting region at a distal end of the mounting region, the spring section being generally planar and having a pair of diverging lateral edges defining a region of maximum width and a region of minimum width, the region of maximum width being disposed adjacent the mounting region and the region of minimum width being disposed at a distal end of the spring section; and

a load beam for supporting the head, the load beam being fixed to the distal end of the spring section and having a maximum width less than the baseplate width.

2. The suspension of claim 1, wherein the load beam further comprises upswept rail means for stiffening the load beam, the upswept rail means extending at least partially along each lateral edge of the load beam.

3. The suspension of claim 1, wherein the load beam further comprises reverse rail means for stiffening the load beam, the reverse rail means extending at least partially along each lateral edge of the load beam.

4. The suspension of claim 3, wherein the load beam further includes an exterior boundary defining a first area and an interior boundary defining a void, wherein the interior boundary encompasses an area greater than about 20% of the first area.

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5. The load beam of claim 4 wherein the void is generally trapezoidal.

6. An improved cantilevered suspension for an in-line rotary actuator assembly for use in a disk drive, the suspension having a proximal end and a distal end and comprising:

a mounting region at the proximal end;

a baseplate fixed to the mounting region for mounting the suspension to the actuator assembly;

a spring section fixed to the mounting region distal to the mounting region, the spring section being generally trapezoidal and having a region of greatest width adjacent the mounting region and having a region of least width at a distal end of the spring section, the spring section having a lateral edge disposed on a side of the suspension;

an elongated, generally planar load beam fixed to the distal end of the spring section, a lateral edge of the load beam being disposed on the side of the suspension; and

wherein the lateral edge of the load beam forms an obtuse angle with the lateral edge of the spring section on the side of the suspension.

7. The suspension of claim 6, wherein the load beam further comprises a pair of laterally spaced apart rail members extending along at least a portion of each lateral edge of the load beam.

8. The suspension of claim 7, wherein the suspension is substantially bilaterally symmetric about a central longitudinal axis.

9. A suspension for supporting a magnetic read/write head on an actuator assembly, the suspension comprising:

a baseplate for mounting the suspension to the actuator assembly;

a mounting region fixed to the baseplate at a proximal end of the suspension;

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a load beam for supporting the head, the load beam being located at a distal end of the suspension and having a maximum width adjacent a proximal end thereof; and

a spring section interconnecting the mounting region and the proximal end of the load beam, the spring section being generally planar and having a pair of diverging lateral edges defining a region of maximum width and a region of minimum width, the region of maximum width being adjacent the mounting region and the region of minimum width being adjacent the load beam, the region of minimum width having a width substantially equal to the maximum width of the load beam.

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AMENDED CLAIMS

[received by the International Bureau on 21 June 1996 (21.06.96); original claims 1-9 amended; new claims 10-20 added; remaining claims unchanged (4 pages)]

1. A cantilevered suspension for supporting a read/write head on an in-line rotary actuator assembly for use in a disk drive, the suspension having a proximal end and a distal end and comprising:

a mounting region at the proximal end of the suspension;

a baseplate fixed to the mounting region for mounting the suspension to the actuator assembly;

a spring section fixed to a distal end of the mounting region, the spring section being generally trapezoidal and having a region of greatest width adjacent the mounting region and having a region of least width at a distal end of the spring section, the spring section having a pair of lateral spring edges disposed along lateral sides of the suspension; and

an elongated, generally planar load beam including gimbal means at a distal end of the load beam for attaching the read/write head, a proximal end of the load beam being connected to the distal end of the spring section, the load beam having a pair of substantially straight major lateral edges along the lateral sides of the suspension, each of the major lateral edges of the load beam forming an obtuse exterior angle with an adjacent one of the lateral spring edges.

2. The suspension of claim 1, wherein the load beam further comprises a pair of laterally spaced apart rail members extending along at least a portion of each major lateral edge of the load beam.

3. The suspension of claim 1, wherein the load beam further comprises reverse rail means for stiffening the load beam, the reverse rail means extending at least partially along each lateral edge of the load beam.

4. The suspension of claim 3, wherein the load beam further includes an exterior boundary defining a first area and an interior boundary defining a void, wherein the interior boundary encompasses an area greater than about 20% of the first area.

5. The load beam of claim 4 wherein the void is generally trapezoidal.



6. A suspension for a supporting a read/write head, comprising:

an elongated load beam having a pair of substantially straight major lateral edges converging at a first rate along a central longitudinal axis of the suspension from a proximal end to a distal end of the load beam;

a delta-shaped spring section connected to the proximal end of the load beam, wherein the delta shaped spring has a pair of lateral spring edges that converge along the longitudinal axis at a rate greater than the first rate.

7. The suspension of claim 6, wherein the overall length of the suspension is between about 20 mm and 30 mm and a maximum spring section width is about 6.0 mm and a maximum load beam width is about 3.2 mm.

8. The suspension of claim 6, wherein the load beam further comprises upswept rail means for stiffening the load beam, the upswept rail means extending at least partially along each lateral major edge of the load beam.

9. The suspension of claim 6, wherein the load beam further comprises reverse rail means for stiffening the load beam, the reverse rail means extending at least partially along each major lateral edge of the load beam.

10. The suspension of claim 9, wherein the pair of substantially straight major lateral edges comprise an exterior boundary defining a first area and wherein the load beam further includes an interior boundary defining a void, the interior boundary encompassing an area greater than about 25% of the first area.

11. The suspension of claim 10 wherein the void is generally trapezoidal.

12. A suspension for supporting a low mass magnetic read/write head on an actuator assembly for a hard disk drive, the suspension being substantially bilaterally symmetric about a central longitudinal axis and comprising:

a baseplate for mounting the suspension to the actuator assembly;

a mounting region fixed to the baseplate at a proximal end of the suspension;

a load beam for supporting the head, the load beam being located at a distal end of the suspension and having a maximum width adjacent a proximal end thereof, the load beam including a pair of substantially straight major lateral edges, each major lateral edge forming an angle with respect to the central longitudinal axis between 0 and 10 degrees. inclusive;

a spring section interconnecting the mounting region and the proximal end of the load beam, the spring section being generally planar and having a pair of converging lateral spring edges defining a region of maximum width and a region of minimum width, the region of maximum width being adjacent the mounting region and the region of minimum width being adjacent the load beam; and

wherein each converging lateral spring edge forms an acute angle with respect to the central longitudinal axis that is greater than about 25 degrees.

13. The suspension of claim 12, wherein the load beam further comprises a pair of laterally spaced apart rail members extending along at least a portion of each major lateral edge of the load beam.

14 The suspension of claim 13, wherein the overall length of the suspension is between about 20 mm and 30 mm and the maximum width of the load beam is about 3.2 mm.

15. A suspension for a supporting a read/write head, comprising:

an elongated load beam having a pair of substantially straight converging major lateral edges and having a maximum width at a proximal end of the load beam and having a distal end for attachment of the read/write head, the substantially straight major lateral edges defining a first interior angle;

a generally trapezoidal spring section attached to the proximal end of the load beam, the spring section having a pair of lateral spring edges tapering towards the load beam, wherein an interior angle between the pair the pair of lateral spring edges is greater than the first interior angle.

16. The suspension of claim 15, wherein the loadbeam has a width varying substantially linearly from the proximal end to the distal end.

17. The suspension of claim 15, wherein the loadbeam further comprises flanges along the major lateral edges for rigidifying the loadbeam.

18. The suspension of claim 15, wherein the loadbeam further comprises rails positioned along the major lateral edges for rigidifying the loadbeam.

19. The suspension of claim 18, wherein the rails are upswept.

20. The suspension of claim 18, wherein the rails are reverse rails.