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surface during start and stop operations, use a dedicated landing zone where the slider is parked when the drive is not operating. Typically, the landing zone is a specially textured nondata region near the inside diameter (ID) of the disk. In contrast to CSS disk drives, "load/unload" disk drives address the stiction problem by mechanically unloading the slider from the disk when the power is turned off, and then loading the slider back to the disk when the disk has reached a speed sufficient to generate the air bearing. The loading and unloading is typically done by means of a ramp that contacts the suspension when the actuator is moved away from the data region of the disk. The slider is thus parked off the disk surface with the suspension supported in a recess of the ramp.

A separate reason for parking the actuator when the disk drive is not operating is that the head, disk, or suspension can be damaged by a sudden external force that drives the slider onto the disk. This is especially likely in laptop computers.

In contrast to conventional air-bearing disk drives, contact or near-contact disk drives have been proposed that place the head carrier in constant or occasional contact with the disk or a liquid film on the disk during read and write operations. Examples of these types of disk drives are described in IBM's U.S. Patent 5,202,803 and published European application EP 367510; U.S. Patent 5,097,368 assigned to Conner Peripherals; and

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U.S. Patent 5,041,932 assigned to Censtor Corporation. These types of disk drives may also be of the type that park the actuator with the head carrier away from the data region of the disk when the drive is not operating.

Because of the adverse consequences if the head carrier contacts or impacts the data region of the disk, disk drives that park the actuator typically have some type of actuator lock to prevent the actuator from moving the carrier toward the data region of the disk in the event of an external shock. Passive magnetic or spring locks apply restraining forces that are overcome when the drive is turned on and the actuator is activated. Solenoid locks engage the actuator when power is off and release when a current pulse is applied. A rotary inertial lock, as described in U.S. Patent 5,189,576 assigned to Integral Peripherals, locks the rotary actuator in the presence of an external force that causes the parked actuator to move away from its crash stop toward the data region of the disk. The passive locks are especially subject to failure in the presence of a sudden external force, the solenoid locks are unreliable, and the inertial rotary lock has been found to be inoperable in the presence of an external force that causes the parked actuator to move into its crash stop.

What is needed is a disk drive with a reliable lock for the parked rotary actuator that operates regardless of the direction of the external force.

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Summary of the Invention

The present invention is a disk drive that uses a bidirectional rotary inertial lock to reliably lock the actuator in the parked position. The lock engages the actuator even in the presence of a rotational acceleration tending to drive the actuator into the crash stop. In the preferred embodiment, the rotary inertial lock includes a flexible latch arm that is also driven into a stop in the presence of the same acceleration, but rebounds to engage the actuator on its rebound from its crash stop.

For a fuller understanding of the nature and advantages of the present invention, reference should be made to the following detailed description taken together with the accompanying drawings.

Brief Description of the Drawing

Fig. 1 is an illustration of a disk drive with a prior art rotary inertial lock in the open position.

Fig. 2 is an illustration of a disk drive with a prior art rotary inertial lock in the locked position.

Fig. 3 is an illustration of a disk drive with a prior art rotary inertial lock showing the inability of the lock to lock the actuator when the actuator rebounds off its crash stop.

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Fig. 4 is an illustration of a disk drive with the rotary inertial lock of the present invention shown rebounding (dashed lines) to lock the actuator following its rebound (dashed lines).

Fig. 5 is an illustration of a disk drive with an alternative embodiment of the rotary inertial lock of the present invention in the open position.

Fig. 6 is an illustration of a disk drive with an alternative embodiment of the rotary inertial lock of the present invention in the locked position.

Detailed Description of the Invention

Prior Art

Referring first to Fig. 1, there is illustrated a top view of the interior of a prior art disk drive with the housing cover removed. For ease of illustration and explanation, the disk drive depicted in Fig. 1 is shown as having a single recording head and associated disk surface, although conventional disk drives typically have multiple heads and disks. The disk drive comprises a housing base 10 to which are secured a disk drive or spindle motor with attached disk 12, a rotary actuator 14, a load/unload ramp 30, and a rotary inertial lock 50. The base 10 and a cover (not shown) provide a substantially sealed housing for the disk drive.

The disk 12 has a data region 13 and includes a thin film of conventional perfluoro-polyether (PFPE) lubricant on its surface.

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The rotary actuator 14 rotates on a pivot 15 mounted to base 10. Actuator 14 is typically a balanced rotary voice coil motor (VCM) actuator having a coil 17 that moves through the fixed magnetic field of a magnet assembly (not shown) mounted to base 10. An outside diameter (OD) crash stop 40 and an inside diameter (ID) crash stop 42 are mounted to base 10 to limit the travel of rotary actuator 14. The crash stops may be rigid posts with elastomeric O-rings, such as O-rings 41, 43 on crash stops 40, 42, respectively. Alternatively, the crash stops my be rubber bumpers or resilient cantilever beams. The actuator 14 has on the end opposite coil 17 a rigid arm 24. A suspension 26 is attached to the end of actuator arm 24. The suspension 26 may be a conventional type of suspension such as the well-known Watrous suspension, as described in U.S. Patent 4,167,765 assigned to IBM. The suspension 26 supports the head carrier or air-bearing slider 22 and includes a tab 28 that extends beyond the slider 22. A read/write head or transducer 20 is formed on the trailing end of slider 22. Transducer 20 may be an inductive read and write transducer or an inductive write transducer with a magnetoresistive (MR) read transducer formed by thin film deposition techniques as is known in the art.

A load/unload ramp 30 having a ramp portion 32 and a recess 34 is mounted to the base 10. Ramp 30 supports the suspension tab 28 in its recess 34 and thus serves as the parking location for actuator 14 when the

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disk drive is not operating. Fig. 1 illustrates the actuator 14 parked, i.e., suspension tab 28 residing in ramp recess 34 and the actuator 14 forced against the O-ring 41 of OD crash stop 40. If the disk drive were a CSS disk drive, then the actuator 14 would be parked against the O-ring 43 of ID crash stop 42 and the slider 22 would be at rest on a textured nondata landing zone at the ID region of the disk 12. A passive actuator lock or a solenoid lock would be used to keep the actuator 14 parked with the slider 22 at the landing zone.

A rotary inertial lock 50 is also mounted on base 10 and includes an arm 51 having a tip 52, a latch stop 53, a counterweight 54, and a torsion spring 55. The inertial lock 50 is a rigid body, rotationally balanced, that rotates on a pivot 56 mounted to base 10. Pivot 56 is parallel to pivot 15 of actuator 14. The torsion spring 55 (or other means) urges the arm 51 up against latch stop 53 to hold the lock in its open position, which allows free rotation by the actuator 14, as shown in Fig. 1.

When the rotary lock is in the locked position (see Fig. 2), the tip 52 is engaged with a mating surface 57 on actuator 14, which prevents actuator 14 from moving the suspension tab 28 off the ramp recess 34. Fig. 2 shows the latch tip 52 and the actuator mating surface 57 at an imaginary engagement point 59, which is the intersection of the circular arcs formed by the tip 52 and mating surface 57. If the disk drive were a CSS disk drive, the rotary lock 50

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would be designed to rotate in the opposite direction from that shown in Fig. 1 and would be located on the other side of actuator 14 near crash stop 42.

During read/write operations of the disk drive, the drive motor rotates the disk 12 at a constant speed, and the actuator 14 rotates about pivot 15 to move the slider 22 generally radially across the surface of the disk 12 so that the read/write transducer 20 may access different data tracks on the data region 13. The arm 51 of rotary lock 50 is biased against latch stop 53 by spring 55 so that actuator 14 is free to rotate about pivot 15. The suspension 26 provides a loading force to the slider 22 to urge it toward the surface of disk 12. The data detected from disk 12 by the transducer 20 is processed into a data readback signal by signal amplification and processing circuitry (not shown). When the disk drive is powered down, the actuator 14 is driven toward ramp 30 while the disk 12 is still rotating. The suspension tab 28 contacts the ramp portion 32, moves up the ramp portion 32 and off the disk 12, and comes to rest in ramp recess 34. At this time, the actuator 14 is parked and pressed against O-ring 41 of OD crash stop 40.

Fig. 2 shows how the conventional rotary inertial lock 50 works to keep the actuator in this parked position when the drive is not operating. When the drive undergoes a rotational acceleration in the clockwise direction (e.g., when the drive is accidentally dropped or subjected to sudden impact), all bodies inside the drive experience a torque in the direction indicated by

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arrow 60, i.e., counterclockwise relative to the drive. If no lock is present, the rotary actuator 14 may rotate away from OD crash stop 40 to move the suspension tab off the ramp 30 and allow the slider 22 to enter the data region 13 of the disk 12. As described above, this could damage the head, disk, or suspension, or allow the slider to come to rest on the disk, thereby presenting the stiction problem. However, the rotary inertial lock 50 also experiences the same torque as the actuator 14 and is also free to rotate in the same direction. By appropriate design of the lock 50, the arm 51 will then rotate about pivot 56 away from latch stop 53 (in the direction indicated by arrow 61) and reach the engagement point 59 before the mating surface 57. The rotating actuator 14 will thus be prevented from moving away from its parked location because, shortly after it begins to rotate, the mating surface 57 will intercept the latch tip 52 near the engagement point 59.

The prior art rotary latch 50 only functions if the external torque is in the direction tending to move actuator 14 away from OD crash stop 40. However, if the drive is subjected to an external torque that tends to force actuator 14 into crash stop 40 (i.e., the actuator 14 shown by dotted lines in Fig. 3 is rotated clockwise as shown by arrow 62), the latch arm 51 will be driven into latch stop 53 (in the direction indicated by arrow 64). The crash stop 40 has the elastic O-ring 41 which is designed to cushion impacts as the actuator 14 reaches the end of its allowed travel in the OD direction. The

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actuator 14 will bounce off the crash stop 40 and travel back in the direction of the disk 12, as shown by arrow 65. However, the rotary inertial lock 50, being essentially an inelastic system, will not work to engage the actuator 14. Thus, the actuator 14 can bounce onto the disk 12 with no response from lock 50. The acceleration caused by the external torque only serves to hold the latch arm 51 open, while the actuator 14 bounces off its crash stop 40 onto the disk 12.

Preferred Embodiments

In the present invention, a bidirectional rotary inertial lock engages the actuator regardless of the direction of the external force. The preferred embodiment of the lock 70 is shown in Fig. 4. The latch arm 71 is made flexible and/or the latch stop 73 is made of elastic material. By appropriate design and selection of materials for the latch arm 71, latch stop 73, and crash stop 80 with O-ring 81, the damping and elasticity of the latch arm/latch stop system and crash stop system can be tailored to cause the latch tip 72 to intercept the mating surface 57 of actuator 14 both directly and on the rebound from crash stop 80.

In the embodiment of Fig. 4, the arm 71 is made of polyimide elastic material and is designed to a specified thickness so that it essentially forms a cantilever spring. In addition, or alternatively, latch stop 73 may also be

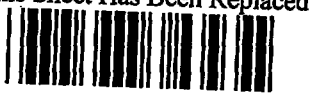
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made elastic by use of an O-ring 77 in a manner similar to the actuator crash stop. When the drive undergoes a counterclockwise acceleration so that the actuator 14 is driven in the direction of arrow 66 into its crash stop 80 (as shown by the dashed line outline of actuator 14), both the actuator 14 and the latch arm 71 rebound off their respective stops 80, 73. The latch arm 71 is driven in the direction of arrow 67 into its elastic crash stop 73 (as shown by the dashed line outline of inertial lock 70) and rebounds in the direction indicated by arrow 68 to the engagement point 59 before the mating surface 57 of actuator 14. The result is that even though the external torque is in a direction not generally considered to be a problem, i.e., in a direction that drives the actuator 14 into the crash stop 80, the unexpected rebound of the actuator 14 in the direction indicated by arrow 69 does not result in the slider 22 contacting or impacting the data region 13 of the disk 12. The lock 70 still functions in the normal manner in the presence of an external torque tending to cause the actuator 14 to move directly away from crash stop 80.

For the latch arm 71 to successfully intercept the actuator, the arm 71 must rotate far enough to engage the actuator before the actuator escapes, i.e., the mating surface 57 on the actuator 14 must not progress counterclockwise beyond the engagement point 59 before the latch tip 72 reaches point 59. The dynamic responses of the actuator 14 and rotary lock 70 in the presence of a

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clockwise rotational acceleration of the disk drive (one that tends to rotate the actuator 14 and latch arm 71 in the direction of arrows 66, 67, respectively) are controlled by certain properties of the actuator and latch systems. For the purpose of this explanation, let I_A and I_L be the rotational inertias of the actuator 14 and lock 70, respectively; K_A and K_L the torsional stiffnesses of the actuator/crash stop and latch arm/latch stop systems, respectively; and Q_A and Q_L the angles through which the actuator 14 and latch arm 71 must travel from their rest positions to reach the engagement point 59. For the case of a counterclockwise rotational acceleration of the disk drive which is a short duration pulse, both the latch arm 71 and actuator 14 will suddenly start rotating clockwise with respect to the drive, pushing each against its respective stop, and causing each to later bounce off their stops. During the time that each is against its stop, each system can be described as a torsional harmonic oscillator, and the bounces can be described as a single half cycle of the oscillator. The actuator/crash stop and latch arm/latch stop systems have characteristic frequencies W_A and W_L, respectively, given by the following equations:

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$$W_A = \sqrt{\frac{K_A}{I_A}} \quad (1)$$

$$W_L = \sqrt{\frac{K_L}{I_L}} \quad (2)$$

The time duration of a half cycle (the total bounce time) for each system is given by π/W_A and π/W_L. The additional time needed to reach the engagement point 59 after rebounding from the stop is given by $Q_A/\alpha T$ and $Q_L/\alpha T$ seconds, where α is the magnitude of the rotational acceleration, and T is the duration of the acceleration. Thus, after completion of each bounce (that is, the moment the actuator 14 and latch arm 71 become free of their respective stops), the time needed for the actuator 14 and latch arm 71 to travel to engagement point 59 is inversely proportional to the angle through which they must travel to reach point 59 from the rest position. Thus, for short duration acceleration pulses (i.e., a small fraction of the half cycle or total bounce time of the faster reacting of the actuator and latch systems), successful latching requires the following relationship to hold:

$$\pi/W_A + Q_A/\alpha T > \pi/W_L + Q_L/\alpha T \quad (3)$$

The above analysis neglects the effects of damping in each system. The behavior of such elastic systems in the presence of damping is well understood. However, in summary, the effect of damping on each system is to slow it down;

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the characteristic frequency of a damped system falls with increasing damping, and the exit velocity after the bounce also decreases with increasing damping. Both such effects of damping increase the time needed to reach the engagement point 59. When the damping of either system reaches or exceeds the well-known criteria of "critical damping", there will be no bounce off the stops at all. Actuator/crash stop systems are typically underdamped, i.e., able to bounce. For such systems, the latch also must be able to bounce in order to intercept the actuator.

For accelerations which are longer than the short pulses described above, the dynamic analysis is more complicated. In such cases, the escape velocity upon completion of the bounce changes, depending on the duration and magnitude of the acceleration. Under some circumstances, the escape velocity for one system or the other may be very low or zero. If the latch arm angular velocity is too slow compared to the actuator angular velocity, latch failure may result. If the actuator and latch characteristic frequencies W_A and W_L are matched, however, then the escape velocities for each system remain equal to each other (even though both vary depending on the nature of the acceleration), and the bounce times for both systems are identical. Then, the condition for successful latching reduces to $Q_A > Q_L$.

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Successful bounce latching for the rotary lock as described and shown in Fig. 4 has been demonstrated on a disk drive with the following parameters:

I_A = 7 gm-cm	I_L = 0.5 gm-cm
$K_A = 1 \times 10^7$ dyne-cm/rad	$K_L = 7.7 \times 10^5$ dyne-cm/rad
W_A = 1200 rad/sec	W_L = 1200 rad/sec
Q_A = 1.2 deg	Q_L = 0.8 deg

The elastic element in the actuator/crash stop system was a rubber O-ring 81, and the elastic element in the latch arm/latch stop system was a flexible latch arm 71 (Fig. 4). The latch arm 71 is viewed as a cantilever beam with dimensions 2.5 cm long x 0.1 cm thick x 0.25 cm wide. The rotary lock 70, including the arm 71, was made of polyimide with a modulus of elasticity of 3.1×10^{10} dyne/cm^2. Since K_L is calculated from the beam dimensions and modulus of elasticity according to the known relationship for cantilever beams, the selection of the beam material and dimensions results in matched characteristic frequencies W_A and W_L. For arbitrary rotational accelerations in arbitrary directions and with arbitrary durations, the failure rate of this rotary lock was observed to be less than 1%.

A similar system with a thicker cantilever on the latch (0.25 cm thick) was observed to fail about 10% of the time under similar shock conditions. When counterclockwise shocks above a certain threshold were specifically applied to this system, the failure rate reached 100%. For the thicker

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cantilever, two unfavorable results occur: the frequencies W_A and W_L are no longer matched and, more importantly, the physical properties of the latch are such that the system is overdamped and does not bounce at all. Thus, the latch tip fails to engage the actuator at all in the case of counterclockwise rotational accelerations of the file. This overdamped case is typical of prior art inertial rotary locks; they do not bounce appreciably and are unable to capture a bouncing actuator.

An alternative embodiment of the bidirectional rotary inertial lock is shown in Figs. 5 and 6. This bidirectional lock 90 is capable of rotating in both directions about a pivot 96. Lock 90 has an end 91 with a slot 92. On the opposite end, the lock 90 has a magnet 93. A ferromagnetic post 94 is mounted on base 10. The actuator 14 has a pin 95 in place of the mating surface 57 present in the Fig. 3 embodiment. In the absence of an external force, the lock 90 will be maintained in a neutral position with the magnet 93 aligned with ferromagnetic post 94. In this open position, the actuator engagement pin 95, which is rigidly attached to the actuator 14, can pass freely through the escape slot 92 on the lock end 91. This allows the actuator to freely rotate and move the slider 22 across the data region 13 of disk 12. However, in the event of a rotational acceleration of the drive in either a clockwise or counterclockwise direction, the lock end 91 will swing away from its open neutral position, capturing the actuator 14 in its parked position. If

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the total angle through which the lock end 91 can swing is large compared to the angle of the escape slot opening, the failure rate due to actuator rebound or random bouncing can be minimized. In the locked position shown in Fig. 6, the lock end 91 has rotated approximately 10 degrees, with plenty of room to spare, while the actuator 14 has been locked within a range of rotation of only a few degrees. Thus, in the time it takes for the actuator 14 to rotate into crash stop 80 (in the direction of arrow 100), rebound off crash stop 80, and attempt to travel toward the data region 13 on disk 12 (in the direction of arrow 101), the lock end 91 is free to continue swinging further closed (in the direction indicated by arrow 102).

While the magnet 93 and post 94 are the preferred means for maintaining the lock 90 in its neutral position, a torsion spring could be used instead.

While the preferred embodiments of the present invention have been illustrated in detail, it should be apparent that modifications and improvements may be made to the invention without departing from the spirit and scope of the invention as described in the following claims.

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What is claimed is:

1. A data recording disk drive comprising:

a disk having a data region;

a motor connected to the disk for rotating the disk;

a transducer for writing data to or reading data from the data region of the disk;

a carrier supporting the transducer;

a rotary actuator having a pivot and connected to the carrier for moving the carrier generally radially across the disk;

a crash stop for limiting the rotation of the actuator;

a rotary lock having a pivot generally parallel to the actuator pivot for engaging the actuator in the presence of an external force tending to rotate the actuator into the crash stop; and

means for supporting the motor, rotary actuator and rotary lock.

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* C L M S *

2. The disk drive according to claim 1 wherein the rotary lock further comprises:

a flexible arm having a tip for engagement with the actuator;

a latch stop mounted to the actuator supporting means for limiting movement of the arm in the presence of an external force tending to rotate the actuator into the crash stop, whereby when said force ceases the flexible arm rebounds from the latch stop to engage the actuator on the rebound from the crash stop; and

means for urging the arm against the latch stop in the absence of an external force.

3. The disk drive according to claim 1 wherein the rotary lock further comprises:

an arm having a tip for engagement with the actuator;

a resilient latch stop mounted to the actuator supporting means for limiting movement of the arm in the presence of an external force tending to rotate the actuator into the crash stop, whereby when said external force ceases the resilient latch stop rebounds the arm to engage the actuator on the rebound from the crash stop; and

means for urging the arm against the latch stop in the absence of an external force.

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* C L M S *

4. The disk drive according to claim 1 wherein the rotary lock further comprises:

an arm having an end for engagement with the actuator; and

means for maintaining the arm at a neutral position in the absence of an external force, the arm being freely rotatable in either direction away from its neutral position in the presence of an external force;

whereby the arm rotates in a first direction to engage the actuator in the presence of an external force tending to rotate the actuator away from the crash stop, and in a second direction to engage the actuator on the rebound from the crash stop in the presence of an external force tending to rotate the actuator into the crash stop.

5. The disk drive according to claim 4 wherein the arm end has a slot, and further comprising a pin on the actuator for engagement by the arm end in the presence of an external force, the pin being movable through the slot when the arm is maintained in its neutral position in the absence of an external force.

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6. The disk drive according to claim 4 wherein the means for maintaining the arm at a neutral position in the absence of an external force is a magnet.

7. The disk drive according to claim 1 further comprising means for parking the carrier when the disk is not rotating.

8. The disk drive according to claim 7 wherein the carrier parking means comprises a load/unload ramp mounted to the actuator supporting means.

9. The disk drive according to claim 7 wherein the carrier parking means comprises a carrier landing zone located on the disk surface away from the data region and an actuator lock for restraining the actuator to keep the carrier parked at the landing zone.

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10. A magnetic recording disk drive comprising:

a support base;

a magnetic recording disk having a region for the recording of data;

a motor mounted to the base and connected to the disk for rotating the disk;

a head for writing data to or reading data from the disk;

a carrier for supporting the head;

a rotary actuator mounted to the base and connected to the carrier for moving the carrier generally radially across the disk;

a crash stop mounted to the base for limiting the rotation of the actuator;

a load/unload ramp mounted to the base for parking the carrier when the disk is not rotating; and

a rotary lock mounted to the base and rotatable about an axis generally parallel to the actuator rotation axis for engaging the actuator in the presence of an external force tending to rotate the actuator into the crash stop.

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* C L M S *

11. The disk drive according to claim 10 wherein the rotary lock further comprises:

a flexible arm having a tip for engagement with the actuator;

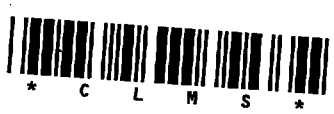
a latch stop mounted to the base for limiting movement of the arm in the presence of an external force tending to rotate the actuator into the crash stop, whereby when said force ceases the flexible arm rebounds from the latch stop to engage the actuator on the rebound from the crash stop; and

a spring for biasing the arm against the latch stop in the absence of an external force.

12. The disk drive according to claim 11 wherein the rotary actuator has a surface for engaging the latch tip, wherein the rotary actuator and crash stop have a characteristic frequency generally equal to the characteristic frequency of the flexible arm and the latch stop, and wherein the angle of rotation for the actuator from its crash stop to engage the tip of the latch arm is greater than the angle of rotation for the arm from the latch stop to the engagement surface of the actuator.

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13. The disk drive according to claim 10 wherein the rotary lock further comprises:

an arm having a tip for engagement with the actuator;

a resilient latch stop mounted to the base for limiting movement of the arm in the presence of an external force tending to rotate the actuator into the crash stop, whereby when said external force ceases the resilient latch stop rebounds the arm to engage the actuator on the rebound from the crash stop; and

a spring for biasing the arm against the latch stop in the absence of an external force.

14. The disk drive according to claim 13 wherein the rotary actuator has a surface for engaging the latch tip, wherein the rotary actuator and crash stop have a characteristic frequency generally equal to the characteristic frequency of the latch arm and resilient latch stop, and wherein the angle of rotation for the actuator to engage the tip of the latch arm is greater than the angle of rotation for the arm from the latch stop to the engagement surface of the actuator.

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15. The disk drive according to claim 10 wherein the rotary lock further comprises:

an arm having an end for engagement with the actuator; and

means mounted to the base for maintaining the arm at a neutral position in the absence of an external force, the arm being freely rotatable in either direction away from its neutral position in the presence of an external force;

whereby the arm rotates in a first direction to engage the actuator in the presence of an external force tending to rotate the actuator away from the crash stop, and in a second direction to engage the actuator on the rebound from the crash stop in the presence of an external force tending to rotate the actuator into the crash stop.