

MINIMUM BEARING LOAD, HIGH BANDWIDTH, MOVING MAGNET
ACTUATOR

5 Field of the Invention

This invention relates to data storage systems employing HDDs (hard disk drives) for use in data processing systems. More specifically, the invention
10 pertains to a single stage disk drive actuator design having high loop gain (servo bandwidth) for high-density data recording.

15 Background of the Invention

A HDD typically includes an actuator mechanism carrying one or more read/write heads for recording information. Information is recorded on one or more
rotating magnetic disks, having recording surfaces on
20 opposite sides of the disk as a plurality of concentric tracks. An actuator mechanism or head positioning system is employed to move the read/write heads in unison to position them at selected radial track locations on the disk surfaces.

25 Advances in the area of magnetic recording heads and media over the last decade have pushed recording density up to a point where further improvement is likely to be impeded by mechanical constraints. As the data
30 tracks on the recording surface becomes increasingly dense, the performance of the actuator or the head positioning system becomes increasingly critical. The actuator has to maintain tracking accuracy even in the presence of
35 mechanical disturbances in the HDD. One way to improve the performance of the head positioning system to handle high track density recording in the presence of mechanical disturbances is to improve the servo bandwidth.

Presently, the servo bandwidth of most conventional head positioning systems is limited by the in-plane resonance modes of the actuator mechanism. For a typical 3.5-inch drive actuator, the lowest in-plane resonance occurs between 3 to 4 kHz. This is due to the elasticity of the pivot bearing and the mass of the moving parts of the actuator. From here on, this in-plane resonance mode will be referred to as the QR mode (quasi-rigid body mode) of the actuator. Most HDDs today use a moving voice-coil motor to drive the actuator arm carrying the read/write heads. However, the driving force produced by the conventional moving voice-coil motor has a large in-plane component in the data track seeking direction. This creates substantial reaction force at the pivot bearing which can potentially excite the QR mode of the actuator. The QR mode, if excited, causes undesirable vibration of the arm in the data track seeking direction. This causes difficulty in head positioning during track following and limits the bandwidth of the servo system.

Summary of the Invention

The present invention has been developed with a view to substantially solving the above described disadvantages and has as its object the provision of an improved actuator mechanism for high density recording in hard disk drives.

A further object of the present invention is to improve the performance of the actuator by employing a predominantly torque drive so that the QR mode of the actuator is not excited during high frequency track-following operations.

Yet another object of the present invention is to provide a rotary actuator having uniform torque and zero biasing force over the whole range of movement. Most

moving magnet actuator design faces the problem of non-uniform torque constant and the presence of biasing forces due to unbalanced magnetic flux distribution.

5 Accordingly, the present invention provides an actuator for a hard disk drive which includes:

 (a) an arm adapted to carry one or more read/write heads, the arm being mounted at one end for pivoting movement;

10 (b) a motor for moving the arm, the motor including:

 (i) a pair of permanent magnets connected to the arm, centrelines of the magnets being spaced apart by an angle α , and wherein $100^\circ \leq \alpha \leq 180^\circ$;

15 (ii) a support member of magnetic material which is stationary relative to the arm;

 (iii) a pair of coils wound about portions of the support member, the coils being positioned on the support member so that they have portions of their windings immersed in, and substantially orthogonal to, a magnetic field generated by the permanent magnets.

 The present invention also provides a hard disk drive which includes: a housing; one or more magnetic disks adapted for storing information, the magnetic disks being mounted within the housing; and an actuator, the actuator including:

25 (a) an arm carrying one or more read/write heads for reading, or writing to, the magnetic disks, the arm being mounted to the housing at one end for pivoting movement;

 (b) a motor for moving the arm, the motor including:

35 (i) a pair of permanent magnets connected to the arm, centrelines of the magnets being spaced apart by an angle α , and wherein $100^\circ \leq \alpha \leq 180^\circ$;

 (ii) a support member of magnetic

material connected to the housing and stationary relative to the arm;

- (iii) a pair of coils wound about portions of the support member, the coils being positioned on the support member so that they have portions of their windings immersed in, and substantially orthogonal to, a magnetic field generated by the permanent magnets.

Brief Description of the Drawings

The present invention is described further with reference to the accompanying drawings, of which:

Fig. 1 illustrates a prior art moving voice-coil actuator or head positioning system.

Fig. 2 is a plan view of a simplified illustrative disk drive according to a first embodiment of the invention.

Fig. 3 is a partial plan view of the actuation end of the arm and an accompanying magnetic circuit according to the first embodiment.

Fig. 4 illustrates an alternative motor configuration for the actuator according to a second embodiment of the present invention, where a short coil is utilised.

Fig. 5 illustrates an alternative motor configuration according to a third embodiment of the present invention, where the inner yoke is integrated with the arm of the actuator by using magnetic material for the arm.

Description of the Preferred Embodiment

The principal operation of a conventional head positioning system for hard disk drives, as well as its main components, is illustrated in Fig.1. A conventional motor, indicated generally by the number 1, applies a pair of magnetic force F_A to the end of arm 2. Unless otherwise stated, the term "arm" is used herein to refer not only to the arm itself but also to the other elements, such as the

head assemblies that are attached to and move with the arm, contributing to the moment of inertia of the body that the motor drives.

5 The arm of the conventional head positioning system is mounted on a pivot bearing 4. The force F_A acts at a distance from the pivot axis to create a torque to move the arm. Since the arm does not translate but rotates about the pivot, a reaction force F_R arises, which acts
10 against the bearing 4. In a conventional system, this bearing reaction force, F_R , limits the bandwidth. This is because the motor 1, when driven by an alternating current during track-following, will generate an alternating bearing reaction force which excites the pivot bearing to
15 resonate about its resonance frequency. The resulting vibration is in the data seeking direction and therefore affects the accuracy of the head positioning system.

Fig.2 illustrates the main components of a hard
20 disk drive and a head positioning system according to a first embodiment of the present invention. The hard disk drive has a housing 5, which protects, and forms a base for, the other components. A spindle motor (not shown) spins a plurality of magnetic memory disks 6. According to
25 a first embodiment of the present invention, a head 7 is mounted on the end of a suspension 8 which is in turn mounted on the end of an arm 9. The arm is mounted on a pivot bearing 10 which allows the arm to rotate substantially about the pivot axis, in a plane parallel to
30 the plane of the disks. To reduce the moment of inertia of the arm, it is preferable that the centre of mass of the arm passes through the pivot axis.

A motor indicated generally by the number 11
35 includes a pair of permanent magnets 12a and 12b rigidly mounted on a first arcuate support member, hereinafter referred to as inner yoke 13, made of magnetic material. The

inner yoke 13 is connected to the end of the arm 9. As shown in Fig.3, the magnets 12a and 12b are spaced apart by an angle α (measured from the centrelines of the two magnets), where α can range from 100° to 180° . The stator of the motor consists of a second arc-shaped support member, hereinafter referred to as outer yoke 14, mounted on the base 5, with a pair of coils 15a and 15b wound on portions of the outer yoke 14. The coils have portions of their windings immersed in and aligned orthogonal to the magnetic field created by the magnets. When they are carrying current, these portions of the coils will react with the magnetic field to generate force. Therefore, when the control circuitry supplies electric current to the stator windings 15a and 15b, a force pair F_A will be generated. In the case illustrated in Fig.3, where current in the coil 15a and 15b is in the counter-clockwise direction, as seen from direction A, F_A will act in the direction as shown. This creates a torque about the pivot axis, which rotates the arm.

The bearing reaction force (F_R) the present invention will vary depending on the angle α . When α is 180° , the force pair will generate pure torque and the bearing reaction force will be approximately zero and hence the QR mode will not be excited. When α decreases ($\alpha < 180^\circ$), F_R will increase in magnitude. As long as F_R is small and can be damped out by pivot bearing damping, the bandwidth of the head positioning system in accordance to the present invention will be high.

In a second embodiment of the present invention, the motor can have a shorter coil as illustrated in Fig.4. This reduces the inductance of the motor at the expense of a reduction in the motor torque. A third embodiment is illustrated in Fig.5. Here, the inner yoke 13 is integrated with the arm 9 by using a magnetic material for the arm.

In other respects, the actuators of the second and third embodiments work in the same way as the actuator of the first embodiment.

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In most cases, it is not practical to make the angle α equal to 180° due to space constraints in the disk drive. When the angle α is less than 180° , a small reaction force will be generated at the bearing. The nearer α is to 180° , the smaller the reaction force. By careful tailoring of the magnitude of bearing reaction force to the pivot bearing damping, vibration can be critically damped out to effectively suppress the QR mode.

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The present invention also allows a reduction of the influence on the actuator dynamics of the flex cable which carries information from/to the read write head. In the present invention, the motor coil is wound on the stationary outer yoke. The leads from the motor coil are not routed through the flex cable as in the conventional moving voice-coil design. This reduces the size of the flex cable and minimises the influence of the flex-cable spring rate on the actuator.

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In the present invention, the inner yoke and the magnets replaces the coil in the conventional moving voice-coil actuator. This yoke and magnet structure is more rigid than the coil structure. This improves the in-plane stiffness, and therefore the natural frequency of the first in-plane elastic bending mode of the actuator.

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THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. An actuator for a hard disk drive which includes:
 - 5 (a) an arm adapted to carry one or more read/write heads, said arm being mounted at one end for pivoting movement;
 - (b) a motor for moving said arm, said motor including:
 - 10 (i) a pair of permanent magnets connected to said arm, centrelines of said magnets being spaced apart by an angle α , and wherein $100^\circ \leq \alpha \leq 180^\circ$;
 - (ii) a support member of magnetic material which is stationary relative to said arm;
 - 15 (iii) a pair of coils wound about portions of said support member, said coils being positioned on said support member so that they have portions of their windings immersed in, and substantially orthogonal to, a magnetic field generated by said permanent
20 magnets.
2. An actuator as claimed in Claim 1 which further includes a control means for controlling supply of current to said coils to rotate said arm.
- 25 3. An actuator as claimed in Claim 1 or Claim 2, wherein said arm is made of a magnetic material and said arm is formed integrally with said permanent magnets
- 30 4. An actuator as claimed in any one of Claims 1 to 3, wherein the centre of mass of said arm passes through an axis around which said arm pivots.
5. An actuator as claimed in any one of Claims 1 to
35 4, wherein said permanent magnets are arc-shaped.
6. An actuator as claimed in any one of Claims 1 to



5, wherein said support member is arc-shaped.

7. An actuator as claimed in any one of Claims 1 to 6, wherein α is approximately 180° .

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8. An actuator as claimed in any one of Claims 1 to 6, wherein α is chosen such that the in-plane resonance mode, or quasi-rigid body mode, of said actuator will not be excited.

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9. An actuator as claimed in any one of Claims 1 to 6, wherein α is chosen in conjunction with damping of said pivot bearing such that the in-plane resonance mode, or quasi-rigid body mode, of said actuator will not be excited.

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10. A hard disk drive which includes: a housing; one or more magnetic disks adapted for storing information, said magnetic disks being mounted within said housing; and an actuator, said actuator including:

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(a) an arm carrying one or more read/write heads for reading, or writing to, the magnetic disks, said arm being mounted to the housing at one end for pivoting movement;

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(b) a motor for moving said arm, said motor including:

(i) a pair of permanent magnets connected to said arm, centrelines of said magnets being spaced apart by an angle α , and wherein $100^\circ \leq \alpha \leq 180^\circ$;

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(ii) a support member of magnetic material connected to said housing and stationary relative to said arm;

(iii) a pair of coils wound about portions of said support member, said coils being positioned on said support member so that they have portions of their windings immersed in, and substantially orthogonal to, a magnetic field generated by said permanent

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magnets.

11. A hard disk drive as claimed in Claim 10 which further includes a control means for controlling supply of
5 current to said coils to rotate said arm.

12. An actuator as claimed in Claim 10 or Claim 11, wherein said arm is made of a magnetic material and said arm is formed integrally with said permanent magnets
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13. An actuator as claimed in any one of Claims 10 to 12, wherein the centre of mass of said arm passes through an axis around which said arm pivots.

14. An actuator as claimed in any one of Claims 10 to 13, wherein said permanent magnets are arc-shaped.
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15. An actuator as claimed in any one of Claims 10 to 14, wherein said support member is arc-shaped.
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16. A moving magnet actuator as claimed in any one of Claims 10 to 15, wherein α is approximately 180° .

17. A moving magnet actuator as claimed in any one of
25 Claims 10 to 15, wherein α is chosen such that the in-plane resonance mode, or quasi-rigid body mode, of said actuator will not be excited.

18. A moving magnet actuator as claimed in any one of
30 Claims 10 to 15, wherein α is chosen in conjunction with damping of said pivot bearing such that the in-plane resonance mode, or quasi-rigid body mode, of said actuator will not be excited.