

HEAD POSITIONING SYSTEM FOR MAGNETIC DISK DRIVES

FIELD OF THE INVENTION

This invention relates to data storage systems for use in data processing systems and, more particularly, concerns an improved head positioning system for a magnetic disk drive, particularly, though not exclusively, a hard disk drive.

BACKGROUND OF THE INVENTION

A hard disk drive typically includes an actuator mechanism comprising a pivotally mounted arm carrying one or more read/write heads for reading and recording information. Information is recorded on a plurality of concentric tracks of one or more rotating circular magnetic disks, having recording surfaces on opposite sides thereof. 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 with respect to the disk surfaces.

Advances in the area of magnetic recording heads and media over the last decade have pushed the information recording density up to a point where further improvement is likely to be impeded by mechanical constraints. As the data tracks on the recording surface becomes increasingly dense, so the performance of the actuator mechanism or positioning system becomes

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increasingly critical. The actuator has to maintain tracking accuracy even in the presence of mechanical disturbances in the hard disk drive. One way to improve the ability of the head positioning system to handle high track density recording in the presence of mechanical disturbances is to improve the servo bandwidth of the system.

At the present time, the servo bandwidth of most conventional head positioning systems is limited by the in-plane resonance mode of the actuator mechanism. For a typical 3.5-inch hard disk drive, the lowest in-plane resonance of the actuator occurs at about 3 kHz. This is due to the elasticity of the actuator pivot bearing and the mass of the moving parts of the actuator. Hereinafter, this in-plane resonance mode will be referred to as the QR mode (quasi-rigid body mode) of the actuator. Most hard disk drives today use a moving voice coil motor to drive the actuator arm carrying the read/write heads. However, the driving force produced by a conventional moving voice coil motor has a large in-plane component in the data seek direction. This creates substantial reaction force at the pivot bearing which excites the QR mode of the actuator.

The QR mode, if excited, causes undesirable vibration of the arm in the data track seeking direction. Such vibration can significantly reduce the ability of the actuator to keep the read-write heads at the centremost part of the data track. This is known as "track following error" to those skilled in the art.

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OBJECTS AND SUMMARY OF THE INVENTION

The principal object of the present invention is to overcome or at least substantially reduce the abovementioned problems.

5 According to the present invention, in order to improve the servo bandwidth of the head positioning system, the actuator is arranged to be driven with a force couple which creates pure torque such as to give rise to substantially no reaction forces at the bearing.

10 Because a force couple applied to a body acts as pure torque about the centre of mass of the body, no reaction force arises if the body is mounted for rotation about its centre of mass. The force couple that is applied to the actuator in accordance with the teachings of the present invention creates a substantially pure torque on the actuator arm about its pivot axis. As a result, there is no substantial reaction force at the pivot bearing to excite the QR
15 mode of the arm. This allows the actuator to position the read-write head with greater precision than is possible with existing actuator arrangements.

20 The foregoing and other features of the present invention are set forth in the appended claims and will be explained in the following by reference to specific exemplary embodiments wherein, not only are reaction forces on the pivot bearing of the actuator arm substantially eliminated so as to permit the actuator to operate with higher servo bandwidth without exciting its QR mode during high frequency track following operations, but also the windings and

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the permanent magnets of the actuator arm motor are arranged so that the torque generated by the motor is substantially uniform regardless of the angular position of the arm. Furthermore, in the described embodiments of the invention, four substantial linear coil portions are utilised for developing the force couple acting on the arm which, as will be explained, maximises the coil utilization and improves the efficiency of the motor.

DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a prior art moving voice coil actuator or head positioning system;

FIG. 2 is a view from above of a simplified illustrative embodiment of a disk drive incorporating a first embodiment of the present invention;

FIG. 3 is an isometric view of the actuator arm and associated drive motor of the disk drive shown in Fig 2;

FIG. 4 illustrates the magnetic circuit of the embodiment of Figs 2 and 3, the symbol $\odot$ indicating a force F_A directed out of the plane of the drawing and $\oplus$ indicating an opposed force F_A directed into the plane of the drawing;

FIG. 5 illustrates how a force couple is exerted on the arm when the coil is energised in operation of the embodiment of Figs 2, 3 and 4;

FIG. 6 illustrates a variation of the first embodiment where the yoke of the actuator arm drive motor is formed as a single piece instead of two pieces as shown in Figs. 2, 3 and 4;

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FIG. 7 illustrates another variation of the first embodiment where the motor coil is bent so as to define an angle θ less than 180° ;

FIG. 8 schematically illustrates a second embodiment of the present invention by reference to its magnetic circuit, the second embodiment using
5 two coils instead of one, with the electric currents in both coils flowing in the same sense in order to generate torque on the actuator arm; and

FIG. 9 illustrates a variation of the second embodiment where the electric currents in the two coils flow in opposite senses in order to generate torque on the actuator arm.

10 DETAILED DESCRIPTION OF THE EMBODIMENTS

The principle of operation of a conventional head positioning system for a hard disk drive, 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 forces F_A to the end of the arm 2. Unless otherwise stated, the term
15 "arm" is used to refer not only to the arm itself but also to the other elements, such as the head assembly 3, that are attached to and move with the arm, contributing to the moment of inertia of the body that the motor drives.

The arm 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
20 does not translate but rotates about the pivot, a reaction force F_R arises which acts 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

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alternating current during track-following, will generate an alternating bearing reaction force which excites the pivot bearing to vibrate at its resonant frequency. The resulting vibration is in the data seeking direction and therefore will affect the precision of head positioning.

5 FIG.2 illustrates the main components of a disk drive incorporating a head positioning system according to the present invention. The arrangement includes a housing 5 which protects and forms a base for the other components. A spindle motor (not shown) is arranged to spin a plurality of memory disks 6 mounted with spacing one above another. A read/write head
10 7 comprising a plurality of discrete read/write elements (not shown) is mounted on the end of a suspension 8, which is in turn mounted on the end of an arm 9. The arm 9 is mounted on a pivot bearing 10 which allows the arm to rotate about the pivot axis in the plane of the paper. To reduce the moment of inertia of the arm, it is preferable that the centre of mass of the arm locates on
15 the pivot axis.

The arm 9 is generally T-shaped and has associated therewith a drive motor indicated generally by the number 11 which includes an elongate rectangular coil 12 rigidly attached to the part of the arm which corresponds to the cross-member of its T-shape such that the coil axis (the axis of the coil
20 perpendicular to the coil-winding plane) is aligned and parallel to the longitudinal axis of the part of the arm 9 which corresponds to the upright of its T-shape. The coil 12 has substantial portions of its winding located on the

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left and right side of the longitudinal axis of the arm, parallel to the plane of the paper. These portions of the coil will hereinafter be referred to as the left coil winding part and the right coil winding part. A pair of yokes 13a and 13b made of magnetic material are fixed to the base 5 in positions such as to co-operate respectively with the left and right coil winding parts as illustrated more clearly in FIG.3, each yoke having a curved, projecting central part of rectangular cross-section which extends through its co-operating coil winding part with relatively narrow spacing therefrom and having upper and lower parts which are similarly curved and are spaced respectively above and below the central part with the coil winding extending through the upper and lower spaces between the central part and the upper and lower parts. A pair of thin, laminar permanent magnets 14a, 14b and 15a, 15b, which may for example be rare earth transition metal magnets such as Nd-Fe-B or Sn-Co based magnets and are curved similarly to the upper and lower yoke parts is fixed to each yoke 13a and 13b respectively, one on the inner surface of the upper part of the yoke and the other on the inner surface of the lower part of the yoke, such that the gaps between the magnets and the coil windings is very small.

FIG.4 shows the magnetic circuit of the first embodiment of Figs 2 and 3. The magnets 14a, 14b and 15a, 15b, together with the yokes 13a and 13b respectively create strong magnetic fields 16 which pass orthogonally through the left and right coil winding parts. Control circuitry, designated CNTL in Fig 2 and not described any more fully herein since it can be conventional, supplies

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electrical current to the coil 12. By changing the strength and polarity of the current, the control circuitry can determine the speed and direction of movement of the actuator arm and thus determine the movement of the head 7 relative to the disks 6. When an electric current flows in the coil 12, the interaction between the electromagnetic field developed by the current and the magnetic field developed by the magnets creates a force couple, as illustrated in FIG.5, which drives the actuator arm 9 with pure torque about its pivot axis 10. By driving the actuator arm 9 in this way, the effect of reaction forces on the pivot bearing of the arm is substantially eliminated, thus allowing the actuator to operate at higher servo bandwidth without exciting its QR vibration mode during high-frequency track following operation.

It can be seen in Fig 2 and in the hereinafter described embodiment of Fig 6 that the central and upper and lower yoke parts which interact with coil 12 and the magnets 14a, 14b and 15a, 15b are curved generally on a radius from the pivotal axis of the actuator arm in the plane of movement of the arm. This ensures that the magnets react uniformly or substantially uniformly with their respective coil winding parts throughout the full range of operating movement of the arm, namely those movements which translate the head 7 across the disks 6. The motor can thus drive the actuator arm with uniform torque over the entire range of operative angular positions of the arm. The use of relatively large area magnets 14a, 14b and 15a, 15b which interact with correspondingly large sections of the coil 12 also ensures optimum interaction

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between the magnetic field and the field developed by current flow in the winding and this enhances the coil utilisation of the actuator motor and makes the motor more efficient. The form of the yokes 13a and 13b and their close spacing from the coil 12 also ensures that the disks 6 are only minimally
5 exposed to stray magnetic fields which might otherwise corrupt disk data. Additionally, the fact that the coil 12 has its left and right coil winding parts located on opposite sides of the longitudinal axis of the actuator arm and co-operating with likewise oppositely located yokes 13a and 13b means that the motor constituted by coil 12 and yokes 13a and 13b develops only forces
10 such as to rotate the actuator arm about its pivotal mounting, whereby higher torque can be generated with increased motor efficiency.

As a variation of the above described embodiment, the motor can have a one-piece yoke as illustrated in FIG.6 instead of a two piece yoke. As will be readily understood, the use of a two piece yoke rather than a one piece
15 yoke enables the magnetic circuits of the left and right winding parts to be kept substantially isolated from each other, which may be advantageous in certain circumstances, for example where the left and right winding parts are formed of separate windings as is described hereinafter with reference to Fig 8. Another variation of the first embodiment is as illustrated in FIG.7 where the
20 coil 12 is formed with an included angle θ less than 180° . This coil configuration allows the pivot 10 to be placed nearer to the edge of the disk 6, thereby reducing the overall moment of inertia of the arm about its pivot axis.

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For this configuration, the force generated at the pivot axis will not be a pure torque, but if the angle θ is kept only a little less than 180° , the bearing reaction force can be made insignificant and the advantages described above will still be obtained.

5 A second embodiment of the present invention is illustrated in FIG.8 by reference to its magnetic circuit, other features being as described for the first embodiment. In this embodiment, two coils 12a and 12b are used instead of one and the electric currents flowing through the two coils are directed in the same sense, namely they both flow clockwise or anti-clockwise as viewed from
10 the arm tip. A variation of the second embodiment is illustrated in FIG.9 by reference to its magnetic circuit. Here, the electric currents in the two coils flow in opposite senses.

 Having described the invention by reference to specific embodiments, it is to be well understood that the embodiments are exemplary only and that
15 modifications and variations thereto will occur to those possessed of appropriate skills without departure from the spirit and scope of the present invention as set forth in the appended claims. For example, whereas the described embodiments are single-stage actuators, that is to say they employ
20 only one motor to drive the actuator arm, dual-stage actuators have been proposed in which a secondary motor is provided at the tip of the actuator arm in addition to the primary motor provided at its pivotally mounted end, the secondary motor being driven to effect fine movements of the arm and thereby

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increase the bandwidth of the actuator, and the present invention is applicable to such dual-stage actuators.

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CLAIMS:

1. In or for a disk drive for data processing, an actuator arm for positioning one or more read/write heads at selected radial positions of a data storage disk, said actuator arm being pivotally mounted and having associated
5 therewith an electric motor adapted and arranged to apply a force couple to said arm such as to create substantially no reaction forces at the pivotal mounting of the arm.

2. An actuator arm as claimed in claim 1 wherein said motor comprises
10 first and second operative parts disposed symmetrically on opposite sides of the centre line of said arm passing through said pivotal mounting, one of said parts being adapted to generate electromagnetically a force in a first direction and the other of said parts being adapted to generate electromagnetically a force in a second direction opposite to said first direction, said forces applying
15 to said actuator arm a force couple as aforesaid.

3. An actuator arm as claimed in claim 2 wherein said arm is generally T-shaped, said pivotal mounting is located in the part of the arm corresponding to the upright of the T-shape and said first and second operative parts of the
20 motor comprise respective spaced-apart parts of the part of the arm that corresponds to the cross-member of the T-shape.



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4. An actuator arm as claimed in claim 3 wherein the motor is a moving coil motor having respective coil parts spaced apart from each other on the cross-member part of the T-shaped arm and arranged for co-operation with respective magnets spaced apart from each other on a magnetic material yoke of the motor.
5. An actuator arm as claimed in claim 4 wherein the spaced-apart coil parts comprise opposite ends of the same coil.
6. An actuator arm as claimed in claim 4 wherein the spaced-apart coil parts comprise separate coils.
7. An actuator arm as claimed in claim 4 or 5 or 6 wherein said magnets are curved in the plane of pivotal movement of the arm generally on a radius from the pivotal axis of the arm.
8. An actuator arm as claimed in any of claims 3 to 7 wherein the two halves of the cross-member part of the T-shaped arm form with each other an included angle of less than 180° on the side of the cross-member part that is opposite the upright part of the T-shaped arm.



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9. An actuator arm as claimed in any of claims 4 to 8 wherein the magnetic material yoke of the motor comprises portions which extend through said coil parts and portions above and below said coil parts.
- 5 10. An actuator arm as claimed in claim 9 wherein said yoke portions are curved in the plane of pivotal movement of the arm generally on a radius from the pivotal axis of the arm.
- 10 11. An actuator arm as claimed in claim 9 or 10 wherein said magnets are supported in opposed relationship by said yoke portions which are above and below said coil parts.
- 15 12. An actuator arm as claimed in any of claims 4 to 11 wherein said magnets are thin laminar magnets formed of a high magnetic strength material, for example rare earth transition metal magnets.
13. An actuator arm as claimed in any of the preceding claims wherein the pivotal mounting is located at the centre of mass of the arm.
- 20 14. A disk drive for data processing incorporating an actuator arm as claimed in any of the preceding claims.



15. A data processing system incorporating a disk drive as claimed in claim

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