



166166

Controlling motions of a head actuator assembly of a hard disk drive

Field of the Invention

5 The present invention relates to an arm for use in a head actuator assembly of a hard disk drive. It further relates to a head actuator assembly incorporating one or more (usually several) such arms, and to a hard disk drive incorporating such head actuator assemblies.

10 Background of the Invention

Hard disk drives (HDDs) are sophisticated mechanical assemblies integrated with delicate electronics and electrical components. FIG.1 shows a conventional HDD assembly having a base 1, an electronic board 3, and a spindle motor 5.

15 On the shaft of the spindle motor 5 are stacked several disks 7, which each have a thin film of magnetic material 9 provided on at least one surface. The HDD has a head actuator, which includes a plurality of arms 13. Each arm 13 supports a suspension 15 having a gimbal which in turn supports a slider (not shown). Each slider incorporates a magnetic type read/write head (not shown)

20 at a flying-height over a surface of a corresponding disk 7. The head is driven by the arm 13 and suspension 15 to track across the disk 7 for tracking-seeking and track-following over the disk medium 9. In particular, a voice coil motor (VCM) assembly 17 actuates the arms 13 and suspension 15 to cause them to



G00002

pivot and move the heads to a desired track on the disk 7 by a lateral movement.

In recent years, the areal density and storage capacity of HDDs have been
5 increased dramatically, and this trend is likely to continue. Increasing the track
density and storage capacity requires both extremely high precision of the head
actuator which rapidly moves read/write heads across disk surfaces and holds
them over a specific data track for information exchange, and very low flying-
height of the slider which has the read/write transducer. However, the accessing
10 speed and positioning accuracy are directly affected by vibrations of the
mechanical components in the head actuator. Thus, vibration control in the
head actuator, especially suppression of the mechanical resonance in lateral
direction which significantly affects the performance of the servo system, has
become increasingly important. In addition, decreasing the flying-height tends to
15 deteriorate transducer reliability over a service life of the HDD. Thus,
maintaining the predetermined flying-height over each disk in a drive and
between different disk drives of the same type is critical. Since the efficiency of
the magnetic recording process changes significantly with the flying-height,
variations in flying-height result in corresponding variations in recording storage
20 densities, and are thus critical for stable flying-height control. Furthermore,
since there is the asperity on the medium surface and since there may be
external shocks, it is desirable to adjust flying-height to a safe position to
alleviate dynamic head-disk contact.

In order to attain high accuracy track-following, some efforts have been made to improve the dynamic characteristics of a head actuator. One of them is to use a dual-stage actuator, which will provide an additional degree of flexibility in controlling the motion of the head actuator to compensate the positioning error caused by residual vibration. In such a system, the VCM is used as the primary source of actuation that provides coarse positioning, and second-stage actuation is then utilized to provide micro level, fine tuning for head actuator positioning. Descriptions of such systems can be found in scientific and patent literature. Some representative references are as follows. In U.S. Pat. 6,046,888, Todd A. Krinke *et al* disclosed a base plate-mounted microactuator for a suspension, in which a new suspension configuration including flexure hinges and a piezoelectric microactuator is presented. In U.S. Pat. 6,100,623, Fu-Ying Huang *et al* disclosed a piezoelectric element to simultaneously actuate and sense a displacement of an arm assembly, in which the piezoelectric microactuator together with its support and flexure is inserted in between a conventional arm and suspension. The high-frequency excitation technique and the bridge circuit design are adopted to extract the piezoelectric deformation signal for displacement sensing. Obviously, these architectures require changes either in the conventional mechanical plant in the head positioning servo-system of the HDD or in the related process/assembly flow, which in turn increases the manufacturing costs. In addition, it is difficult to balance the bridge circuit perfectly in the real state using the disclosed methods for displacement sensing. In this regard, the sensing voltage may include large noise due to the imperfection of the bridge circuit.

Another technique to improve the dynamic characteristics of a head actuator is to use an active/passive damping technique, which is considered to be a cost-effective method since does not require any change of the mechanical plant in the head positioning system servo system in the HDD. One such investigation utilizes an additional strain sensor, feedback loop and conventional voice coil motor (VCM) to actively damp the vibration mode, as described by *Fu-Ying Huang et al., Active Damping in HDD Actuator, IEEE Transactions on Magnetics, Vol. 37, No. 2, March 2001, pp. 847-849*. Although this technique provides an alternative way of stabilizing a servo-controlled actuator system, due to some limitations such as the nonlinear response of the ball-bearing friction, a conventional VCM actuator poses some challenges in providing a level of tracking accuracy in the range to less than 25 nm so as to increase the track density to a level of more than 100,000 tracks per inch, which corresponds to tracks of less than 250 nm wide. In addition, it is not a trivial task to actively suppress mechanical resonance using a single VCM actuator for the non-collocation case.

In U.S. Pat. 6,307,719B1, Michael Mallary disclosed a suspension assembly with an adjustable gramload, in which the suspension assembly includes at least one power conductor, or power trace having one end electrically attached to the load beam and another end electrically attached to a power source. The power source may heat a predetermined portion of the load beam to adjust the gramload of the suspension assembly for controlling the flying-height of the

head. Although this technique provides a solution to flying-height adjustment, however, the response time of the thermal-electrical actuation is slower than that of piezoelectric actuation. This causes a delay which may made it impossible for the read/write head to respond effectively to the detection of
5 asperity or shocks. In addition, the proposed formation of the power conductor includes plating the load beam with high resistance and low anneal temperature material. This increases the technical complexity of its manufacturing process.

Summary of the Invention

10

The present invention aims to provide a new and useful arm for a head actuator assembly for a hard disk drive, a new and useful head actuator assembly incorporating on or more such arms, and a hard disk drive incorporating one or more such head actuator assemblies.

15

In general terms, the present invention proposes that, in a head actuator assembly comprising an arm, and a suspension supported by the arm and for supporting a reading/writing head (usually via a gimbal), one or more piezoelectric elements should be provided on the arm and that control circuitry
20 should be provided to power the piezoelectric elements so as to deform the arm.

Note that a head actuator according to the invention can be formed, apart from the piezoelectric elements and the circuitry controlling them, in the same way as

known head actuator assemblies. Accordingly, the present invention may be implemented without great changes to present manufacturing techniques for head actuator assemblies, and thus at relatively low cost.

- 5 Specifically, the invention is an arm for use in a head actuator assembly of a hard disk drive, the arm being according to any of claims 1 to 4.

A second expression of the invention is a head actuator assembly for a hard disk drive, the head actuator being according to any of claims 14 to 17.

10

The piezoelectric elements can be controlled, either via external signals or via signals they generate themselves (particularly in the invention as defined by claims 1 and 14), to suppress vibrations in the assembly, and/or to control the positioning of the head in relation to the recording medium such as by

- 15 controlling the flying height.

Brief description of the Figures

An embodiment of the invention will now be described for the sake of example
5 only with reference to the following figures, in which:

FIG. 1 is a schematic view of a conventional hard disk drive (HDD) assembly.

FIGS. 2a, 2b, 2c and 2d show head actuator according to the invention having
10 the actuator arm, on which are surface-bonded piezoelectric elements.

FIG. 3 depicts electrical connection of the piezoelectric elements of the actuator
arm of FIG. 2(a) for accurate actuation in track-following servo.

15 FIG. 4 shows the static displacement of slider (not shown) with the piezoelectric
actuation provided by the arm of Fig. 2(a).

FIG. 5 shows a piezoelectric element and its coordinate system.

20 FIGS. 6a and 6b show a piezoelectric element suitable for use in the
embodiments of the invention.

FIG. 7 depicts a self-sensing piezoelectric actuator with an offset circuit,
suitable for use in the embodiments.

FIG. 8 depicts a self-sensing piezoelectric actuator with an offset piezoelectric element, suitable for use in the embodiments.

- 5 FIG. 9 shows two main vibration modes in the mechanical transfer function of a head actuator.

FIG. 10 shows an adaptive architecture for active vibration control of in-plane arm bending and/or suspension sway in an embodiment of the invention.

10

FIG. 11 shows a block diagram of the head positioning servo system with an adaptive controller for the dynamic improvement of head actuator according to the invention.

- 15 FIG. 12 depicts an alternative electrical connection of the piezoelectric element for flying-height adjustment in an embodiment of the invention.

FIG. 13 shows an arm which is an embodiment of the invention being deflected out of its plane by an amount proportional to the applied voltage.

20

FIG. 14 shows two piezoelectric actuation modules bonded onto an actuator arm which is a further embodiment of the invention.

Detailed description of the embodiments

FIG. 2(a) is a view (in the direction perpendicular to the disk surface) of a conventional head actuator having an actuator arm 21 according to the invention, on which are surface-bonded piezoelectric element 23. Two possible
5 realizations of the piezoelectric elements 23 are shown by Figs. 2(b) and Figs. 2(c), which each represent an area of the arm 21 marked A in Fig. 2(a) and are views from the same direction as in Fig. 2(a). Fig. 2(b) shows a first form of the elements 23, while FIG. 2(c) shows a form in which each element 23 includes two piezoelectric components 23a, 23b (here also referred to as "elements")
10 spaced along the length of the arm 21. The components 23a and 23b are respectively an actuator device and a sensor device. FIG. 2(d) is a side view of the assembly (showing multiple arms 21, but not their respective suspensions).

Preferably, each element 23 is made from ceramic-based piezoelectric
15 materials such as PZT (lead zirconate titanate). Either conductive or non-conductive adhesive may be used to bond the piezoelectric element(s) 23 onto the surface of arm 21.

A HDD according to the invention usually includes multiple such arms. It is to be
20 understood that the actuator arms are substantially identical to each other in construction and configuration. Consequently, for clarity of disclosure only, the uppermost actuator arm 21 is particularly described. Each arm is formed automatically with one cutout 25, around which are two legs 27. The piezoelectric elements 23 are bonded on the top and bottom surface of legs 27,

respectively. The piezoelectric elements 23 may be actuators only as shown in FIG. 2(b), or either element 23 may comprise an actuator 23a in combination with a sensor 23b, the actuator-sensor having two separate surface electrodes. The location and orientation of piezoelectric elements 23 may be optimized to
5 maximize their observability and improve their actuation effectiveness. Such an architecture provides a solution to accurate track-following and flying-height adjustment, as described below.

The actuator arm 21 of FIG.2 may be used in a piezoelectrically actuated dual-
10 stage servo system. In this regard, FIG. 3 depicts a possible electrical connection of the piezoelectric elements 23 for accurate actuation in track-following servo. The piezoelectric elements may have a polarization direction which is vertical, with respective orientations such that one pair of piezoelectric elements 23 on the surface of one cutout leg 27 are controlled to in-plane
15 extend, while the other pair are controlled to in-plane contract, resulting in an accurate motion of the slider (not shown but having a position indicated generally as 29) in the lateral direction, as shown in FIG.4. Thus, the induced-strain piezoelectric actuator of the invention implements geometrical control of displacement, which is different from the existing dual-stage actuators, in which
20 a piezoelectric actuator either directly drives the slider or drives the slider via flexure hinges. For this reason the present invention preferably uses piezoelectric elements with high actuation capability.

FIG. 5 shows a piezoelectric element 31 and its coordinate system. This piezoelectric element may be any of the actuators or sensors described above or below. The length, width and thickness of the element itself are marked as l , w and t respectively, while the coordinate axes are indicated as 1, 2 and 3. For an element 31 which functions as an actuator, $\Delta l = nd_{31}V_a l/t$, $\Delta w = nd_{31}V_a w/t$, $\Delta t = nd_{33}V_a$, whereas for an element 31 which functions as a sensor, $V_m = nd_{31}F/(\epsilon l)$, $V_m = nd_{31}F/(\epsilon w)$, $V_m = nd_{33}Ft/(\epsilon l w)$, where V_a is an applied voltage, d_{ij} is the piezoelectric constant, F is an applied force along any of the length, width, or thickness directions, V_m is the measured voltage across the electrodes (in the thickness direction), ϵ is the dielectric permittivity of the material, and n is the number of active layers. Obviously, the actuation capability of piezoelectric element will increase with increase of n and decrease of t . With a multi-layer piezoelectric element, an actuator with high actuation capability and small driving voltage may be achievable. Alternatively, a high-performance piezoelectric material such as PMN-PT ($d_{31}=520, d_{33}>1500$) is suitable for high-sensitivity and high-actuation applications. In a further alternative, the actuation can be arranged to employ the d_{33} mode of the piezoelectric material which may enhance the in-plane driving force since the d_{33} constant is bigger than d_{31} . However, the d_{33} mode of the piezoelectric materials is usually used to produce a deformation along the polarization direction, so that how one produces in-plane deformation in the piezoelectric element is not straightforward.

FIG. 6(a) depicts a top view of a piezoelectric element 35 which produces an in-plane deformation utilizing the d_{33} mode. The element 35 uses interdigital

electrodes (IDE) 37 deposited on piezoelectric substrate 39, as indicated by Fig. 6(b) which is a cross-section in the line marked as c-c in Fig. 6(a). The IDE pattern causes the electrical field, as shown in Fig. 6(b) which indicates field lines extending through the substrate 39, to be in the plane of the actuator, rather than perpendicular to it. As a result, d_{33} coupling produces a in-plane force in one direction, which is larger than that from the d_{31} force induced in the other in-plane direction. Thus, this provides the actuator with highly directional properties. According to the relationship $\Delta l = nd_{33}V_a$, the output displacement of piezoelectric actuator with surface IDE is proportional to the equivalent n (see above), which is inversely proportional to the electrode gap with a fixed space. This indicates that adoption of the narrow electrode gap is helpful to improve output displacement.

It is to be understood that such a piezoelectric element 35 is also suitable as a sensor with high sensitivity. However, when the multi-distributed induced-strain actuator element 35 or other form of piezoelectric element is used as an actuator it provides a way of increasing output displacement at the slider, since the input energy is increased. Here, the piezoelectric element 35 is designed to have high sensitivity and high actuation capability. Preferably, all embodiments of the present invention use such a type of piezoelectric element.

As discussed above, most dual-stage servo controllers only utilize the position error signal (PES) of the magnetic head relative to the center of data track for closed-loop track-following control. These systems have a single-input-multi-

output control architecture. However, the particular interest herein is to use multi-input-multi-output control architecture, in which an additional relative position error signal (RPES) through piezoelectric sensing may be used to damp out the second actuator's resonance and enhance the robustness of the whole system. In this regard, a piezoelectric element with two separate surface electrodes may be bonded onto the actuator arm (an element 61 of this kind is shown in Fig. 10, which is described in detail below).

Alternatively, a pair of piezoelectric elements 23a, 23b adjacent to each other as shown in FIG. 2(c), and used as an actuator and a sensor, respectively, may be bonded onto the actuator arm. Still alternatively, a plurality of piezoelectric actuators, as described in FIG. 2(b), may be bonded onto the actuator arm, each functioning as a self-sensing actuator with a right signal processing and extraction method, as described below.

Specifically for a plurality of piezoelectric actuators, when an excitation voltage: $v=v_0\sin(\omega t)$ is applied to the piezoelectric layers, the strain-induced charge due to the piezoelectric effect may be expressed by

$$Q = -Gwd \int_{x_1}^{x_2} e_{31} \frac{d^2 y}{dx^2} dx = -GAde_{31}\psi \quad (1)$$

where Q is the signal charge, G is the total electronic circuit gain, d is the distance from the surface of piezoelectric element to the center of host

structure, e_{31} is the piezoelectric field intensity constant, A is the area of piezoelectric element, Δx is its length, and ψ is the averaged local structure curvature. Thus, the piezoelectric charge is related to piezoelectric constant and structural dimensions of the piezoelectric element. Also it may reflect the structural deformation/vibration directly. The total output current of the piezoelectric element with the applied voltage can be expressed by

$$i = \frac{dQ}{dt} \sin(\omega t + \Phi) + C \omega \sin(\omega t + 90^\circ) + \frac{v}{R} \sin(\omega t) \quad (2)$$

where C and R are the equivalent capacitance and resistance of the piezoelectric element, respectively. It is noted that the output current includes three components, namely, the piezoelectric charge current, the piezoelectric capacitance current and the piezoelectric resistor current. Only the first part reflects the structural deformation/vibration.

15

As shown in Fig 7, an equivalent $C - R$ parallel connected circuit 41 may be used to offset and extract the piezoelectric charge current to sense structural deformation/vibration. Specifically, the circuit 41 includes resistor R and capacitor C having values tuned to match those of a piezoelectric actuator 43. The actuator 43 and circuit 41 receive the same input voltage v and generate respective output currents i_2, i_1 . The difference i_Q between these is found by a differential amplifier 45.

20

Alternatively, as shown in FIG. 8, the equivalent capacitance (C) and resistor (R) may be produced by a second piezoelectric element 53 with the same geometry and characteristics as one 55 bonded on the actuator arm 21. FIG. 8 thus depicts a self-sensing actuator 55 with an offset piezoelectric element 53 which is fixed in a location where it generates no significant strain-induced charge output.

Active Vibration Control

FIG. 9 shows two main vibration modes in the mechanical transfer function of head actuator: an in-plane arm ending (as shown in FIG. 9(a)) and suspension sway (as shown in FIG. 9(b)). Both contribute the off-track errors and limit the improvement of servo bandwidth for track-following. It is also found that there are vibration-induced strain zones on the legs 27 of an arm cutout under these vibration modes. The smart piezoelectric element 23 of Fig. 2(a) is preferably bonded onto the surface of the legs 27 of the arm cutout, it is thus capable of detecting the mechanical resonance at these two frequencies effectively. Preferably, the piezoelectric elements 23 are optimally located for high vibration-induced strain zones under these two modes.

20

FIG. 10 shows an adaptive architecture for active vibration control of either in-plane arm bending, suspension sway or both of them. In this architecture, at least one piezoelectric element 61 having two separate surface electrodes 63 is adopted as both a sensor and actuator, and the sensor and actuator are quasi-

collocated. Both sensing and actuating way may be in the form as described in FIG. 3. Preferably, the piezoelectric element 61 has both high sensitivity and high actuation capability. Alternatively, a pair of piezoelectric elements adjacent to each other on the arm surface may be used as an actuator and sensor, respectively, for active vibration control. In a further alternative, the piezoelectric element(s) bonded onto one leg of arm cutout may be one or more of sensors, and the piezoelectric element(s) bonded onto the other leg of arm cutout may be one or more of actuators.

10 In these architectures, the piezoelectric element(s) on the actuator arm may *in-situ* sense structural vibrations via measuring vibration-induced deformation, and actively adjust structural deformation via voltage-driven signal with feedback loops. Such an adaptive controller having piezoelectric sensors and actuators, suitable feedback laws and electronics may be packaged as an

15 independent module to add into the conventional head positioning servo system.

Such a control system diagram is shown in FIG. 11, including an actuator 64 (including one or more arms, each with one or more piezoelectric elements as

20 described above, and the associated control circuitry), a VCM 65, a digital servo 66 and a current converter 67. The actuator 64 generates a position error signal (PES) which is fed to the digital servo 66, and is then combined with a reference signal r , and fed to the current converter 67 which controls the VCM 65. Without the piezoelectric elements of the present invention the actuator 64 would have a

response $G_o(s)$, but according to the present invention this is improved to raise the dynamic characteristics of head actuator to a new level $G_n(s)$, and enhance the robustness of the whole system for accurate track-following. In this regard, the additional controller actively suppresses the flexible vibration modes in head
5 actuator, but its implementation requires no change of either the conventional mechanical configuration or the servo system hardware.

Flying-Height Adjustment

10 In most commercial HDDs, the gramload provided by a suspension is approximately several tens of mN during normal operation. A slight adjustment of the loading force would result in a change of the flying-height. An actuator arm with surface-bonded piezoelectric elements according to the present invention may be used to provide piezoelectrically actuated flying-height
15 adjustment in HDDs. In this regard, FIG. 12 depicts an electrical connection of the piezoelectric elements 71 for flying-height adjustment in HDDs. Note that this concept is not limited to this specific circuit. The arrows indicate the polarization direction.

20 Each leg 27 of arm cutout may be a PZT/metal/PZT multimorph design, which results in an out-of-plane deflection of the actuator arm 21 in the direction of flying-height adjustment when the ceramic 71 is energized. FIG. 13 depicts that the arm 21 is deflected. The amount of deflection is proportional to the applied voltage. An out-of-plane actuation of actuator arm 21 results in a change of Z-

height as well as of gramload, which in turn provides tolerance for an adjustment of flying-height. Such an adjustment may be used to compensate for a variation of the Z-height and/or the gramload of the suspension assembly due to either manufacturing or assembling errors of the disk drives.

5

It should be understood that, with the adjustment and reduction of the flying-height, the potential storage density of a disk 7 may be increased. However, the service life of the read/write head may be reduced due to increasing the possibility of dynamic contact between the head and disk 7. To reconcile these conflicting factors, either a self-sensing or an active flying-height adjustment is preferable. The self-sensing actuation methods proposed above are suitable for the *in-situ* relative position measurement in the direction of flying-height and for flying-height adjustment. Active flying-height adjustment provides an effective way in allowing the head to be lowered for application in a high-density storage device during a read/write operation and to be raised to a safe height when there is asperity on the medium surface or an external shock. In this regard, it is critical to sense the dynamic contact or shocks in real-time. Due to dynamic contact or shocks the reaction force of the slider may exceed the predetermined gramload, which causes the slider to jump and further induce the suspension bending mode as well as arm's bending mode, in the direction of flying-height. Since the piezoelectric element(s) 23 are bonded onto the legs 27 of arm cutout, they are capable of detecting the dynamic contact/shock induced vibration, and actively adjusting structural deformation as well as flying-height.

20

The adaptive architecture, as shown in FIG. 10, may thus provide active flying-height adjustment/control.

It is to be understood that the architecture and method of the present invention
5 might realize 1-dimensional actuation. Alternatively, it might realize 2-dimensional actuation, in which either a step-by-step control method or two piezoelectric actuation modules are adopted. The latter possibility is shown in FIG. 14, in which there are piezoelectric elements 83 for in-plane actuation of the arm 87 and piezoelectric elements 85 for out-of-plane actuation of the arm
10 87, respectively.

Embodiments of the invention have been described above for the sake of example only, and many variations are possible within the scope of the invention as will be clear to a skilled reader.

Claims

1. An arm for use in a head actuator assembly of a hard disk drive, the arm being provided with one or more piezoelectric elements located on the arm and
5 with control circuitry for controlling at least one actuator piezoelectric element among the piezoelectric elements to deform the arm, whereby, when the arm supports a suspension which in turn supports a read/write head, actuation of the actuator piezoelectric elements by the control circuitry deforms the arm and thereby moves the head, at least one of the piezoelectric elements being a
10 sensor element arranged to generate an output signal which is a control input to the control circuitry.

2. An arm for use in a head actuator assembly of a hard disk drive, the arm being provided with one or more piezoelectric elements located on the arm and
15 with control circuitry for controlling at least one actuator piezoelectric element among the piezoelectric elements to deform the arm, whereby, when the arm supports a suspension which in turn supports a read/write head, actuation of the actuator piezoelectric elements by the control circuitry deforms the arm and thereby moves the head, the arm including a cut-out portion and a pair of legs
20 surrounding the cut-out portion, the piezoelectric elements being provided on at least one of the legs.

3. An arm for use in a head actuator assembly of a hard disk drive, the arm being provided with one or more piezoelectric elements located on the arm and

with control circuitry for controlling at least one actuator piezoelectric element among the piezoelectric elements to deform the arm, whereby, when the arm supports a suspension which in turn supports a read/write head, actuation of the actuator piezoelectric elements by the control circuitry deforms the arm and
5 thereby moves the head, at least one of the piezoelectric elements including a plurality of electrodes having inter-arranged fingers.

4. An arm for use in a head actuator assembly of a hard disk drive, the arm being provided with one or more piezoelectric elements located on the arm and
10 with control circuitry for controlling at least one actuator piezoelectric element among the piezoelectric elements to deform the arm, whereby, when the arm supports a suspension which in turn supports a read/write head, actuation of the actuator piezoelectric elements by the control circuitry deforms the arm and thereby moves the head, the piezoelectric elements being arranged to deform
15 in the d_{33} mode.

5. An arm according to claim 2, claim 3 or claim 4 in which at least one of the piezoelectric elements is a sensor element arranged to generate an output signal which is a control input to the control circuitry.

20

6. An arm according to claim 1 or claim 5 in which at least one of the piezoelectric elements is an actuator-sensor element arranged both to generate an output signal which is a control input to the control circuitry, and to be operative to deform under the control of the control circuitry.

7. An arm according to claim 6 in which the control circuitry is processes the output signal by subtracting from it a second signal from a mimic circuit arranged to mimic the output of the actuator-sensor element in the absence of
5 vibration.

8. An arm according to claim 7 in which the mimic circuit includes a second piezoelectric element located such that it is not deformed by vibration of the arm.

10

9. An arm according to any preceding claim in which the actuator elements include at least one actuator element arranged to cause in-plane deformation of the arm.

15 10. An arm according to any preceding claim in which the actuator elements include at least one actuator element arranged to cause out-of-plane deformation of the arm.

11. An arm according to claim 10 in which control circuitry is arranged to
20 control the at least one actuator element which is arranged to cause out-of-plane deformation of the arm so as to selectively vary the spacing between a head supported from the arm via a suspension and a disk surface.

12. A head actuator assembly for a hard disk drive including at least one arm according to any preceding claim.

5 13. A hard disk drive including a head actuator assembly according to claim 12.

14. A head actuator assembly for a hard disk drive, the head actuator comprising at least one arm, an actuator for moving the at least one arm, a
10 respective suspension supported by each arm, and a respective head supported via each respective suspension, each head being for transferring data to and/or from a magnetic medium, the assembly further comprising one or more piezoelectric elements provided on each arm to deform the arm and thereby move the head, at least one of the piezoelectric elements being a
15 sensor element arranged to generate an output signal which is a control input to the control circuitry.

15. A head actuator assembly for a hard disk drive, the head actuator comprising at least one arm, an actuator for moving the at least one arm, a
20 respective suspension supported by each arm, and a respective head supported via each respective suspension, each head being for transferring data to and/or from a magnetic medium, the assembly further comprising one or more piezoelectric elements provided on each arm to deform the arm and thereby move the head, each arm including a cut-out portion and a pair of legs

22b

surrounding the cut-out portion, the piezoelectric elements being provided on at least one of the legs.

16. A head actuator assembly for a hard disk drive, the head actuator
- 5 comprising at least one arm, an actuator for moving the at least one arm, a respective suspension supported by each arm, and a respective head supported via each respective suspension, each head being for transferring data to and/or from a magnetic medium, the assembly further comprising one or more piezoelectric elements provided on each arm to deform the arm and
- 10 thereby move the head, at least one of the piezoelectric elements including a plurality of electrodes having inter-arranged fingers.

22c

17. A head actuator assembly for a hard disk drive, the head actuator comprising at least one arm, an actuator for moving the at least one arm, a respective suspension supported by each arm, and a respective head supported via each respective suspension, each head being for transferring
- 5 data to and/or from a magnetic medium, the assembly further comprising one or more piezoelectric elements provided on each arm to deform the arm and thereby move the head, the piezoelectric elements being arranged to deform in the d_{33} mode.