

## **PIEZOELECTRIC DEVICES, ESPECIALLY FOR DUAL STAGE SERVO SYSTEMS OF HIGH DENSITY HARD DISK DRIVES**

### **FIELD OF THE INVENTION**

The present invention relates to the field of piezoelectric devices and more particularly, but not by way of limitation, to piezoelectric actuators suitable for use as the secondary actuators in dual stage head positioning servo systems of hard disk drives. This invention will be primarily described in relation to this application but is not so limited in scope.

### **DESCRIPTION OF THE RELATED ART**

Piezoelectric actuators have been widely used for fine positioning in fields such as optics, precision machining, fluid control and optical disk drives due to their characteristics of small size, simple structure, quick response, and, most important, controllable displacement down to nanometers.

Multilayer piezoelectric actuators and bimorph (or unimorph) piezoelectric actuators are the two most commonly used types. Their merits and demerits are quite different. Multilayer actuators have large generated force, quick response speed, and high resonance frequency, but relatively large dimensions. Hence, they are generally used in cases where relatively large driving force is needed and enough space can be provided to incorporate the actuator. However, bimorph and unimorph actuators have high displacement/voltage sensitivity, and simple structure,

but small generated force. They are generally used in cases where relatively large displacement output is needed.

In some special cases, such as the dual stage head positioning servo system of hard disk drives, these two types of actuators are not well suited for use directly as the secondary stage fine positioning actuator.

The dual stage servo system comprises a conventional voice coil motor (VCM) as primary actuator for track seeking, and a secondary micro-actuator cooperating with the VCM for settling and track following. Adding a secondary stage micro-actuator is one of the solutions to achieve a high bandwidth servo system for hard disk drives with very high track density. Various micro-actuators, including piezoelectric, electromagnetic and electrostatic, have been developed to meet this purpose. However, so far there are still many difficulties in implementing them in real hard disk drives, such as high cost, high driving voltage, poor reliability and robustness, and so on.

The structure and performance of the secondary actuator are key factors affecting the overall dual stage servo system design. A dual stage servo system is disclosed in US patent 5189578 by Kenji Mori et.al, wherein a stack or multilayer piezoelectric actuator mounted into the arm is employed as the secondary piggyback actuator. In addition to its high cost, the multilayer piezoelectric actuator can only be located on the arm. Because of the relatively large mass and moment of inertia to be driven by the actuator and the poor dynamics of the suspension, it is difficult for the multilayer actuator to take advantage of its high resonance frequency. As to the bimorph actuator, a low resonance frequency restrains its application in high bandwidth head positioning servo systems.

To meet the high resonance frequency requirement, the mounting place of the secondary stage actuator should be as close to the magnetic head as possible, but the operation of the actuator should not affect the

read/write process of the recording head. From this point of view, one ideal location of the secondary actuator is on the suspension. For hard disk drives with multiple heads and disks, the ideal secondary actuator for a dual-stage servo system should have low profile to preserve disk to disk space and low mass to maintain high access speed. This requires developing a piezoelectric actuator with relatively high resonance frequency, small height and mass, and low cost for the dual stage servo system of hard disk drives.

## **SUMMARY OF THE INVENTION**

A general object of the present invention is to provide a planar piezoelectric device which in a preferred embodiment, can have a relatively small height or thickness, and a relatively large width and length, and can generate lateral bending deformation along the widthwise direction.

A specific object of the present invention is to provide a piezoelectric device which, in a suitable form, can be used as a secondary actuator in a dual stage servo system of a hard disk drive.

A more specific object of the present invention is to provide a piezoelectric actuator which, in a preferred adaption, can be part of the suspension to directly drive the slider and head so as to obtain a head positioning servo system with high bandwidth.

Yet another specific object of the present invention is to provide a piezoelectric device which can be of simple structure so that it can be easily realised with low additional cost.

Another object of the present invention is to provide a piezoelectric actuator, which, at least in a preferred embodiment, has enough

displacement stroke to meet the requirement of compensating tracking misregistration under supply voltage less than 12 volts.

The above objects can be achieved by designing or selecting an appropriate electrode configuration, and preferably a corresponding poling scheme, for a piezoelectric body.

The invention provides, in one aspect, a piezoelectric device comprising an integral body of piezoelectric material which is longer and wider than it is thick. The device is characterised in that it further includes, in contact with the body, respective pairs of electrodes, in that the electrodes of each pair are opposed in the thickness direction, and in that the pairs are spaced in a direction transverse to the thickness direction, whereby the body of piezoelectric material deflects along said transverse direction when a voltage is applied to the electrode pairs.

In a preferred embodiment, the piezoelectric device is divided into two or more symmetric parts by splitting the electrodes. Polarisation vectors in these parts are preferably in the direction of its thickness and can be polarised in the same or opposite orientation. Driving voltages are preferably so arranged that they make half of these parts expand by the "31" action while the other half, ie., their symmetric part, contracts. This will result in a bending motion of the actuator along the direction of its width, like the bending of a bimorph actuator, where the bending is in the direction of its thickness. The preferred said actuator is actually a split electrode in-plane bending piezoelectric actuator. Analogous to the term "bimorph", it can be defined as "split-morph". If the poling vectors in the two corresponding symmetric parts are oppositely oriented, the said actuator is called anti-parallel split-morph, and if the poling factors are the same, it is called parallel split-morph.

If one of two longitudinally spaced ends of the actuator is clamped to a base, like a cantilever, the motion of the free end or the tip can be

realised. Furthermore, the displacement of the tip can be precisely controlled by a driving voltage.

An advantage and novel aspect of a preferred embodiment of the present invention is its simple plate-like structure and the concept of split electrode, which enable the actuator to have small height or thickness and low added cost, and to generate lateral displacement within the electrode plane. With these advantages and features, the actuator can be installed on the suspension of a hard disk drive to position the read/write head to track the runout fast and accurately.

Another important preferred feature of the present invention is that although the device is electrically divided into two or more parts by the respective pairs of electrodes, the body of the device is actually an integrated piece of solid ceramics. This integrated piece may be a single element, or it may be formed by bonding together separate elements of the piezoelectric material, e.g. a pair of such elements bonded together at the aforesaid plane of symmetry. Therefore, the troublesome problem of the adhesive film, which commonly melts in bimorph devices, can be avoided.

Other objects, as well as structures and features of the present invention able to achieve those objects, will be understood by considering the following detailed description of preferred embodiments, presented with reference to the accompanying drawings.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is a top perspective view of the basic structure of a split-morph piezoelectric device, being an embodiment of the invention.

FIG. 2 is a top perspective view of a split-morph with varying width along the direction of its length.

FIG. 3 is a top perspective view and cross-sectional view of a split-morph of U-shape cross-section.

FIG. 4 is a top perspective view of a dual-layer stacked split-morph.

FIG. 5 through FIG. 8 are cross-sectional views of several structures of stacked split-morph.

FIG. 9 is a plan view of a hard disk drive with a dual stage positioning servo system.

FIG. 10a and FIG. 10b are a plan view and a side view, respectively, of an existing swage-mounted suspension assembly.

FIG. 11 through FIG. 16 are views of several variations of compound suspension.

## **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

Hereinafter, basic structures and preferred embodiments of the present invention will be described with reference to the drawings. FIG. 1 through FIG. 9 show the basic structures and the corresponding operations of such embodiments.

Referring more particularly to the drawings, FIG. 1 illustrates the basic structure of a split-morph according to an embodiment of the present invention. It includes a single piece of piezoelectric material rectangular plate 1 of length,  $l$ , width,  $w$ , thickness,  $t$ , and polarised in the direction of its thickness.

The piezoelectric plate 1 has upper and lower electrodes split into two separate parts, a and b, by an intervening gap or crevice 4 where no electrode is applied on piezoelectric plate 1. 2a, 2b and 3a, 3b are pairs of symmetric parts of the upper electrode 2 and the lower electrode 3, respectively, forming a pair of opposed electrodes 2a, 3a; 2b, 3b. The piezoelectric plate 1 is rigidly clamped at one end on a base, which is

designated as 5. As described above, the two parts a and b can be poled either in the same orientation or opposite to form parallel split-morph or anti-parallel split-morph. Shown in FIG. 1 is an anti-parallel split-morph. Arrows shown in all the drawings hereinafter represent polarisation directions.

As shown in FIG. 1, we designate the length direction of the split-morph as x-axis, the width direction as y-axis and the height direction as z-axis. The deflection of the split-morph as it moves under a driving voltage is then along the y-axis. It should be noted that the drawings referred to in this document are not to scale. The displacement/voltage sensitivity and resonance frequency of the actuators can be controlled by varying the dimensions of its length,  $l$ , width,  $w$ , and thickness,  $t$ .

FIG. 2 illustrates a modification of the basic structure shown in FIG. 1. The only difference is that the width of the piezoelectric plate varies along its length, i.e., x-axis. In FIG. 2, reference numeration is the same as that in FIG. 1. The operation of this actuator is the same as that shown in FIG. 1. Generally, the width of the rigidly clamped end should be larger than that of the free end and the shape of width edge can be arbitrarily changed according to its application requirement, provided it is symmetrical about a plane of symmetry at the electrode crevices 4. For example, when viewed from the top, the device cantilever beam can have a trapezoidal or other symmetric configuration.

To obtain high resonance frequency is a basic requirement of most actuator design, especially for the secondary stage actuator of the dual stage servo system. Generally, the higher the element's rigidity, the higher its first resonance frequency. The resonance frequency of the split-morph in the y direction is much higher than that in the z direction because the width is much larger than the thickness. Although the main vibration of the split-morph stimulated by applied voltage is along the width direction, it is very easy to excite the vibration along the height or

thickness direction because it has much lower flexural rigidity than that of the widthwise direction. It is preferred to increase the rigidity in the height or thickness direction while maintaining relatively high displacement/voltage sensitivity of the actuator, i.e., large displacement output under low driving voltage. In order to fulfil this purpose, other preferred structures are proposed and described below with reference to the drawings.

To improve the flexural rigidity in the z-axis (thickness) direction, the cross-section of the said piezoelectric element can take the shape of U-section, I-section, T-section, E-section, H-section, circular arch and so on. Shown in FIG. 3 is a split-morph with U-type cross-section. Polarisation is in the thickness direction. The thickness of the piezoelectric element is thin and even everywhere so that the two symmetric parts, a and b, of the element can expand or contract uniformly under relatively lower applied voltage. This structure can increase the flexural rigidity of the actuator along the z-axis significantly and suppress the torsion deformation perpendicular to the x-axis.

The strength of thin piezoelectric ceramic plates is always a problem in mounting and servicing. To solve this problem, a stack structure is preferably employed in which the devices are bonded together to increase stiffness in said thickness direction, and electrically connected and polarised so that the piezoelectric devices generate a synchronised bending motion. FIG. 4 shows a two-layer stacked structure. Two thin split-morphs 6 and 7 as described in FIG. 1 are bonded together so that the stiffness as well as the strength in the z direction is increased.

There are several different configurations of this bi-laminar split-morph due to differences in manufacturing method. Typical forms and variations will be depicted below with reference to FIG. 5 through FIG. 8.

In FIG. 5, designated by reference 6 and 7 are two anti-parallel split-morph, where 8, 9 and 10 are the upper, intermediate and lower

electrode, respectively. The polarisation vectors of the adjacent parts of 6 and 7 are all opposite in orientation. The intermediate electrode 9 is connected to one terminal of the input voltage while the upper and lower electrodes 8 and 10 are connected to the other one. When the voltage is applied, parts 6 and 7 can generate a synchronous bending motion. Therefore, this bi-laminar split-morph has similar displacement/voltage sensitivity to the single plate one. Also, a multi-layer split-morph structure is proposed in FIG. 6. Its operating mechanism is similar to that of the bi-laminar split-morph.

FIG. 7 shows another configuration of bi-laminar split-morph. In FIG. 7, designated by 6 and 7 are two parallel split-morphs with their polarisation vectors directed towards each other. 8a and 8b, 9a and 9b, 10a and 10b are three pairs of symmetric electrodes. 4 are the electrode gaps or crevices. 8b, 9a and 10b are connected to one terminal of the voltage source while 8a, 9b and 10a are connected to the other one. This configuration can also generate lateral bending motion under an applied driving voltage and has the same sensitivity with the configuration shown in FIG. 5.

The robustness of the bi-laminar anti-parallel split-morph shown in FIG. 5 can also be improved at the cost of decreasing the displacement/voltage sensitivity by using a central metal layer so that the tri-laminar structure is obtained. FIG. 8 shows an actuator with this structure. Designated by 11 is a central metal layer in the form of a metal shim. Reference numbers are the same as those in FIG. 5. This metal shim can improve the strength of the actuator. The thickness of the central metal layer can significantly affect the performance of the actuator. The central metal shim 11 is extended beyond the piezoelectric plates at both the length ends to provide simple mounting and allow electric contact to be made to the intermediate electrode 9.

Hereinafter, preferred embodiments of the present invention will be described with reference to FIG. 9 through FIG. 16. In these embodiments the present invention, as the secondary fine positioning actuator, is applied to the dual stage servo system of hard disk drives.

FIG. 9 illustrates a first embodiment of this aspect of the present invention. Shown in FIG. 9 is a top plan view of a hard disk drive with high bandwidth dual stage servomechanism. Designated by reference D1 is a plurality of data disks and S0 is a spindle motor for rotating the disks all together at a high speed. An array of vertically aligned head sliders, one of which is designated by reference S1, is attached through a plurality of compound suspensions S2 to a plurality of supporting arms S3. An electromagnetic voice coil motor (VCM) A1 is used as the primary stage rotary actuator to move all the head slider in a long stroke to any desired one of a plurality of tracks on the surfaces of the disk D1 along an accurate path A for seeking. Any suitable one of the specific piezoelectric actuators of the present invention, designated by reference A2, is mounted on the compound suspension as the secondary stage fine positioning actuator to drive the individual head slider in a fine stroke at very high speed for settling and track following.

This embodiment can provide a valuable advantageous effect on individually correcting off-track states so that the respective head can be positioned with high accuracy. Although the dual stage servo system in this embodiment is illustrated by an example of hard disk drive, it is also applicable to an optical disk system for obtaining high compact feature.

Turning now to the compound suspension which is another embodiment of the present invention. During operation of the disk drive, there exists an air bearing between the head slider and the rotating disk or media due to aerodynamics. This air bearing affects the flying height of the head as well as the magnetic spacing between head and medium. The head-to-medium spacing is a decisive factor for signal-to-noise

characteristics and, naturally, the bit density of the disk drive. In order to maintain proper head/media compliance and obtain high servo bandwidth, the design of the gimbal and suspension should be such that it is relatively soft in the vertical, pitch and roll direction and stiff in the in-plane directions. Therefore, one of the suspension design objectives is to preferably increase the in-plane stiffness. As described before, for the dual stage servo system, one of the ideal mounting locations of the secondary actuator should be on suspension. As shown in FIG.9, the long axis of the suspension is parallel with the long axis of the arm. In this case, the driving direction of the secondary actuator should preferably be perpendicular to the long axis of the suspension. As described above, split-morph just possesses this property so that it is suitable for mounting on the load beam of the suspension to form a compound suspension. To design a compound suspension, it is necessary to know the details of the conventional suspension.

FIG. 10 shows an existing swage-mounted suspension assembly. It is made up of three components: load beam, gimbal-slider and base plate designated by 12, 13 and 14, respectively. The suspension supports a head slider and provides the preload necessary for the head to fly at the desired height above a disk. The suspension is attached to a supporting arm (designated by reference S3 in FIG. 9) by means of a swaging operation via a hollow cylinder or boss 15 at the base plate 14. The suspension also incorporates flanges 16 as stiffening ribs for suppressing out-of-plane motion by the respective piezoelectric devices. The compliance of the suspension is mainly attributed to the load beam where no flange exists. The gimbal 13 has a high compliance that mechanically isolates the slider from the rest of the mechanism and allows it to follow moderate axial runout of the disk.

FIG. 11 shows an embodiment of the present invention in which a split-morph described in FIG. 1 is mounted on the suspension as the

secondary stage actuator to form a compound suspension. In FIG. 11, a hole 12c is punched on the existing suspension along the edge of the load beam so that the suspension is divided into two parts 12a and 12b which are connected by flanges 16. A single plate split-morph 17 is then mounted across the hole by clamping its two ends on the two parts 12a and 12b. The two flanges of the suspension is preserved and act as a pair of leaf springs which has low rigidity in the driving direction of the split-morph and high rigidity in the other direction. The advantages of the flanges are obvious because the in-plane bending motion of the split-morph is unconstrained, but the out-of-plane motion is greatly suppressed. These features will not only reduce the peak stress at the root of the split-morph, but also suppress uncontrollable torsion deformation during the operation of the actuator.

FIG. 12 shows another embodiment of the present invention in which another configuration of the compound suspension is proposed. In FIG. 12, the middle part of the suspension designated by reference 12 in FIG. 11 is cut away and replaced by a bi-laminar split-morph 18 shown in FIG. 5. It should be noted that the actuator must be electrically isolated from the suspension so that the read/write process of the magnetic head is not affected by the operation of the actuator.

In fact, the bi-laminar split-morph 18 can be substituted by any one of the specific preferred actuators of the present invention. FIG. 13 shows another configuration of the compound suspension in which a bi-laminar split-morph with central metal shim (described in FIG. 8) 19 is used as the secondary actuator. In this case, the two piezoelectric actuators are arranged to be driven by applied voltages to generate a synchronised actuating action to drive the head slider for settling and track following. Taking the suspension as the central metal shim, then a simple structure of the compound suspension can be constructed. It is illustrated in FIG. 14. In this structure, the effect of the actuator's driving

operation to read/write process should be considered. The same references as those in FIG. 8 designate the same components.

FIG. 15 shows another embodiment of the present invention in which another configuration of the compound suspension is proposed. In this design, the front part of the existing suspension is replaced by any of the previously mentioned actuators, and the slider-head gimbal is directly attached to the tip of the actuator. This structure makes the previous design configurations much simpler and improves their resonance performance by removing the tip of the suspension 12 b in FIG. 12. To improve the performance of the secondary actuator, the actuator can take varying width shape along its length. FIG. 16 shows an embodiment of the present invention with a varying width shaped actuator along its length. It also should be noted that the actuator must be electrically isolated from both the load beam and head-slider gimbal, so that the read/write process of the magnetic head is not affected by the driving operation of the actuator.

Although the above explanation is made by referring to swage-mounted suspensions, it is also applicable to screw-mounted suspensions.

The advantages of the proposed compound suspension are obvious. In addition to providing high bandwidth and therefore high track density, such a servo system will help tremendously in reducing access time, realizing high compact structures, decreasing the cost of the secondary actuator, and allowing simultaneous tracking of individual heads. The last feature is particularly important for the video server/digital editing application; with the ability to keep every single read/write head on track, all of the recording channels can now work in parallel so that it is possible to substantially increase the data transfer rate.

Properties of an example of a typical actuator and compound suspension of the present invention are given below. As described before, the stroke and resonance frequency of said actuators depend on

their dimensions. For the actuators with thickness from 0.1 mm to 0.3 mm, length from 6 mm to 12 mm and width from 2 mm to 5 mm, the stroke at the tip at 12 volts applied driving voltage is between 0.3  $\mu\text{m}$  to 1.0  $\mu\text{m}$ , while the resonance frequency is between 4 kHz to 17 kHz. As to the compound suspension with stainless steel front end 12 a in FIG. 12, the stroke at the tip, i.e., the location of the slider, will be amplified but the resonance frequency will be reduced as compared with that of the actuator alone. Nevertheless, the order of magnitudes are still maintained at micrometer order for stroke and about 10 kHz for resonance frequency.

It is evident that the present invention achieves the objects and meets the ends set forth above, as well as those inherent therein. Various modifications may occur to one skilled in the art. Accordingly, the present invention is not limited to the embodiments as described in details herein and as shown in the accompanying drawings.



## CLAIMS

1. A piezoelectric device comprising an integral body of piezoelectric material which is longer and wider than it is thick, characterised in that the device further includes, in contact with said body, respective pairs of electrodes, in that the electrodes of each pair are opposed in the thickness direction, and in that the pairs are spaced in a direction transverse to said thickness direction, whereby said body deflects along said transverse direction when a voltage is applied to said electrode pairs.
2. A piezoelectric device according to claim 1, further characterised in that said integral body of piezoelectric material is an elongated plate and said transverse direction is the width direction of the plates.
3. A piezoelectric device according to claim 2, further characterised in that the device is configured to exhibit a plane of symmetry extending longitudinally of the plate between the respective pairs of electrodes.
4. A piezoelectric device according to claim 3, further characterised in that said electrodes are planar electrodes applied to respective faces of said integral body of piezoelectric material, and in that on each face respective electrodes of each pair are separated by a narrow gap in said plane of symmetry.
5. A piezoelectric device according to claim 1, further characterised in that said integral body of piezoelectric material is polarised in said thickness direction, the polarisation vectors being parallel and of uniform orientation.



6. A piezoelectric device according to claim 1, further characterised in that said integral body of piezoelectric material is polarised in said thickness direction, the polarisation vectors at the respective sides of said plane of symmetry being oppositely oriented.
7. A piezoelectric device according to claim 1, further characterised in that said integral body of piezoelectric material is formed by bonding together separate elements of the material.
8. A piezoelectric device according to claim 7, further characterised in that there are a pair of said separate elements bonded together at said plane of symmetry.
9. A piezoelectric device according to claim 1, further characterised in that the device is configured so that its cross section transverse to said longitudinal direction is shaped to enhance the flexural rigidity of the device in the thickness direction while being responsive to relatively low driving voltages.
10. A piezoelectric actuator characterised by a stack of piezoelectric devices according to claim 2 bonded together to increase stiffness in said thickness direction, and electrically connected and polarised so that the piezoelectric devices generate a synchronised bending motion.
11. A piezoelectric actuator according to claim 10, wherein said stack has two of said piezoelectric devices, further characterised in that a metal shim is sandwiched between the devices to enhance robustness.
12. A dual stage head positioning servo system for a hard disk drive having one or more disks and a respective head slider for each of the



disks supported by a respective compound suspension, and further including primary and secondary actuators for course and fine position control respectively of the head sliders relative to their corresponding disk surfaces, characterised in that the or each secondary actuator includes a piezoelectric device or actuator according to any one of claims 1 to 11.

13. A dual stage head positioning servo system according to claim 12, further characterised in that, for supporting each secondary actuator, the respective piezoelectric device is incorporated as a component of said suspension.

14. A dual stage head positioning servo system according to claim 12, further characterised in that said suspension includes one or more stiffening ribs for suppressing out-of-plane motion by the respective piezoelectric devices.

15. A dual stage head positioning servo system according to claim 12, further characterised in that each head slider is adjustable by a pair of secondary actuators comprising piezoelectric devices according to any one of claims 1 to 11, and in that the actuators are arranged to be driven by applied voltages to generate a synchronised actuating action to drive the head slider for settling and track following.

16. A dual stage head positioning servo system according to claim 12, wherein the suspension for the head slider includes a cantilevered load beam and a gimbal mounting for the slider, further characterised in that the piezoelectric device is positioned with a first end mounted to the load beam and a second end linked to the gimbal.