

## A PIEZOELECTRIC DEVICE AND SERVO SYSTEM

### Field of the Invention

- 5 The invention relates to a servo system and a piezoelectric device particularly, but not exclusively, for use in a servo system.

### Background of the Invention

- 10 Piezoelectric devices effect mechanical displacement upon application of a voltage thereto so as to function as a highly controllable mechanical actuator. Piezoelectric actuators are in fact widely used for fine positioning in fields such as optics, bio-instruments, precision machining, fluid control and hard disk drives due to their characteristics of small size, high energy density, simple structure, quick response, and, most important, controllable displacement  
15 down to nanometers.

Piezoelectric actuators are commonly available in the form of either stack (multi-layer) piezoelectric actuators or bimorph (or unimorph) piezoelectric actuators. Stack actuators are able to produce a relatively large displacement force, with a high response speed and  
20 resonance frequency, but such actuators have relatively large dimensions and small displacement sensitivity. Hence, they are generally used in cases where relatively large driving force is needed and sufficient space can be provided to incorporate the actuator. Bimorph and unimorph actuators on the other hand have high displacement sensitivity, and simple structure, but are only able to generate relatively low displacement forces with low  
25 resonance frequency. They are generally used in cases where relatively large displacement output is needed.

A common property for all types of piezoelectric devices is their poor shock resistant capability. Some bimorph actuators use a piece of central steel shim to improve their stock  
30 resistant capability. However, their displacement sensitivity is reduced as a result.

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In some circumstances, large displacement sensitivity is required in combination with high shock resistant capability, such as for secondary positioning in a servo system of a hard disk drive of a laptop PC. In such circumstances, neither of the above types of actuators would be suitable. It is, however, becoming of increased importance to provide a suitable actuator  
5 for such a servo system since the demand for high capacity hard disk drives is generating an annual increase of areal density at about 60%. It is expected that the track density per inch (TPI) will achieve or exceed 30 KTPI in the near future and at the same time the track width (TW) will be reduced to less than  $1\mu\text{m}$ . At such a high TPI, the influence of high frequency disturbances and nonlinearities on track misregistration (TMR) becomes more serious. To  
10 keep a read/write channel error rate better than  $10^{-9}$ , a servo bandwidth as high as 1.5 to 2 KHz is required to suppress the high frequency disturbance.

A possible solution to satisfy the increased operating requirements of the servo system is to incorporate dual-stage control algorithms and a secondary stage microactuator into a  
15 conventional servo system to form a dual-stage servo system. That is, a conventional voice coil motor may be used for first stage positioning, to generate coarse but large displacement and the microactuator may be used as a secondary stage to provide fine and fast positioning. The secondary stage actuator can help in both track seeking to reduce track to track access time and track following to reduce TMR level. To get a high secondary stage bandwidth, the  
20 microactuator should be put as near as possible to a read/write element of the system.

A dual stage servo system is disclosed in US patent 5,189,578 by Kenji Mori *et al*, wherein a stack or multi-layer piezoelectric actuator is mounted into an arm of an access mechanism and is employed as the secondary piggyback actuator. However, because of the relatively  
25 large mass and moment of inertia to be driven by the actuator, as well as the poor dynamics of the suspension, it is difficult for the multi-layer actuator to take advantage of its high resonance frequency and, further, the displacement sensitivity is limited.

### Summary of the Invention

The present invention seeks to provide a piezoelectric actuator, which has high displacement sensitivity, good shock resistant capability and low profile and which is suitable for use in a  
5 dual-stage servo system.

A more specific object of the present invention is to provide a piezoelectric actuator which forms part of the suspension of a positioning arm of a servo-system for driving a read/write head of the servo system.

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In accordance with the invention, there is provided a piezoelectric device including a piezoelectric plate with a reinforcing element provided on one side thereof, the element having discontinuities intermediate ends thereof so as to provide the element with predetermined compliance, whereby to allow for movement of the element with associated  
15 displacement of the plate.

In another aspect, there is provided a servo system for positioning a read/write device including:

- an arm for positioning the read/write device;
- 20 an actuator; and
- a suspension assembly at a free end of the arm, wherein  
the suspension assembly includes a base plate and a beam supporting the read/write device, the beam being connected to the baseplate via a pivot coupling and the actuator includes a piezoelectric device, as claimed in any one of claims 1 to 4,  
25 arranged to bridge between the base plate and the beam so that displacement of the plate or plates effects relative rotation of the beam about the coupling for positioning the read/write device.

Preferably, the beam includes a "C"-shaped section extending transversely across the beam,  
30 the section being resilient so as to enhance suspension properties of the assembly.

An advantage of the piezoelectric device of the present invention is its simple structure and the concept of a reinforcing element, which is preferably planar, in combination with a "C"-shaped section enables the actuator to have improved shock resistant capability, high displacement sensitivity, low profile and low added cost. With these advantages and features,  
5 the said actuator can be combined into a servo system's suspension to position the read/write head to track the runnout quickly and accurately.

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

#### Brief Description of the Drawings

Figure 1a is a perspective view of a reinforcement element used in the invention;  
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Figure 1b is a perspective exploded view of the actuation device of the invention;

Figure 1c is a perspective view of the device in an assembled condition;

20 Figure 2a is a perspective view of a modified reinforcing element;

Figure 2b is a perspective exploded view of the device with the modified reinforcing element;

Figure 2c is a perspective view of the device of Figure 2b in an assembled condition;  
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Figure 3a is a perspective view of a further modified reinforcing element;

Figure 3b is a perspective view of the device with the modified reinforcing element of Figure 3a;  
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Figure 3c is a perspective view of the device of Figure 3b in an assembled condition;

Figure 4 is a top view of a hard disk drive;

5 Figure 5 is a perspective view of a conventional swage-mounted suspension assembly for hard disk drives;

Figure 6a and Figure 6b are perspective views of a suspension assembly with two piezoelectric actuators;

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Figure 7 is a diagrammatic cross-section of the suspension assembly of Figure 6, illustrating electrical connection of the piezoelectric devices;

Figure 8a and Figure 8b are perspective views of a modified suspension assembly;

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Figures 9 and 10 are perspective views of modified suspension assemblies; and

Figure 11 is a diagrammatic cross-section of the suspension assembly of Figure 9, illustrating electrical connection of the piezoelectric devices.

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#### Detailed Description of Preferred Embodiments

Hereinafter, basic structures and preferred embodiments of the present invention will be described with reference to the drawings.

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Figure 1 illustrates the basic structure of the present invention. A reinforcing element, in the form of a meanderline planar spring shim 22 is sandwiched in between two thin piezoelectric rectangular plates 23, 24, which are polarised in the direction of its thickness.

In Figure 1 the plates 23, 24 are up and down piezoelectric plates. For each piezoelectric plate, there are two electrodes on the respective top and bottom surfaces. A driving electric field is created by applying a voltage to the top and bottom electrodes. The up and down piezoelectric plates can be polarised in either the same direction or the opposite direction to form a "parallel" or "anti-parallel" piezoelectric actuator.

As shown in Figure 1, the meanderline planar spring 22 is sandwiched in between two thin piezoelectric plates 23 and 24. Let us compare it with two thin piezoelectric plates laminated together without a central spring shim or one piezoelectric plate with double thickness. The shock resistant capability without a central shim is very poor. If the meanderline planar spring is replaced by a solid steel shim with the same thickness as the meanderline spring, the displacement of the actuator in its length direction is dramatically constrained. With the meanderline spring 22 sandwiched in between the top and bottom piezoelectric plates 23 and 24, both problems are solved. The stiffness of the meanderline spring 22 in its lengthwise direction should be designed sufficiently small.

Figure 2 illustrates a modification of the basic structure shown in Figure 1. The only difference is that the central meanderline spring shim 22 is replaced by a back-to-back meanderline shim. In Figure 2, reference numeration is the same as that in Figure 1. The operation of this actuator is the same as that shown in Figure 1.

Figure 3 illustrates another modification of the basic structure shown in Figure 1. The only difference is that the central meanderline spring shim 22 is replaced by a round-hole spring shim. In Figure 3, reference numeration is the same as that in Figure 1. The operation of this actuator is the same as that shown in Figure 1.

By changing the pattern of the central planar spring, different types of reinforcing elements may be formed such that different types of shock resistant piezoelectric actuators can be obtained. More particularly, providing discontinuities intermediate ends of the element in a predetermined manner results in the element having predetermined compliance to allow for  
5 movement of the element with associated displacement of the plates 22, 23. If it is desired to improve the shock resistant capability of a piezoelectric actuator with only a single piezoelectric plate, the spring shim 22 need only be applied to a single plate.

Although the above explanation is made by referring to piezoelectric actuators, it is also  
10 applicable to piezoelectric sensors.

Hereinafter, preferred embodiments of the present invention will be described with reference to Figure 4 through Figure 11. In these embodiments, the piezoelectric device of the present invention is used as a secondary fine positioning actuator, in a compound suspension for a  
15 dual stage servo system of a hard disk drive.

Figure 4 illustrates an embodiment of this aspect of the present invention. Shown in Figure 4 is the top view of a hard disk drive with a high bandwidth dual-stage servo-mechanism. Designated by reference A1 is a plurality of data disks, only one of which can be seen in plan  
20 view, and A2 is a spindle motor for rotating the disks all together at high speed. An array of vertically aligned head sliders, one of which is designated by reference C1, is attached through a respective compound suspensions C2 to a plurality of associated supporting arms B3. An electromagnetic voice coil motor (VCM) B1 is used as the primary stage rotary actuator to move all the supporting arms around a pivot bearing B2 in a long stroke to any  
25 desired one of a plurality of tracks on the surfaces of the disk A1 along an accurate path P for track seeking. Any suitable two of the piezoelectric device actuators of the present invention, designated by reference C3 and C4, are integrated on the compound suspension C2, toward a free end of the arm, as the secondary stage fine positioning actuators to drive an individual read/write head slider in a fine stroke at very high speed for settling and track following. D1  
30 is a flexible cable and D2 is a connector as an interface to a computer.

This embodiment can allow each individual head to position itself on the track center with high accuracy and fast speed. 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 or magneto-optical storage device.

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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  
10 of the disk drive. In order to maintain proper head/media compliance and obtain high servo bandwidth, the suspension design should be such that it is relatively soft in the vertical, pitch and roll directions and stiff in the in-plane directions. Therefore, one of the suspension design objectives is to preferably increase the in-plane stiffness. For the dual-stage servo system, an ideal mounting location for the secondary actuator is on the suspension itself. As  
15 shown in Figure 4, the longitudinal axis of the suspension C2 is parallel with the longitudinal axis of the arm B3. In this case, the driving direction of the secondary actuator should preferably be perpendicular to the longitudinal axis of the suspension. To obtain such a motion, two shock resistant piezoelectric actuators of this invention may be mounted between a baseplate and a suspension loadbeam of the suspension.

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Next, let us discuss the details of the conventional suspension. Figure 5 shows a conventional swage-mounted suspension assembly. It is made up of four main parts: a baseplate 11 with swage boss 12, a spring beam 30, a rigid load beam 40, and a slider/head assembly 50. The suspension supports a head slider and provides the gramload necessary for the head to fly at  
25 the desired height above a disk. The suspension is attached to a supporting arm (designated by reference B3 in Figure 4) by swaging the boss 12 on the baseplate to a hole on the arm B3. The suspension also incorporates flanges 41 and 41' as stiffening ribs. The compliance of the suspension is mainly attributed to the load beam where no flange exists. There is one flexure between the distal end of the suspension and the slider/head assembly (not shown in the  
30 figure), which has high compliance in the pitch, roll and vertical directions and high stiffness

in the yaw and in-plane directions. Thus, the servo system can move the slider/head assembly rapidly and accurately, and simultaneously the slider can follow the disk surface profile well.

Figure 6 shows an embodiment of the present invention in which two shock resistant  
5 piezoelectric actuators 200 and 200' described in Figure 1 are mounted on the suspension as  
the secondary stage actuators to form a compound suspension. The two actuators are  
mounted in between the baseplate 10 and spring beam 30. Between two piezoelectric  
actuators there is a beam 20 with a pivot coupling 21. Two piezoelectric actuators 200 and  
200' are driven in such way that one expands while the other contracts, thus making the  
10 loadbeam 40 turn around the coupling 21 and an amplified displacement is generated at the  
distal end 43. Four stiff ribs 13, 13', 14 and 14' are designed to reinforce the stiffness of the  
suspension assembly at either side of the actuators 200, 200'. Since there is a spring beam  
30 between the actuation part and the slider/head assembly, the effect of servo actuation on  
fly height can be reduced.

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The cross-section driving connections for in-plane servo motion are shown in Figures 7a and  
7b. Figure 7a shows two parallel piezoelectric actuators, which are constructed with two  
parallel-polarized piezoelectric plates 23, 24 and 23', 24', respectively. Driving voltage is  
applied to two piezoelectric actuators from points A and B. When A is "+" and B is "-", the  
20 left piezoelectric actuator (200 in Figure 6) with two plates 23 and 24 expands while the right  
piezoelectric actuator (200' in Figure 6) with two plates 23' and 24' contracts. Thus the  
loadbeam 40 in Figure 6 is turned around the hinge 21 in the anti-clockwise direction when  
viewed from the top. Therefore, servo motion at the distal end 43 in Figure 6 is obtained.  
If the polarity of the applied voltage is reversed, then the motion obtained at the distal end  
25 43 in Figure 6 is in the clockwise direction.

Figure 7b shows two anti-parallel piezoelectric actuators, which are constructed with two  
parallel-polarized piezoelectric plates 23, 24 and 23', 24', respectively. Driving voltage is  
applied to two piezoelectric actuators from points A and B. When A is "+" and B is "-", the  
30 left piezoelectric actuator (200 in Figure 6) with two plates 23 and 24 contracts while the

right piezoelectric actuator (200' in Figure 6) with two plates 23' and 24' expands. Thus the loadbeam 40 in Figure 6 is turned around the hinge 21 in the clockwise direction when viewed from the top. Therefore, servo motion at the distal end 43 in Figure 6 is obtained. If the parity of the applied voltage is reversed, then the motion obtained at the distal end 43 in Figure 6 is in the anti-clockwise direction.

From a fabrication aspect, the planar spring 22 and 22' can be chemical-etched with exactly the same process as that for the etching of suspensions. Adding planar spring 22 and 22' to suspensions will not change the fabrication process and increase the fabrication complexity.

Figure 8 shows another embodiment of the present invention. A compound suspension has two piezoelectric actuators 200 and 200', which are constructed with one piezoelectric plate 23 and 23' and meanderline planar spring 22 and 22', respectively. The operation of this embodiment is the same as the previous embodiment, i.e., two piezoelectric actuators 200 and 200' are driven in such a way that one expands while the other contracts, thus making the loadbeam 40 turn around the hinge 21 and an amplified displacement is generated at the distal end 43.

Figure 9 shows another important embodiment of the present invention. A compound suspension with four piezoelectric actuators 23, 24 and 23', 24' has a "C" channel 27 in front of the piezoelectric microactuator. Here, the "C" channel 27 serves to relieve the vertical stress imposed on the piezoelectric actuators due to the air bearing effects and shock loads caused by head disk separation. Thus, the shock resistant capability of the piezoelectric actuator can be further improved by using the "C" channel. The "C" channel can take any relevant curved shapes. Holes, slots, or partial-etching surface can also be made on the "C" channel. The operation of this embodiment is the same as the previous embodiment. The electrical connection is the same as shown in Figure 7. Figure 10 shows a similar embodiment with two piezoelectric actuators 23, and 23'. Again, the "C" channel functions the same as described above. The location and the number of "C" channel used can be varied according to different applications. The "C" channel can also be used to replace the spring

beam design of both the conventional and compound piezoelectric suspension used in hard disk drives.

The application of "C" channel in the design of piezoelectric actuator to relieve stress and enhance shock resistant capability is by no means limited to compound suspension for dual stage servo system. It can be applied as a general method in the design of piezoelectric actuator which requires shock resistant treatment.

Furthermore, with certain voltage-driving patterns, that is, the top piezoelectric elements 23 and 23' expands (or contracts) while the bottom element 24 and 24' contracts (or expands), motion in the vertical direction can be achieved. This motion can be employed to adjust the gramload value and reduce the stiction force during start/stop period. The cross-section driving connections for vertical motion are shown in Figures 11a and 11b. As shown in Figure 11a are two parallel piezoelectric plates 23, 24 and 23', 24', respectively. Driving voltage is applied to two piezoelectric actuators from points A and B. When A is "+" and B is "-", two top piezoelectric plates 23 and 23' expand while two piezoelectric plates 24 and 24' contract. Therefore, the loadbeam 40 in Figures 6 and 9 is bent downward. If the polarity of the applied voltage is reversed, the loadbeam 40 in Figures 6 and 9 is bent upward.

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

The advantages of the proposed compound suspension are obvious. A dual-stage servo system with such compound suspensions will provide high servo bandwidth and help tremendously in access time, runout and noise compensation, and nonlinearity compensation. Thus, high track density can be achieved. The simple structure makes its fabrication process not too dissimilar from that of conventional suspensions. The chemical-etching process can also be used to make a compound suspension with arbitrarily shaped planar springs on a single piece of stainless steel which can then be attached to piezoelectric plates with proper

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bonding techniques.

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.

5 Accordingly, the present invention is not limited to the embodiments as described in detail herein and shown in the accompanying drawings.



THE CLAIMS:

1. A piezoelectric device including a piezoelectric plate with a reinforcing element provided on one side thereof, the element having discontinuities intermediate ends thereof so  
5 as to provide the element with predetermined compliance, whereby to allow for movement of the element with associated displacement of the plate.
2. A piezoelectric device as claimed in claim 1, wherein the device includes a second piezoelectric plate and the element is provided between the plates.
- 10 3. A piezoelectric device as claimed in claim 1 or 2, wherein the element is in the form of a planar spring.
4. A piezoelectric device as claimed in claim 1 or 2, wherein the discontinuities are in  
15 the form of circular openings arranged along the length of the element.
5. A servo system for positioning a read/write device including:  
an arm for positioning the read/write device;  
an actuator; and  
20 a suspension assembly at a free end of the arm, wherein  
the suspension assembly includes a base plate and a beam supporting the read/write device, the beam being connected to the baseplate via a pivot coupling and the actuator includes a piezoelectric device, as claimed in any one of claims 1 to 4,  
25 arranged to bridge between the base plate and the beam so that displacement of the plate or plates effects relative rotation of the beam about the coupling for positioning the read/write device.
6. A servo system as claimed in claim 5, wherein the beam includes a "C"-shaped section extending transversely across the beam, the section being resilient so as to enhance suspension  
30 properties of the assembly.



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7. A servo system as claimed in claim 6, wherein the piezoelectric device couples directly to the section.
8. A servo system as claimed in any one of claims 5 to 7, wherein the reinforcing  
5 element of the piezoelectric device is integrally formed with the base plate and beam.
9. A servo system as claimed in any one of claims 5 to 8, wherein a second piezoelectric device formed in accordance with the device as claimed in any one of claims 1 to 4, is provided on an opposite side of the coupling to provide enhanced control of the  
10 read/write device and allow for movement of the device in both a plane parallel to the arm and traverse thereto.
10. A servo system as claimed in any one of claims 5 to 9 including a voice coil motor arranged to drive the arm about a pivot to move the read/write device relative to a  
15 disk drive and wherein the actuator provides for secondary positioning of the arm.