

An Optical System

This invention relates to an optical system and particularly, but not exclusively, to an optical system and method to actively compensate dynamic skews of an optical element in an optical system.

In optical data storage systems, a light source in the form of a laser beam is used to detect (read) or create (write) information pits on an optical recording medium such as an optical disc. The positioning and focusing of the laser beam on the optical disc is critical to ensure the accuracy of the read or write operation and to maximise the storage capacity. This is particularly important for recording formats that are of higher areal density such as Digital Video Disc (DVD).

A typical optical pickup includes an objective lens mounted on a lens holder/bobbin. The lens holder is mounted on a suspension frame. Due to the high flexibility of the suspension frame, dynamic skews of the objective lens during a read or write operation can cause positioning errors of the laser beam resulting in read/write errors. Other factors that contribute to positioning errors of the laser beam include deformation of the optical disc, disturbances and dimensional tolerances of the different components that make up the optical pick-up.



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To overcome these problems, it has been proposed that adjustment of the objective lens in relation to the optical system is performed during production or at the initial period when the optical disc is first loaded into the optical system.

5 However, such adjustment takes into consideration positioning errors only at the time the adjustment is made and does not consider the dynamic skew of the objective lens caused by the drive mechanisms during a read or write operation. Therefore this solution has the disadvantage that it does not compensate errors occurring in real time during a read or write operation.

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In another proposed solution, the accuracy of the light beam is improved by generating a light beam of a smaller focus size on the optical disc. This is accomplished by having an objective lens of a larger numerical aperture (NA) and generating a light beam of shorter wavelength. In this way, a higher
15 recording capacity is achieved.

However, a smaller focus size results in a reduction in the skew tolerance of the objective lens in relation to the optical disc. In addition, as the depth of focus is inversely proportional to the square of the N.A., this will result in a reduced
20 depth of focus for the light beam. The depth of focus is of particular importance as the thickness of the clear substrate on the optical disc is non-uniform. Therefore, with a reduced depth of focus and a smaller focus size, this solution has the disadvantage that there is greater difficulty in reading and writing of the information signal.

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In accordance with a first aspect of the present invention, there is provided an optical system comprising an optical element having an optical axis, a mounting device on which the optical element is mounted, and an actuator located between the optical element and the mounting device and arranged to receive a control signal, the actuator comprising a deformable material which deforms in response to the control signal; actuation of the actuator moving the position of the optical axis relative to the mounting device.

In accordance with a second aspect of this invention, there is provided a method of moving the position of an optical axis of an optical element mounted in a mounting device, the method comprising:

- the optical element transmitting a feedback signal;
- detecting the feedback signal with an optical detector;
- analysing an output from the optical detector for one or more of a tracking error signal, a focus error signal and a RF signal detected in the optical feedback signal;
- generating a control signal in response to the result of the analysis; and
- using the control signal to actuate an actuator mounted between the optical element and the mounting device to move the optical element with respect to the mounting device to move the position of the optical axis with respect to the mounting device.

An advantage of the invention is that the use of an actuator located between the mounting device and the optical element to control the position of the optical

axis of the optical element enables real time compensation for dynamic skew of the optical element.

Typically, the optical element is a lens such as an objective lens. However,
5 alternatively, the optical element may be a mirror.

Preferably, the actuator is located adjacent the periphery of the optical element.

Typically, the optical system may comprise a number of actuators to facilitate
10 movement of the optical axis in a number of different planes. Preferably, the actuators are positioned adjacent to the periphery of the optical element, typically spaced apart from each other, and most preferably, spaced equidistantly around the periphery.

15 Preferably, the position of the optical axis with respect to the mounting device is moved by a rotation of the optical axis.

Typically, the actuator is actuated by a control signal which may be, for example, an electrical signal, a magnetic signal or an optical signal.

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As noted above, the actuator may comprise a deformable material which deforms in response to the applied signal. For example, the actuator may comprise a piezoelectric material, a shape memory alloy or a magnetostrictive material. Where a piezoelectric material is used, the piezoelectric material may
25 be, for example, lead zirconate titanate ($\text{Pb}(\text{Ti}, \text{Zr})\text{O}_3$) (PZT).

Typically, the actuator may comprise a bulk deformable material or alternatively, a number of layers of deformable material, which could be bonded or laminated together.

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Preferably, the optical system comprises an optical pick-up. For example, an optical pick-up for an optical data storage device reader and/or writer, such as a CD player and/or writer, a CD-ROM reader and/or writer, or a DVD reader and/or writer. For example, in the second aspect of the invention, the feedback
10 optical signal may be a reflected signal from an optical data storage device.

Preferably, in the second aspect of the invention a jitter value is derived from the RF signal and analysed with the tracking error signal to generate the control signal. Preferably, the control device compares the analysed signal with a
15 reference value to derive an error signal which is used to generate the control signal.

Examples of an optical system in accordance with the invention will now be described with reference to the accompanying drawings, in which:

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Figure 1 is an example of a piezoelectric actuator;

Figure 2 shows an optical lens mounted on two actuators;

Figure 3 shows an effect of applying voltage to the actuators of Figure 2;

Figure 4(a) is a schematic diagram of an optical pick-up including a first
25 example of a lens assembly;

Figure 4(b) is an enlarged cross-sectional view of the optical pick-up in region A in Figure 4(a);

Figure 4(c) is a plan view of the first example of the lens assembly;

Figure 5 shows a feedback control system for the optical system shown in Figures 4(a) to 4(c);

Figure 6(a) is a cross-sectional view of the lens assembly with an objective lens in a zero skew position;

Figure 6(b) is a cross-sectional view of the lens assembly with the objective lens skewed by $+0.1$ degrees from the zero skew position;

Figure 6(c) is a cross-sectional view of the lens assembly with the objective lens skewed by -0.1 degrees from the zero skew position;

Figure 7 is a graph illustrating calculation of an error signal;

Figure 8 shows another example of the invention with a second example of a lens assembly with a two-element objective lens; and

Figure 9 is a plan view of a third example of a lens assembly.

Figure 1 is an example of a piezoelectric actuator 1 that is formed from bulk PZT (lead zirconate titanate) material using ceramic fabrication technology.

When a voltage is applied to the ceramic material forming the actuator 1, a

deformation occurs and the magnitude of the deformation is proportional to the applied voltage. With its simple structure, such an actuator 1 has the ease of miniaturisation and with its quick response, it can be employed to control an

optical element. Alternatively, the actuator 1 can be formed by MEMS techniques with the use of silicon, diamond-like carbon (DLC) and ceramic

materials. As a further alternative, the actuator may be a commercially

available actuator, such as a multi-layer PZT actuator with a high piezoelectric constant.

Figure 2 shows an optical element 2, having an optical axis, mounted on a flexure 3 and supported by two actuators 1. Figure 3 shows the effect of applying a voltage to the actuators 1 to change the optical axis thereby changing the position of the optical element 2. In one instance, when the voltage is applied to the actuators 1, expansion and contraction of the actuators 1 changes the orientation of the optical axis such that the inclination of the optical element 2 changes. In this way, skew adjustment of the optical element 2 can be achieved.

In another example, the expansion and contraction may create a vertical movement of the optical element but maintain the orientation of the optical axis. In this way, adjustment of the focusing position of the optical element can be achieved.

Figure 3 shows how a voltage applied to the actuators 1 to deform the actuators 1 can be used to generate movement of the optical element to move the position of the optical axis by rotating the optical axis. It will be apparent to a skilled man in the art that this movement may also be accomplished with a single actuator. It will also be apparent to the skilled man that a plurality of actuators may be used to actuate the optical element in other directions.

Figure 4(a) shows an optical pickup 10 being used to read from or write to an optical disc 11. The optical pick-up 10 includes a lens assembly 12 and a laser source/light sensor 13. The lens assembly 12 is mounted on suspension frames 15. Figure 4(b) shows an enlarged view of region A of Figure 4(a), which shows in more detail the components of the lens assembly 12. The lens assembly 12 comprises an objective lens 62 supported by a support ring 53 and mounted on the lens holder 14 with two actuators 1 located between the support ring 53 and the lens holder 14. Figure 4(c) is a plan view of the lens assembly 12 shown in Figure 4(b). The output from the light sensor 13 is fed to a control unit 50.

The control unit 50 is shown in more detail in Figure 5. Figure 5 shows a block diagram of the control unit 50. The control unit 50 is used to control the position of the optical axis of the objective lens 62 in real time. The control unit 50 includes a controller 4 and a driver 5, which outputs control signals 51 to the actuators 1. The sensor 13 detects reflected signals from an optical data storage device 11 and outputs an output signal 52 to a signal processing unit 7. An output of the signal processing unit 7 is coupled to a comparator 8. The controller 4 controls the overall system behaviour and may be a conventional PID (Positional-Integral-Derivative) controller implemented using ASIC design or a suitable off-the-shelf commercially available controller.

For the control unit 50 to function, it is necessary to obtain a reference value r . Therefore, a system calibration of the optical pick-up 10 is required, prior to any read/write operation. In this example, the calibration will be based on the electrical parameter jitter of a RF output in a read operation.

When the optical disc 11 is initially loaded, prior to any read/write operation, a system calibration is performed to obtain the reference jitter value r . The controller 4 initialises the actuators 1 so that the actuators 1 are not energised so that the objective lens 62 is in a zero skew position, as shown in Figure 6(a).
5 The optical pickup 10 moves radially to the middle, or to a pre-determined track of the optical disc 11 for the calibration operation. At the same time a laser beam 16 transmitted through the objective lens 2 to impinge on the optical disc 11 as a focused laser spot. The optical disc 11 is rotated at a constant velocity
10 by a spindle servomotor (not shown).

It should be noted that calibration may be conducted at a plurality of locations within the area of the disc, especially for recording formats of higher densities, such as at the inner and/or outer region of the optical disc to enhance the
15 accuracy of the calibration data.

The laser beam 16 is reflected off from the optical disc 11 and passes back through the objective lens 62 and is detected by the light sensor 13, which typically consists of a plurality of photo detectors. From the output signal 52 an
20 electrical RF signal is obtained and processed by the signal processing unit to generate the jitter value 17 (see Figure 6(d)) in this orientation of the objective lens.

Figure 6 (b) shows the next step in the calibration process. In this step the
25 controller 4 actuates the actuator 1 to incline the objective lens 2 in the radial

direction so that the optical axis 56 of the lens 62 is $+0.1^\circ$ from the zero skew position. The jitter value 18 at this angle of inclination is obtained.

Subsequently, as shown in Figure 6(c), the controller 4 actuates the actuator 1 to move the lens 62 in the opposite direction so that the optical axis 56 is -0.1° from the zero skew position to obtain the jitter value 19.

To enhance the accuracy of the calibration, more measurements could be carried out with different inclinations of the objective lens to increase the data points. In this example, the measurement is carried out in the radial direction of the disc. In addition, calibration data may be taken in the tangential direction, particularly if the optical pick-up 10 comprises the function to actuate the optical objective lens 62 in the tangential direction.

Figure 6 (d) shows the three jitter values (17, 18, 19) being fitted to form an imaginary curve to derive the best jitter location. The best jitter position as a function of radial skew is that which generates a minimum jitter value. In this example of Figure 6 (d), the lowest jitter value 17 is that obtained when the objective lens is in the zero skew position. Therefore, the jitter value 17 is the reference jitter value r .

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After calibration, the reference jitter value r can be used during a read or write operation to move the optical axis of the objective lens 62 to compensate for dynamic skews during the read or write operation. During a read operation, the optical pick-up 10 moves to a desired track to read the information signal on the optical disc 11. The light sensor 13 detects the reflected laser beam 16 to

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generate the output signal 52. The output signal 52 is processed by the signal processing unit 7 to generate the measured jitter value 54 in this position of the read operation. The measured jitter value 54 is then compared with the reference jitter value r by the comparator 8.

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The difference or error e between the measured jitter value 54 and reference jitter value r denotes the magnitude and direction of adjustment required to move the optical axis of the objective lens 62 to compensate for the positioning errors. Figure 7 is a graphical representation showing the error e between the

10 measured jitter value 54 and reference jitter value r .

The error signal e is then passed to the controller 4 for computation to derive the desired change in the actuation signal 55 to compensate for the positioning errors to obtain an optimum read-back RF signal. The actuation signal 55 is

15 then sent to the driver 5 and the driver 5 amplifies the actuation signal 55 proportionately to the required voltage level and outputs this as the control signal 51. The control signal 51 controls the actuator 1 to move the objective lens 62 with respect to the mounting device to position the optical axis of the objective lens 62 to minimise the error e and so provide active compensation.

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When the control system is balanced (i.e. $e=0$), the controller 4 maintains the actuation signal 55 constant and thus the optical axis remains in the same position. However, whenever the control system is out of balance, a new error signal e is generated and passed to the controller 4 to generate a change the

actuation signal 55 to attempt to maintain the balanced condition. In this manner, active compensation is achieved.

Hence, real time compensation/adjustment of the objective lens 62 is achieved
5 using actuators 1 to control the position of the optical axis of the optical element 2 to reduce or eliminate positioning errors of the light beam 16. In addition, this invention eliminates errors due to the deformation of the optical recording medium 11 and disturbances of the drive mechanism.

10 Figure 8 shows a second example of a lens assembly 70. The lens assembly 70 has two lens 72, 73 mounted in a holder 74. Two actuators 1 are mounted between the lens 72 and the holder 74. The actuators 1 are controlled in the same manner as described above for the optical pick-up 10 to control the skew of optical axis 75 relative to the optical disc 11.

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Figure 9 shows a third example of a lens assembly 80, which uses three actuators 1 spaced equidistantly around the lens 62, to control the orientation of the lens 62 with respect to the holder 14. The advantage of the lens assembly 80 is that the use of three actuators 1 enables the three degrees of freedom for
20 movement of the optical axis of the lens 62.

CLAIMS

1. An optical system comprising an optical element having an optical axis, a
5 mounting device on which the optical element is mounted, and an actuator
located between the optical element and the mounting device and arranged to
receive a control signal, the actuator comprising a deformable material which
deforms in response to the control signal; actuation of the actuator moving the
position of the optical axis relative to the mounting device.
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2. An optical system according to claim 1, wherein the optical element is a
lens.
3. An optical system according to claim 1 or claim 2, wherein the actuator is
15 located adjacent the periphery of the optical element.
4. An optical system according to any of the preceding claims, wherein
actuation of the actuator generates a rotational displacement of the optical axis
with respect to the mounting device.
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5. An optical system according to any of the preceding claims, further
comprising an optical radiation detector and a control device coupled to the
output from the optical radiation detector, the optical radiation detector detecting
optical radiation passing through the optical element and generating an output

signal, the control device in response to the output signal from the optical radiation detector generating the control signal to actuate the actuator.

6. An optical system according to any preceding claim, wherein the
5 deformable material comprises a piezoelectric material.

7. An optical system according to any of the preceding claims, wherein the optical system comprises a number of actuators.

10 8. An optical system according to claim 7, wherein the actuators facilitate movement of the optical axis in a number of different planes.

9. An optical system according to claim 8, wherein the actuators are spaced equidistantly around the periphery of the optical element.

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10. An optical pick-up comprising an optical system according to any of the preceding claims.

11. An optical data storage device reader and/or writer comprising an optical
20 pick-up according to claim 10.

12. A method of moving the position of an optical axis of an optical element mounted in a mounting device, the method comprising:

the optical element transmitting a feedback signal;

25 detecting the feedback signal with an optical detector;

analysing an output from the optical detector for one or more of a tracking error signal, a focus error signal and a RF signal detected in the optical feedback signal;

generating a control signal in response to the result of the analysis; and

5 using the control signal to actuate an actuator mounted between the optical element and the mounting device to move the optical element with respect to the mounting device to move the position of the optical axis with respect to the mounting device.

10 13. A method according to claim 12, wherein a jitter value is derived from the RF signal and analysed with the tracking error signal to generate the control signal.

14. A method according to claim 12 or claim 13, wherein the result of the
15 analysis is compared with a reference signal to generate the control signal.