

ENVIRONMENTAL STRESS PROTECTION SCHEME
FOR A DATA STORAGE DEVICE

Field of the Invention

5 This application relates generally to data storage devices and more particularly to a system and method for verification of written data automatically in the event a write operation occurs during an out of specification environmental condition.

Background of the Invention

10 Modern disc drives are designed to operate within a predetermined range of environmental conditions. These conditions are chosen based on a number of factors such as normal expected handling activities, ambient and operational temperatures expected, and atmospheric pressures. These ranges are relatively broad, with the intention of accommodating the most expected conditions of use. Such ranges are also a balance between expectations and design constraints. However, in actual practice, operation of the drives can and does occur
15 outside these ranges, as the manufacturer has no control over the ultimate use by the customer in most cases.

 If drive operation occurs outside of the envelope of these expected environmental conditions, the drive is subjected to an "environmental stress". In such conditions, data written to the storage discs may not be accurately recorded or sufficiently recorded to permit accurate
20 and consistent reads. Examples of such stress conditions are operation of the disc drive within a poorly ventilated PC system or surviving a cold boot in a poorly radiated storeroom during the deep of winter. Another example of environmental stress condition is excessive vibration.

 Operating mobile hard disc drives must withstand consistent shock and vibration. In these drives, there is internal hardware protection of the drive to minimize the occurrence of
25 drive fatality, i.e. a head slamming onto disc media as a result of the drive coming into extreme physical contact against other object(s) such as might occur if the laptop is hit or dropped during operation. However this hardware protection does not guarantee or verify a valid write operation. It only potentially safeguards the drive from total malfunction.

Accordingly there is a need for a system and method for avoiding incorrect writing of data during environmental stress conditions. The present invention provides a solution to this and other problems, and offers other advantages over the prior art.

Summary of the Invention

Against this backdrop embodiments of the present invention have been developed. An Environmental Stress Protection Scheme (ESPS) in accordance with an embodiment of the present invention ensures that, under a detected environmental stress operational condition, no data loss will occur when performing write operations to the media by conditionally invoking and applying a Write Integrity Check Algorithm on each write command so long as the stress condition is sensed to exist.

The Write Integrity Check Algorithm (WICA) ensures verifies that a particular sector is written correctly to the media by reading back the write signal from that particular sector direct from the media and verifying its integrity. The read back signal is compared to the intended write signal. Assuming the read signal does not match the intended write signal, that particular sector will be reassigned to another sector. If there are no more spare sectors to be allocated for the reassignment process, the drive will report a write command error to the host system. Following the reassignment sequence, the write/read compare procedure is performed for the just reassigned Logical Block Address (LBA) location. If the data is verified to be valid, then that reassignment process is reported to be successful and the drive will continue its subsequent command servicing. However if the data is verified to be invalid, a write error signal is generated and a write command error is issued to the host system. The WICA is preferably only invoked when a stress condition is identified. Thus, when the drive is operating in a normal environment, the additional processing delays, causing an inherent performance hit, experienced in performing write verification is avoided.

These and various other features as well as advantages which characterize the present invention will be apparent from a reading of the following detailed description and a review of the associated drawings.

Brief Description of the Drawings

FIG. 1 is a plan view of a disc drive incorporating a preferred embodiment of the present invention showing the primary internal components.

FIG. 2 is a block diagram of the control scheme for the disc drive shown in FIG. 1.

FIG. 3 is a block diagram of the Environmental protection scheme in accordance with an embodiment of the present invention.

FIG. 4 is a block diagram of the write Integrity Check algorithm in accordance with an embodiment of the present invention.

Detailed Description

A disc drive **100** incorporating a preferred embodiment of the present invention is shown in FIG. **1**. The disc drive **100** includes a base **102** to which various components of the disc drive **100** are mounted. A top cover **104**, shown partially cut away, cooperates with the base **102** to form an internal, sealed environment for the disc drive in a conventional manner.

The components include a spindle motor **106**, which rotates one or more discs **108** at a constant high speed. Information is written to and read from tracks on the discs **108** through the use of an actuator assembly **110**, which rotates during a seek operation about a bearing shaft assembly **112** positioned adjacent the discs **108**. The actuator assembly **110** includes a plurality of actuator arms **114** which extend towards the discs **108**, with one or more flexures **116** extending from each of the actuator arms **114**. Mounted at the distal end of each of the flexures **116** is a head **118**, which includes a fluid bearing slider, enabling the head **118** to fly in close proximity above the corresponding surface of the associated disc **108**.

During a seek operation, the track position of the heads **118** is controlled through the use of a voice coil motor (VCM) **124**, which typically includes a coil **126** attached to the actuator assembly **110**, as well as one or more permanent magnets **128** which establish a magnetic field in which the coil **126** is immersed. The controlled application of current to the coil **126** causes magnetic interaction between the permanent magnets **128** and the coil **126** so that the coil **126** moves in accordance with the well-known Lorentz relationship. As the coil **126** moves, the actuator assembly **110** pivots about the bearing shaft assembly **112**, and the heads **118** are caused to move across the surfaces of the discs **108**.

The spindle motor **106** is typically de-energized when the disc drive **100** is not in use for extended periods of time. The heads **118** are moved either off of the discs **108** to a park ramp, or over park zones **120** near the inner diameter of the discs **108** when the drive motor is de-energized. The heads **118** are secured over the park zones **120** through the use of an actuator latch arrangement, which prevents inadvertent rotation of the actuator assembly **110** when the heads are parked.

A flex assembly **130** provides the requisite electrical connection paths for the actuator assembly **110** while allowing pivotal movement of the actuator assembly **110** during operation. The flex assembly includes a printed circuit board **132** to which head wires (not shown) are connected; the head wires being routed along the actuator arms **114** and the flexures **116** to the heads **118**. The printed circuit board **132** typically includes circuitry for controlling the write currents applied to the heads **118** during a write operation and a preamplifier for amplifying read signals generated by the heads **118** during a read operation. The flex assembly terminates at a flex bracket **134** for communication through the base deck **102** to a disc drive printed circuit board (not shown) mounted to the bottom side of the disc drive **100**.

Referring now to FIG. 2, shown therein is a functional block diagram of the disc drive **100** of FIG. 1, generally showing the main functional circuits which are resident on the disc drive printed circuit board and used to control the operation of the disc drive **100**. The disc drive **100** is operable connected to a host computer **140** in a conventional manner. Control communication paths are provided between the host computer **140** and a disc drive microprocessor **142**, the microprocessor **142** generally providing top level communication and control for the disc drive **100** in conjunction with programming for the microprocessor **142** stored in microprocessor memory (MEM) **143**. The MEM **143** can include random access memory (RAM), read only memory (ROM) and other sources of resident memory for the microprocessor **142**.

The discs **108** are rotated at a constant high speed by a spindle motor control circuit **148**, which typically electrically commutates the spindle motor **106** (FIG. 1) through the use of back electromotive force (BEMF) sensing. During a seek operation, wherein the actuator **110** moves the heads **118** between tracks, the position of the heads **118** is controlled through the application of current to the coil **126** of the voice coil motor **124**. A servo control circuit **150** provides such control. During a seek operation the microprocessor **142** receives information regarding the velocity of the head **118**, and uses that information in conjunction with a velocity profile stored in memory **143** to communicate with the servo control circuit **150**, which will apply a controlled amount of current to the voice coil motor coil **126**, thereby causing the actuator assembly **110** to be pivoted.

Data is transferred between the host computer **140** or other device and the disc drive **100** by way of an interface **144**, which typically includes a buffer to facilitate high-speed data transfer between the host computer **140** or other device and the disc drive **100**. Data to be

written to the disc drive **100** is thus passed from the host computer **140** to the interface **144** and then to a read/write channel **146**, which encodes and serializes the data and provides the requisite write current signals to the heads **118**. To retrieve data that has been previously stored in the disc drive **100**, read signals are generated by the heads **118** and provided to the
5 read/write channel **146**, which performs decoding and error detection and correction operations and outputs the retrieved data to the interface **144** for subsequent transfer to the host computer **140** or other device.

The firmware of the disc drive **100** typically incorporates a self-monitoring, analysis and reporting tool (SMART) algorithm that processes internally measured parameters that may
10 include operating temperature, atmospheric pressure, vibration, track ECC failure statistics, and other parameters and operational statistics. These measured parameters are preserved for potential failure analysis in the event that drive failure occurs. Such records are invaluable tools for determination of failure modes in a failed drive. The drive manufacturer typically performs this failure analysis. As the SMART sensors and algorithm is often built in to some
15 drives, the addition of temperature detectors, pressure detectors, vibration sensors etc, may not be necessary in order to implement an environmental stress protection scheme (ESPS) in accordance with the present invention, although it is to be understood that such monitoring sensors may be required to be added into the drive in addition to the ESPS routines described below in order to fully implement an embodiment of the present invention described below.

For purposes of the following discussion, it is assumed that environmental and
20 operational parameter sensors are provided in the hardware of the disc drive. Such environmental sensors may include monitors that directly monitor the parameter of interest such as temperature, or may sense a parameter that is related to the parameter of interest, such as signal amplitude, current or voltage level that is proportional to the parameter of interest.
25 The signals from these sensors are fed to appropriate comparators that compare the signals to range limits, such as upper and lower temperature limits for normal data storage device operation. The comparator then provides an output signal to the ESPS if the measured parameter falls outside the predetermined range. For example, the recommended operational temperature range for a disc drive may be 0-60 degrees centigrade. A thermal comparator
30 would then provide an output signal, or set a flag bit, if temperature either exceeds 60 degrees centigrade or falls below 0 degrees centigrade.

An ESPS in accordance with an embodiment of the present invention basically includes an environmental stress monitoring module and a write integrity check algorithm module. The stress-monitoring module may simply tap into existing SMART data outputs already provided in the firmware. The WICA module constitutes a software routine that is invoked whenever
5 the monitoring module indicates a stress condition.

An operational flow block diagram of an ESPS **200** in accordance with an embodiment of the present invention is shown in FIG. **3**. This ESPS **200** is designed to be operational whenever the disc drive **100** is powered on. The ESPS **200** routine begins in operation **202** where, upon drive initial startup, operations **204** and **206** are continuously sequentially
10 performed. Specifically, from start operation **202**, control transfers to operation **204**. In operation **204**, each of the predetermined operational parameters is checked for their environmental attribute values. These parameters may simply be a subset of the parameters monitored in an existing SMART scheme in the firmware of the drive or may be specifically provided in the ESPS **200**. For example, an operational temperature comparator, a pressure
15 comparator, a vibration comparator, may be checked. Other parameters may also be checked that have, either directly or by inference, an environmental component. Control then transfers to query operation **206**.

In operation **206**, the query is made whether the environmental comparator output attributes are all as expected, e.g., zero, signifying that operation is within expected optimal
20 range. If the output attributes are as expected, control transfers back to operation **204**, and the check is performed again. This continual return and recheck of the environmental attribute values continues indefinitely during drive operation until an out of range condition is detected in operation **206**. Once such an out of range condition is detected, control transfers to operation **208**.

25 In operation **208**, a write integrity check algorithm (WICA) is instituted for each and every write command received from the host so long as there is an out of spec condition identified in operation **206**. The WICA is discussed below with reference to FIG. **4**.

Control then transfers to operation **210**. Here, if the write command received was executed successfully, control transfers back to operation **204** and the above check repeats. If,
30 on the other hand, the write was unsuccessful, control transfers to operation **212** where a write error is signaled to the host computer. Control then returns in end operation **214**.

In summary, so long as there is an environmental stress condition present as determined in operations **204** and **206**, every write command will be write verified. If any write errors are detected, processing will stop and a write error will be sent to the host.

Referring now to the WICA block diagram **220** shown in FIG. **4**, if an environmental stress condition has been identified, the WICA begins in operation **222**. First, a write command to write data "X" is received from the host. The data "X" to be written is assigned a logical block address (LBA) and the number of sectors required for storage of the data, Y, is determined. Control then transfers to operation **226**.

In operation **226**, the data is written to X LBA with Y sector count. Control then transfers to operation **228** where the written data is immediately read back. Control then transfers to query operation **230**. Here the written data is compared to the read back data. If the read back data is identical to the written data, control transfers to end operation **232** which transfers overall control back to operation **204** described above, as the write integrity check was successful and the written data has been confirmed. On the other hand, if the read back data is different from the written data, control transfers to operation **231** to write the same data back to the same location. Control will be transferred to operation **233**, which is similar to the operation **228**. Control then transfers to query operation **235** and thus the written data is compared to the read back data. If successfully read back, control transfers to end operation **232** and subsequently back to operation **204** mentioned as this write integrity check has been successful. On the other hand, if the read back data is different from the written data, control transfers to operation **234** for reallocation of the written data.

In operation **234**, a check is made whether there exists a spare sector for reassignment of the written data in operation **226**. Control then transfers to query operation **236**. If yes, there is sufficient spare LBA(s) then control transfers to operation **240**. Operation **240** reassigns LBA X to the allocated spare LBA or LBAs, and writes the data to the spare sectors on the disc. Control then transfers to operation **242** where the data written again, to the spare sectors, is read back and compared with the originally written data. If the read back data for the write command received indicates that the data written was successful, control transfers to operation **244**.

In operation **244**, a success flag is set and control passes back to operation **210** as a successful write, and overall control passes back to operation **226** for the next write instruction in the write integrity check **220**. However, if the query in operation **242** is no, the read back

and written data are not identical, control passes to operation **238**, where a write error is indicated and the routine ends in operation **232**. In this way, the WICA verifies each write command that issues from the host so long as an out of environmental specification condition exists.

5 This arrangement ensures that, during normal operating conditions, unnecessary performance delays are minimized while still providing a measure of reliability for the user in the event of an adverse environmental condition being experienced by the drive. Finally, an additional feature may also be incorporated into the operation **206**. Operation **206** may also include an indication provided to the host to alert the user that an out of specification condition
10 has been sensed and that subsequent operation will be at a reduced performance level until the out of specification condition is corrected.

 It will be clear that the present invention is well adapted to attain the ends and advantages mentioned as well as those inherent therein. While a presently preferred embodiment has been described for purposes of this disclosure, various changes and
15 modifications may be made which are well within the scope of the present invention. For example, the write integrity check **220** may simply be directly incorporated into the routine **200** rather than provided as separate routines as described above. The WICA may be performed on a predetermined batch of writes rather than on each individual write, as it occurs, once an out of spec environmental stress condition is sensed. Also, within the WICA, after the
20 reassignment flag is set as successful in operation **244**, control could return directly to end operation **232** and thus back to the ESPS operation **204**. Numerous other changes may be made which will readily suggest themselves to those skilled in the art and which are encompassed in the spirit of the invention disclosed and as defined in the appended claims.

CLAIMS

What is claimed is:

- 5 1. A system for ensuring written data integrity in a data storage device operating outside of predefined normal operating conditions comprising:
 an environmental stress monitoring module operable to monitor at least two operational parameters each indicative of an environmental stress associated with the data storage device and identify data storage device operation in an environmental stress condition when at least
10 one of the operational parameters falls above or below a predetermined value; and
 a write integrity check module for verifying written data integrity during data storage device operation in the environmental stress condition.
- 15 2. The system according to claim 1 wherein the environmental stress monitoring module has a temperature detector that senses device operational temperature and identifies a stress condition as an operational temperature outside a predetermined range of temperatures, and wherein the environmental stress monitoring module has an additional detector that senses an additional parameter selected from the group consisting of atmospheric pressure, vibration, and track failure statistics, and identifies a stress condition when the additional parameter falls
20 outside a preselected range.
3. The system according to claim 1 wherein the write integrity check module invokes a software routine verifying each write operation following identification of an environmental stress condition by reading back each data written to the data storage device and
25 comparing the read back data with the data written.
4. The system according to claim 3 wherein the monitoring module has a temperature detector that senses device operational temperature and identifies a stress condition as an operational temperature outside a predetermined range of temperatures.
- 30 5. The system according to claim 1, wherein once the environmental stress monitoring module identifies that the data storage device operation is operating in the environmental stress condition, the system is operable to indicate to a user that subsequent operation of the data storage device will be at a reduced performance level.

6. The system according to claim 1 wherein the at least two operational parameters are selected from a group consisting of temperature, atmospheric pressure, vibration, and track failure statistics.

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7. The system of according to claim 1 wherein the at least two operational parameters are temperature and vibration.

8. A method for verifying data integrity in a data storage device comprising:
10 monitoring at least two parameters of the data storage device selected from the group consisting of temperature, pressure, vibration, and track failures;
identifying an environmental stress condition occurring during data storage device operation when at least one of the parameters falls above or below a preselected value;
verifying data written to the data storage device after the environmental stress condition
15 is identified; and
signaling a write error if the data written to the data storage device when verification of the data written is not confirmed.

9. The method according to claim 8 wherein the identifying comprises:
20 monitoring device operating temperature;
signaling a stress condition if the monitored operating temperature is outside a predetermined range of temperatures;
monitoring device vibration; and
signaling a stress condition if the monitored device vibration is above or below a
25 predetermined value.

10. The method according to claim 8 wherein the verifying comprises:
writing data to a logical block address;
reading back the data written to the logical block address; and
30 comparing the data read back with the written data.

11. The method according to claim 10 further comprising:
determining a spare location for the written data if the data read back is not identical to
the written data;
35 writing the written data to the spare location;
reading back the data written to the spare location; and

comparing the data read back from the spare location to the data written to the spare location.

5 12. The method according to claim 11 further comprising:
indicating a write error if the data read back from the spare location is not identical to
the data written to the spare location.

10 13. The method according to claim 8, further comprising detecting when the data
storage device is operating in the environmental stress condition and indicating to a user that
subsequent operation of the data storage device will be at a reduced performance level.

15 14. The method according to claim 8 wherein the identifying comprises:
monitoring a pressure and a temperature associated with the data storage device and
signaling a stress condition if the monitored pressure or temperature is above or below a
predetermined value.

20 15. The method according to claim 8, wherein the identifying comprises
monitoring a temperature and a track failures statistic associated with the data storage device
and signaling a stress condition if the monitored temperature or track failures statistic is above
or below a predetermined value.

25 16. The method according to claim 8, wherein the monitoring of the at least two
parameters of the data storage device comprises communicating with a self-monitoring,
analysis and reporting tool of the data storage device to determine the at least two parameters.