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Disk Drives and Methods for Cleaning Disk Drives

Field of the invention

The present invention relates to a disk drive such as a magnetic hard disk drive, and to methods for cleaning disk drives.

5 Background of the invention

Thermal asperity (TA) is one of most critical issues for MR/GMR (magnetic resistive/giant magnetic resistive) head disk drives. TA can be generally classified into two categories: existing and new. "Existing" TA is the result of disk defects created when the disk was manufactured. This TA has little effect
10 on user data integrity except reduce the capacity of the drive. By contrast, "new" TA is very challenging. It occurs after a drive has passed all tests and has been shipped to a customer. "New" TA is usually the result of loose particles from components or the operation environment. The loose particles may fall onto and adhere to a surface of the disk. During the read/write
15 operation, the air bearing surface of a slider carrying the read/write head over the disk surface can hit the particles and cause TA. Thus, "new" TA can occur in an area at which data is already stored, potentially with catastrophic results.

This is illustrated in Fig. 1, which is a cross-sectional view of a disk drive in which the illustrated portion of the disk 1 (shown in edge view) is moving at
20 velocity v during a read/write operation, and a floating slider 3 is supported by a suspension 5 over a data storage surface of the disk 1. During the read/write operation, the air bearing surface (ABS) 7 of the slider 3 hits particles 9 (each of which is drawn with an arrow to indicate its velocity).

As the flying height of current typical sliders is about 30 nm and lubricant is
25 present on the disk surface, when large amounts of micro-contaminant particles 9 are present in the drive, the smaller contamination particles can easily build up at the trailing end of the air bearing surface of the slider 3 to



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form an agglomerate 11. The larger particles may be pressed, deformed, embedded, disintegrated or sheared on the slider or disk surface. Any agglomerate 11 on the slider close to read/write element can degrade read/write performance. Moreover, the formation of these agglomerates on the slider can cause a loss of the air bearing and lead to a head crash.

Ideally the components of a hard disk drive, and the manufacturing process which produced them, are controlled to be free of particles and other contamination. Moreover, sealed cases and filtering systems are employed to obtain reliably clean disk drives. Generally, the spin of the disk surface causes a repulsive force (due to drag forces and centrifugal force) which tosses loose particles off the disk surface, and a filter provided in the system captures the removed particles. In this way, most of aerosol, out-gassing materials, particles and other contamination inside a hard disk drive can be removed from the head-disk interface. Furthermore, special ABS designs have also been proposed for preventing particles from entering the head/disk interface.

However, the repulsive force needs to overcome adhesion forces which adhere particles to the disk surface. In cases when such adhesion forces are large, it is difficult to remove the attached particles by using the approach described above, so the attached particles cannot be easily removed from the disk by spinning the disk before the read-write operation. Eventually, particles in the head/disk interface may cause a head crash, as widely reported in the literature.

Furthermore, compared with disk drives containing non-removable disks, disk drives for removable disks (here referred to as "removable disk drives") have to undergo more severe usage conditions, since they are inevitably exposed to air from outside the disk drive. Besides the intrinsic contamination of internal components, extrinsic contamination and particles can become

attached to the cartridge surface or directly flow into the system while the cartridge containing the disk is inserted into the disk drive. The level of extrinsic contamination cannot be controlled, but proposals have been made to deal with this issue. These proposals include special material selections, effective sealing, filtering, effective baffling, ABS design, flow organisation, compressed air, nozzles, pumps, brushes, etc. The construction of a known cartridge 13 for a removable disk is shown in Fig. 2, in cross-section (Fig. 2(a)) and in top view (Fig. 2(b)). The cartridge comprises an upper cartridge member 15, a lower cartridge member 17. The members 15, 17 define a space containing a disk 19, and a head access opening ("slot") 21, closed by a sliding door 23.

Note that the above problems are particularly acute in the case of hard disk drives (as opposed to disk drives for floppy disks) since hard disks are less able to flex to accommodate the particles, and thus are more likely to be scratched. While the disks of most hard disk drives are permanently secured within the disk drives, removable hard disk drives are also known.

Summary of the invention

The present invention aims to provide a new and useful methods and systems for cleaning a disk drive system, particularly a disk drive system for removable disks.

In general terms the invention proposes employing an ultrasonic cleaning apparatus within a disk drive, particularly a disk drive for removable hard disks. Ultrasonic cleaning as a technology has been applied in many different devices, though not to our knowledge for cleaning disk cartridges or disk drives. Typically, ultrasonic cleaning generates a wide frequency range of high frequency ultrasonic waves to loosen and remove debris, particles and dust in gas or liquid media

According to a first aspect of this invention, there is provided a disk drive system as defined in claim 1.

- 5 The term "ultrasound" is generally used in this document to mean sound waves of frequency above 20kHz. Preferably, the ultrasound used in the present invention is (at least substantially) in the range 20kHz to 50kHz.

The ultrasonic radiator may be attached to the inner surface of the drive case and is driven electronically to generate ultrasonic waves which are transmitted through
10 the disk chamber to effect cleaning, for example in focused beams.

The waves may be projected towards the cartridge insertion door, to form a repelling/baffling ultrasonic flow which prevents external particles from entering the drive during cartridge insertion operation. Alternatively or additionally, the ultrasonic waves can also be projected towards an inserted cartridge and/or its
15 head access window and/or the disk and/or the slider. In any case, the ultrasonic beam impinges upon the targeted surface and loosens debris/dust there. The loosened particles can be removed from the targeted region by the ultrasonic flow or airflow caused by spinning the disk.

After removal from the targeted surfaces the particles flow with the airflow streamlines and may be finally captured by an internal filter of the disk drive.

The ultrasonic radiator of the present invention may be a piezoelectric plate, a electromagnetic diaphragm, a magnetostrictive device, a pneumatic device or
5 a mechanical device (e.g. a plate moved by a separate electronically driven actuator).

Brief Description of the Drawings

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

10 Fig. 1 illustrates how a flying slider can pick-up contamination;

Fig. 2, which is composed of Figs 2(a) and 2(b), illustrates a known cartridge system;

Fig. 3 shows a circuit equivalent to a typical piezoelectric ultrasonic radiator system;

15 Fig. 4, which is composed of Figs. 4(a) and 4(b), shows a particle attached to a surface, and a model of interaction between the particle and an ultrasonic wave;

Fig. 5 shows a first embodiment of a disk drive system according to the invention;

20 Fig. 6 shows a second embodiment of a disk drive system according to the invention;

Fig. 7 shows a third embodiment of a disk drive system according to the invention;

Fig. 8 shows a fourth embodiment of a disk drive system according to the invention; and

Fig. 9 shows a fifth embodiment of a disk drive system according to the invention.

5 Detailed Description of the embodiments

Firstly, we will explain the principles of an ultrasonic cleaning process, such as that used in the present invention. Consider a simple piezoelectric radiator comprising a piezoelectric plate (or other radiating surface) driven by an electrical circuit. The plate deflects dynamically when it is subjected to an
 10 electric field, and the high frequency motions of the plate leads to vibration of a liquid or fluid medium. Supposing that the vibration amplitude is V_0 with frequency ω , the surface area of the plate is S and the characteristic acoustic impedance is $\rho_0 c_0$. In this case, the velocity is $V = V_0 \sin \omega t$, the resultant acoustic pressure is $p = V_0 \rho_0 c_0 \sin \omega t$, the acoustic intensity is $I = \frac{1}{T} \int_0^T p V dt$
 15 where $T = 2\pi / \omega$, and the radiated acoustic power is $P_{out} = \int_0^S I ds$.

This kind of acoustic-mechanical-electrical coupling system is usually analysed by considering an equivalent circuit in which the electrically driven mechanical radiator system is replaced by an equivalent electrically driven circuit. The equivalent circuit of the system described above is shown in Fig.
 20 3. It comprises a resistor R_f representing internal strain losses of the radiator, a resistor R_D representing resistance losses in the dielectric, a capacitance C_0 representing the capacitance of the radiator, and a resistance R_R which is equivalent to the radiation resistance relevant to the ultrasonic radiation. R_R is given by $R_R = \rho_0 c_0 S / 4 \alpha^2$, where α is the transformation factor of the radiator
 25 used to convert mechanical impedance to electrical impedances of the

system. The currents i_r , i_1 , i_2 and i_3 in various parts of the circuit are shown in Fig. 3. The acoustic power output of the radiator is $P_{out} = i_3^2 R_R$, the electrical power input is $P_{in} = i_1^2 R_D + i_3^2 (R_f + R_R)$. It can be finally derived that

$$P_{out} = \frac{R_D (\rho_0 c_0 S / 4 \alpha^2) P_{in}}{(R_f + \rho_0 c_0 S / 4 \alpha^2) (R_f + R_D + \rho_0 c_0 S / 4 \alpha^2)} \quad (1)$$

An ultrasonic flow at a proper pressure and intensity level and having a particular spectrum can cause particle activation and motion. The acoustic streaming and aviation can intensify the loosening process. Moreover, depending on the properties of the ultrasonic sound used, the ultrasonic wave may even have many other effects on micro-particles in addition to activation, loosening and removal, such as agglomerate crushing, compressing and compaction.

Many interface forces contribute to the adhesion between a particle and the surface. One of most significant forces is the meniscus force, caused, as illustrated in Fig. 4(a), by absorbed liquid 29 around the interface between a particle 25 and the surface 27.

The forces resisting detachment and removal of the particle 25 from the surface can be approximated respectively by $F_d = 4\pi \mu_s \gamma \cos \theta$ and $F_s = 4\pi r \mu_s \gamma \cos \theta$, where γ is the surface tension of the particle-surface absorbed liquid, r is the particle radius, θ is the effective contact angle between the particle 25 and liquid 29, and μ_s is the coefficient of stiction (also called the "adhesive limit") between the surface 27 and the particle 25. Usually, this kind of force is relatively large compared with the air drag force and centrifugal forces. However, this force is less resistive to a dynamic pulse force than against a steady pull force. If the ultrasonic waves have a wide

high frequency spectrum, which includes the resonant frequency of the particle-surface interface system, the particle 25 is particularly sensitive to the ultrasonic action, so the ultrasonic wave can cause strong micro-vibrations of the particle 25, leading to instability of the particle attachment interface. This effect can remarkably reduce the adhesion force effect, and eventually loosen the particles. Fig. 4(b) is a schematic diagram, illustrating how ultrasonic waves 31 impinge on a mechanical system consisting of a mass m representing the particle 25, attached to the surface 27 by a spring 33 representing the forces described above and having a spring constant k . The resonant frequency of the system is $w = \sqrt{k/m}$.

As shown in Fig. 5, a removable disk drive system which is a first embodiment of the invention comprises an case 35 defining a chamber 37. The disk drive further includes a motor device 39. One side wall of the case 35 includes a flap 41, which when it is in a lowered position closes a cartridge insertion window for admitting a cartridge 43 including a hard disk 45. The disk drive system further includes an ultrasonic cleaning apparatus, which is a pair of ultrasonic radiators 47 attached to the floor and ceiling of the case 35 and skew-oriented towards the cartridge insertion window. The ultrasonic cleaning apparatus is driven by electronics to create high frequency ultrasonic waves. The ultrasonic flow has a reducing pressure gradient from the inner part of the chamber 37 towards the cartridge insert window, and thus it has a repelling/baffling effect on particles 49 outside of the drive. Specifically, it does not allow the penetration of the external particles/contamination into the chamber 37 through the window during the cartridge insertion operation.

As Fig. 6 shows a removable disk drive system which is a second embodiment of the invention. Portions of the disk drive system which are equivalent to those shown in Fig. 5 are given the same reference numerals, but in Fig. 6 the cartridge 43 is shown fully inserted into the disk drive system with the motor device 39 engaging the disk 45. The second embodiment

comprises ultrasonic cleaning apparatus comprising two ultrasonic radiators 51 mounted to the inside of the case 35 and skew-oriented towards the sliding doors 53 of the head access slots 59 (refer to Fig. 2). The ultrasonic radiators 51 are electronically driven to create high frequency waves which have a pressure gradient in the direction parallel to the surface of cartridge 43. These waves activate, loosen, dislocate and remove particle debris 57 away from the sliding doors 53 before the doors are opened to expose the head access slot 59. The particles accumulate at filters 55 in the corners of the cover.

Fig. 7 shows a disk drive system which is a third embodiment of the invention. Parts corresponding to those of Figs. 5 and 6 are given the same reference numerals. The ultrasonic cleaning system comprises radiators 63 which are oriented towards the (lower) surface of the cartridge 43, while radiator 61 is directly engaged with the (upper) cartridge surface by a rotary contact transmitter 65 in contact with the radiator 61 and the cartridge 43. The ultrasonic radiators 61, 63 are driven by electronics to create high frequency waves, and the waves are transmitted to the surface of the cartridge 43 to activate, loosen, dislocate and remove particle/debris.

Fig. 8 shows a disk drive system which is a fourth embodiment of the invention. Parts of the fourth embodiment which correspond to parts of Figs. 5 to 7 are given the same reference numerals. The removable disk drive system comprises ultrasonic cleaning apparatus having ultrasonic radiators 67 attached to the case 35 and oriented towards the regions of the head access slot 73 (see Fig. 2). The ultrasonic cleaning apparatus is driven by electronics to create high frequency waves during the disk spinning operation. When the head sliding doors are opened to expose the head access slot 73, the ultrasonic waves project onto the exposed part of the spinning disk 45 and loosen debris 71 located there. The ultrasonic waves greatly improve the particle spin-off process. The particles are finally captured by filters.

Fig. 9 shows a disk drive system which is a fifth embodiment of the invention. Parts corresponding to those shown in Figs. 5 to 8 are given the same reference numerals. The ultrasonic cleaning apparatus comprises ultrasonic radiators 75 attached to the case 35 and oriented towards respective slider
5 bodies 77 which are supported by respective suspensions 79. The radiators 75 are driven by electronics to create high frequency waves which are projected onto the slider bodies 77 to loosen contamination built-up there and to crush agglomerate 81 on the slider air bearing surface. The cleaning operation is performed during the disk spinning operation, so the loosened
10 debris can be easily spun off the interface. The removed debris 82 can be captured by filters 55.

Although the invention has been explained above in relation to particular embodiments, many variations are possible within the scope of the invention as will be clear to a skilled person. For example, the present concepts can be
15 easily implemented in any kind of disk drive to loosen and remove contamination. In general no revision to the existing disk drive designs is required.

With the application of cheap commercial ultrasonic radiators and integrated electronics, the application of this concept is feasible for mass production. In
20 particular, the present invention may provide a robust and flexible disk drive suitable for use in extremely severe contamination conditions where existing methods are invalid or difficult to implement.

Claims

1. A disk drive system comprising:
 - a case defining a chamber for holding a data storage disk, the disk being removable from the chamber;
 - 5 a motor device for rotating the disk;
 - data transfer means for reading data from and/or writing data to the disk;
 - one or more ultrasonic radiators; and
 - means for electrically driving the ultrasonic radiators to generate ultrasonic waves propagating within the chamber to reduce and/or displace
 - 10 contamination within the chamber.
2. A disk drive system according to claim 1 further comprising a data storage disk located within the chamber and engaged with the motor device.
3. A disk drive system according to claim 2 in which the disk is a magnetic hard disk.
- 15 4. A disk drive system according to claim 2 or claim 3 in which the disk is located within a cartridge within which the disk is arranged to rotate, the cartridge including an opening for the data transfer means to access the disk to read data from and/or write data to the disk.
5. A disk drive system according to claim 4 in which the cartridge is
- 20 insertable into and removable from the chamber, the case including a window for inserting the cartridge into the disk, and at least one of the radiators is positioned to generate ultrasonic waves directed towards the window, whereby the entry of contamination into the chamber while the disk is inserted into the chamber is retarded.

6. A disk drive system according to any of claim 4 or claim 5 in which at least one of the radiators is positioned to generate ultrasonic waves directed towards the surface of the cartridge, whereby contamination is removed from the surface of the cartridge.
- 5 7. A disk drive system according to claim 6 in which one or more transmission elements are provided contacting at least one of the radiators and the surface of the cartridge, whereby ultrasonic waves are transmitted to the cartridge through the transmission elements.
8. A disk drive system according to claim 6 or claim 7 in which at least one
10 of the radiators is positioned to generate ultrasonic waves directed towards the disk access opening, whereby contamination on the cartridge surface at or proximate the disk access opening is removed.
9. A disk drive system according to any preceding claim in which at least one of the radiators is arranged to generate ultrasonic waves directed towards
15 the surface of the disk while the data transfer means is accessing the disk.
10. A disk drive system according to any preceding claim in which the data transfer means includes a magnetic read/write head provided on a slider for movement over the surface of the disk, and at least one of the radiators is arranged to generate ultrasonic waves directed towards the slider while the
20 slider is moving over the surface of the disk.
11. A disk drive system according to any preceding claim in which the radiators are mounted on the case within the chamber.