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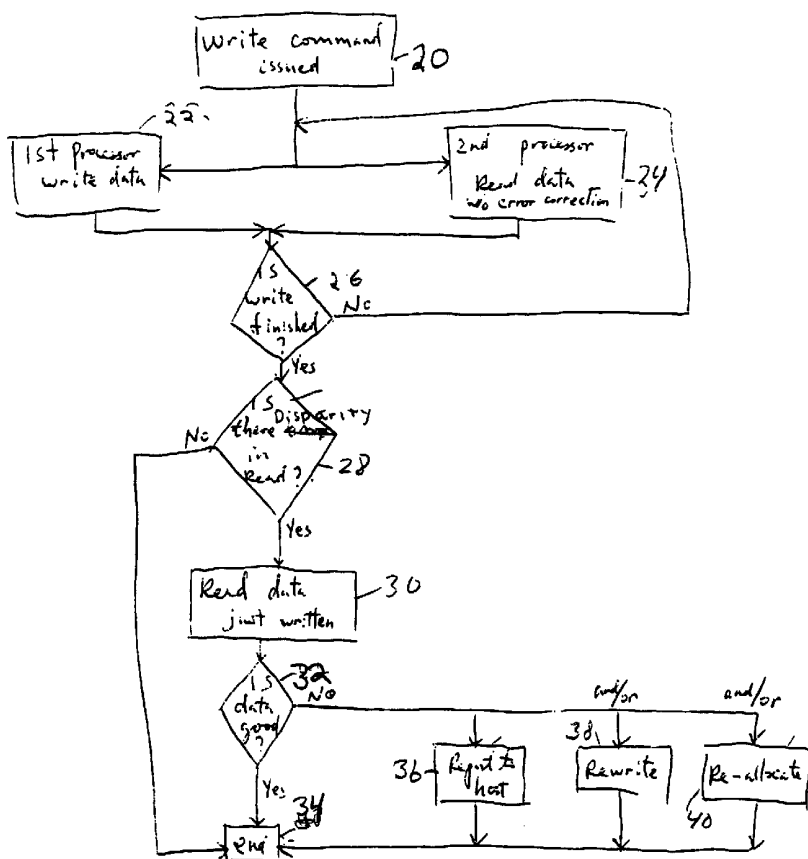
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(54) Title: METHOD FOR DETECTING TRANSIENT WRITE ERRORS IN A DISK DRIVE HAVING A DUAL TRANSDUCER SLIDER



(57) Abstract: In a magnetic or optical disk drive the integrity of data written on a disk is verified by writing data to a portion of the disk, and immediately reading the data from the disk after it has been written. If there is error in reading the data and/or the data read from the disk is substantially different from the data written to the disk an error condition is generated. The error condition may be reporting the error to the host which decides whether to rewrite the data or immediately rewriting the data without further instructions from the host.

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Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations* AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG)
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EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG)

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METHOD FOR DETECTING TRANSIENT WRITE ERRORS IN A DISK DRIVE HAVING A DUAL TRANSDUCER SLIDER

FIELD OF THE INVENTION

This invention relates to disk drives for computer systems. In particular,
5 this invention relates to methods for detecting errors during write operations in disk drives,
especially those caused by transient increases in flying heights.

BACKGROUND OF THE INVENTION

Maximizing the reliability of the data in disk drives, both magnetic and
optical, is a key objective of disk drive designers. Unfortunately, that objective often
10 conflicts with the similarly important need for performance. That is, by increasing the
reliability performance measures, other performance characteristics such as the data
transfer rate, could suffer. For example, when data is written to the disk drive the success
of the write operation, i.e., whether the media accepted the data, is unknown. One sure
way to guarantee the data after each write operation is by re-reading the recorded data after
15 each write operation. However, a technique that requires all data written to be read as well
would severely degrade the performance of the drive. On the other hand, such verification
would ensure high reliability of the data. This verification procedure is referred to as a
“write with verify.” Write with verify takes a long time to perform. It requires that the

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data be written, then the disk is rotated one full revolution, the data is read, and then verified.

U.S. patent 5,588,007, Ma describes a method for detecting transient write errors based on difficulty in reading pre-recorded information on the disk such as servo marks, ID marks and others. It also discusses that in the event of such difficulty, the drive will automatically read the data it just wrote. If errors were encountered during this write process, the drive will either re-write the data or report errors to the host system which will in most cases issue a rewrite operation. However, the pre-recorded information covers only about 20% of the disk space. Therefore, this technique cannot catch all hard errors caused by bad writes. This technique catches about 30% of non-recoverable data errors in one implementation.

In disk drives where (G)MR heads are used, an ID-less format further reduces the effectiveness of the transient error detection method described in U.S. Patent 5,588,007. K.B. Klaassen, J.C.L. van Peppen, "Electronic Abatement of Thermal Interference in (G)MR head Output Signals", IEEE Transactions on Magnetics, Vol. 33, No.5, September 1997 and U.S. Patent 5,650,887 Dovek, et al. describe what is referred to as (G)MR (Giant Magneto Resistance) Technology which is commonly used in heads for hard disk drives. (G)MR heads have been used in rigid disk drives, where a (G)MR read transducer and an inductive write transducer are built into one slider. (G)MR technology is used to increase the density requirement. This increase in linear density possible with (G)MR Technology makes the "phantom write" problem more severe. A "phantom write" is a non-recoverable data error caused by temporary spacing loss during a write. This leads to a greater need for the type of automatic transient error detection method described in U.S. patent 5,588,007.

Similarly in optical recording systems, such as CDRW drives, the only way to verify that data was written correctly is to read it back, taking additional time.

It is an object of the present invention to improve transient error detection to make it more effective in higher density magnetic and optical disk drives.

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Summary of the Invention

In accordance with the present invention, the integrity of data written on a magnetic or optical disk is verified by writing data to a portion of the disk, immediately reading the data from the disk after it has been written, and, if the data read from the disk is substantially different from the data written to the disk, generating an error condition. “Immediately,” as used herein, means within one revolution of the disk.

The present invention recognizes the fact that in recording heads where (G)MR sensors are used there are two transducers, a (G)MR sensor for reading the data and an inductive sensor for writing the data. Furthermore, the two transducers are arranged such that they are in very close proximity of each other and usually line up in the recording track direction. Ideally, the (G)MR read sensor is located towards the trailing edge of the recording head, making it possible to read the data that was just written by the write sensor.

In the case of optical drives, a separate optical read path is provided that can be active simultaneously with writing. Immediately after writing, this optical read path allows verification of the written data. The read path includes appropriate optics and mechanics to place a read spot trailing the write spot by a small amount on the disk. This read spot can be attached to the optical pick up unit (OPU) fine actuator. The read spot can be generated by custom optics such as a hologram from the right laser diode, or it can be generated from a separate low power read laser diode. The reflected light from this read spot is directed to a detector that does not receive the reflected light from the right spot. Thus reading the data occurs immediately after writing the data.

The foregoing objects, features, and advantages of the invention will be better understood from the following more detailed description and appended claims.

25 Short Description of the Drawings

Figure 1 is a plan view of a flexible disk, and a flexure with a read/write transducer:

Figure 2 shows a read/write head slider for use in a magnetic disk drive;

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Figure 3 shows a CD type optical pick up for an optical recording application;

Figure 4 is a flow diagram of the operation of a disk drive in accordance with the present invention;

5 Figure 5 shows the optical write and read paths;

Figure 6 shows an alternate embodiment of optical read and write paths; and

Figure 7 shows reading immediately after writing by a separate read slider/actuator located down track from the write slider /actuator.

10 **Description of the Preferred Embodiment**

Figs. 1 and 2 show a magnetic disk drive with a slider mounted on flexures, such as is shown in U.S. Patent, 5,636,085, Jones, et al. A magnetic read/write head assembly includes a slider 11 with transducers 12 and 13 which read and write data recorded on the flexible magnetic medium 14. Write transducer has a recording gap 15
15 which writes data. The read (verify) sensor 13 is positioned in the direction of movement of media 14 from the recording gap 15.

In accordance with the invention, transducer 12 is used to write data and transducer 13 is used to immediately read the data which has been written.

Transducer 12 is in close proximity to transducer 13 on the same slider.
20 Transducers 12 and 13 are arranged in the direction of the track of data which has been written so that transducer 12 writes data and transducer 13 immediately reads the data which has been written. Transducer 12 is connected to appropriate channel electronics for writing and transducer 13 is connected to error-detection electronics.

Figure 3 shows a CD-optical pick up which can be used in optical recording
25 on the optical disk 15. A recording laser 16 sends laser light to the surface of disk 15 to record data. While writing a beam splitter 17 directs a portion of the return beam into the read sensor 18. Lens 19 and 19a complete the optical path to and from the disk.

Figure 4 is a flow chart depicting the operation of the disk drive in accordance with the present invention. As indicated at 20, a write command is issued. In

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response, data is written to a portion of the disk as indicated at 22. Data is written by a first processor through the write transducer. Data is immediately read through a read transducer by a second processor as indicated at 24 in Figure 4. During this read operation, no extensive error correction is used since it could take more than one revolution in time.

5 When writing is finished, as indicated at 26, a determination is made of whether there is any error during the read back process and/or the data read from the disk is substantially different from the data written to the disk. This step is indicated at 28. If there is disparity in the read, the data is read again as indicated at 30. A disparity is defined as either an error during the read or the data is different from what was written. During this second
10 read process, full error correction scheme will be used. If the data is good as determined at 32, this is the end of the sub-program as indicated at 34. If the data is not good an error condition is generated. This error condition may be reporting the error to the host as indicated at 36 or rewriting the data as indicated at 38, or reallocating the data as indicated at 40. Reallocating is rewriting data at a different location on the disk.

15 Many products on the market today with (G)MR sensors are configured such that the read gap is located towards the leading edge of the slider in reference to the write gap such that the drives have to wait essentially one revolution to read the data just written using the current invention. Substantial performance limitation could result. An alternative approach is to have the read gap read the data that was already on the disk
20 before being overwritten by the write gap. In this approach, the read operation precedes the write operation. Since disk surfaces are certified for defects during the drive and/or cartridge manufacturing process, all available data sectors contain readable data. These data can be either written at the factory or in the field during regular usage. Any error during the read operation would indicate potential spacing loss and an error flag would be
25 generated. Error recovery scheme as described in steps 30 through 40 of previous paragraph would be activated if an error flag is indicated.

It is realized that the present approaches require the use of two separate processors, increasing the cost of the disk drive controller. An alternative method can be used where the read back signal is monitored for negative modulation. Since the presence
30 of negative modulation in the read back signal indicates spacing loss during the write process, an error condition will be set. This alternative approach is more cost effective than

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the method with two microprocessors.

Figures 5 and 6 depict techniques to generate an optical spot closely following the read spot. The read spot must be centered on the same track 40 that is being written. While the read detector can be a separate module from the writing OPU, a better
5 embodiment is to integrate the read spot detector into the OPU. As shown in Figure 5 light from laser 41 passes through diffraction grating 42 and beam splitter 43 and focus lens 44 to a track 40 on the optical disk. A portion of the reflected light is transmitted by beam splitter 43 through collector lens 44 to the multi-beam detector 45.

As shown in Figure 6 light from laser 41 passes through hologram 46 which
10 combines the grating and light collection functions. The reflected light is directed to a read spot detector 47 and a write spot detector 48.

Detection of the reflected light from the read spot can be accomplished using a photodiode, similar to the common photodiodes used in OPUs. Since the write power is much higher than the read power, a method to shield the reflected light from the
15 write spot from reaching the read spot detector is necessary. A variety of techniques are possible for getting a good quality reflected signal on the read spot detector. Some possible techniques include using beam splitters, diffraction gratings, holograms, baffles, and/or customized detectors.

Standard decoding techniques can be used to decode the detected signal.
20 The data received from the read spot can be compared to the data was intended to be written in hardware or software.

As shown in Figure 7 it is also possible to immediately read after write by putting the read transducer on a separate slider/actuator located down track from the slider/actuator having the write transducer. In Figure 7 the write transducer 50 is carried
25 on actuator 51. Read transducer 52, carried by actuator 53 is located down track from actuator 50. The read transducer 52 reads data to verify good writing within one revolution of the data being written.

While a particular embodiment has been shown and described various modifications may be made. All modifications within the true spirit and scope of the
30 invention are covered by the appended claims.

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In the Claims:

1. A method of verifying the integrity of data written on a disk in a disk drive system, comprising the steps of :
writing data to a portion of the disk;
immediately reading said data from said disk after it has been written; and
if there is a disparity in reading the data, generating an error condition.
2. The method recited in claim 1 wherein the step of generating an error condition comprises the further step of re-writing the data to the disk
3. The method recited in claim 1 wherein the step of generating an error condition comprises the further step of reporting an error condition.
4. The method recited in claim 1 wherein the steps of writing and reading are performed by two transducers in close proximity on the same slider.
5. The method recited in claim 4 wherein said writing and reading are performed by transducers arranged in the direction of the track of data which has been written.
6. The method recited in claim 5 wherein one of said transducers writes said data and the other transducer reads said data, said write transducer preceding said read transducer in the direction of said track
7. The method recited in claim 1 wherein said disk is a magnetic recording disk.
8. The method recited in claim 1 wherein said disk is an optical

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recording disk.

9. The method recited in claim 1 wherein said disparity is an error during the read process.

10. The method recited in claim 1 wherein said disparity is that the data read is substantially different from the data written.

11. The method recited in claim 1 wherein said disparity is that negative modulation exists in the read back signal.

12. The method recited in claim 1 wherein the steps of writing and reading are performed by two transducers on two separate sliders arranged along the same track.

13. A method of selectively verifying data written to a disk in a disk drive system, comprising the steps of:

- a) receiving a request to write data to disk;
- b) writing at least one portion of said data to disk;
- c) reading at least one signal arranged on said disk immediately after writing subsequent to said at least one portion of said data such that an error reading said at least one signal indicates that the step of writing said at least one portion of said data may have been erroneous;
- d) comparing said at least one signal to a predetermined value;
- e) if said at least one signal is substantially different from said predetermined value, reading said first portion of said data;
- f) comparing said at least one portion of said data read from the disk to a corresponding at least one portion of said data written to said disk; and
- g) if said at least one portion of said data read from said disk is

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substantially different from said corresponding at least one portion of said data written to said disk generating an error condition.

14. The method recited in claim 13 wherein the step of generating an error condition comprises the further step of re-writing the first data section to disk

15. The method recited in claim 13 wherein the step of generating an error condition comprises the further step of reporting an error condition.

16. The method recited in claim 13 wherein the steps of writing and reading are performed by two transducers in close proximity on the same slider.

17. The method recited in claim 16 wherein said transducers are arranged in the direction of the track of data which has been written.

18. The method recited in claim 17 wherein one of said transducers writes said data and the other transducer reads said data, said write transducer preceding said read transducer in the direction of said track

19. A method of verifying data written to a disk in a disk drive system, comprising the steps of:

- a) receiving a request to write data to disk;
- b) reading at least one portion of existing data at the site to be written;
immediately writing the data to the disk;
generating an error condition if there is error in reading the existing

data.

20. The method recited in claim 19 wherein the step of generating an error condition comprises the further step of reading the data just written.

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21. The method recited in claim 19 wherein the step of generating an error condition comprises the further step of re-writing the data section to disk

22. The method recited in claim 19 wherein the step of generating an error condition comprises the further step of reporting an error condition.

23. The method recited in claim 19 wherein the steps of writing and reading are performed by two transducers in close proximity on the same slider.

24. The method recited in claim 23 wherein said transducers are arranged in the direction of the track of data which has been written.

25. The method recited in claim 24 wherein one of said transducers read existing data and the other transducer write the data to be written, said read transducer preceding said write transducer in the direction of said track

26. The method recited in claim 19 wherein said error in reading is that negative modulation exists in the read signal.

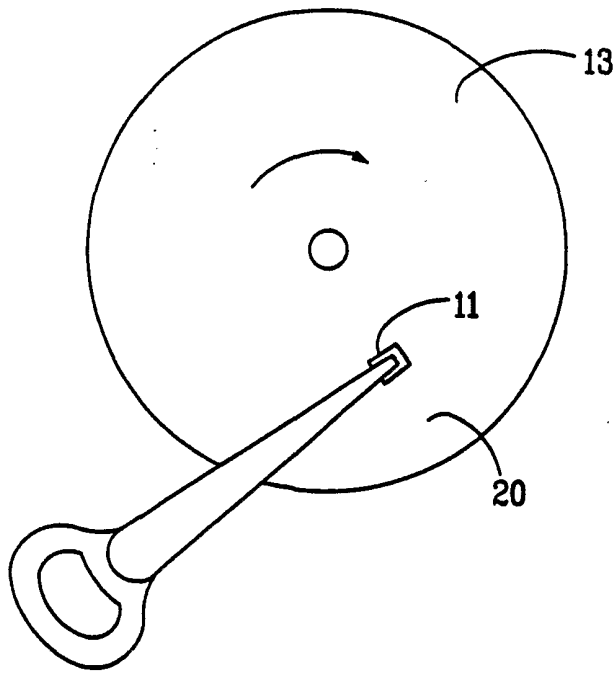


FIG. 1

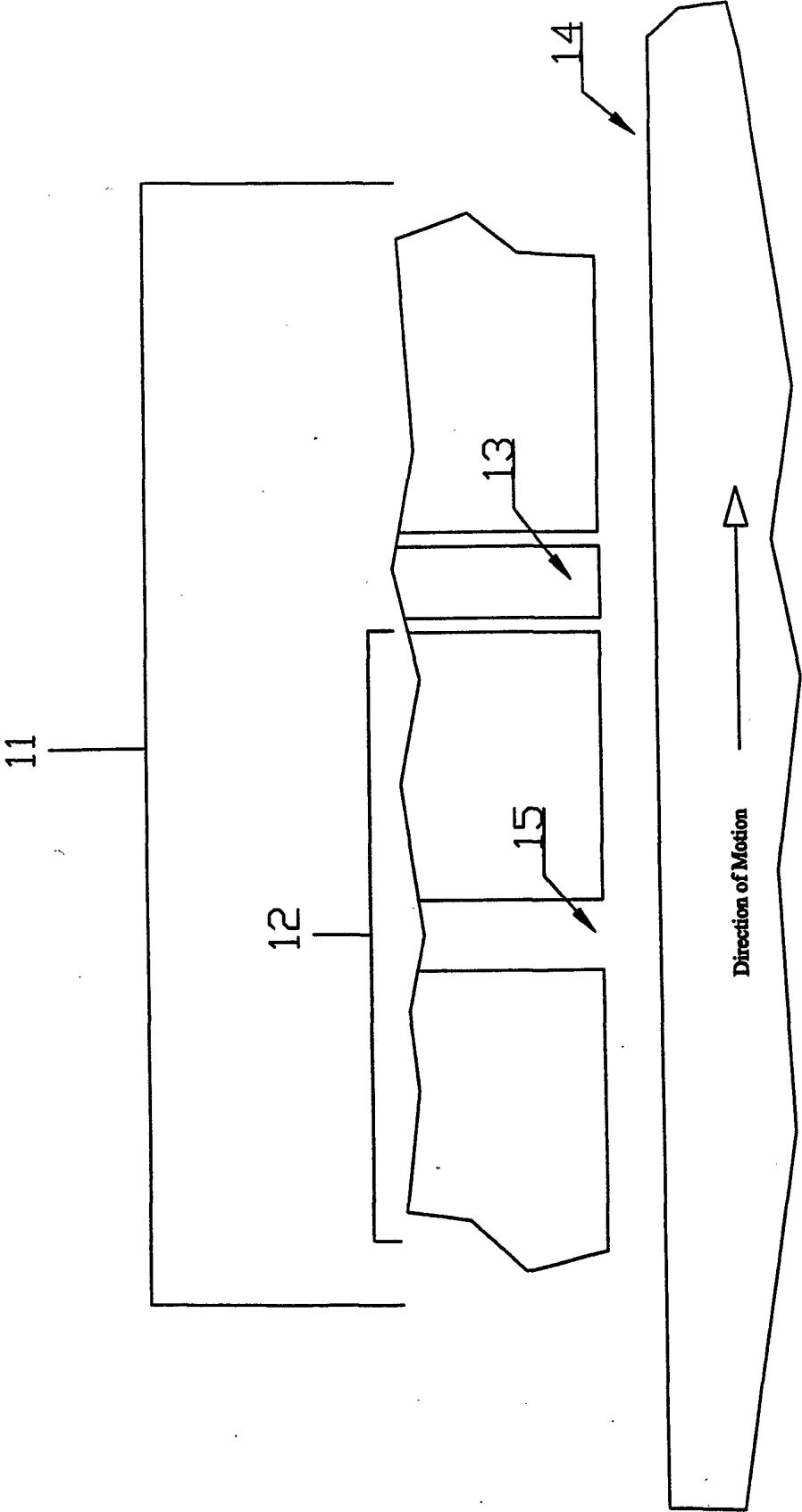
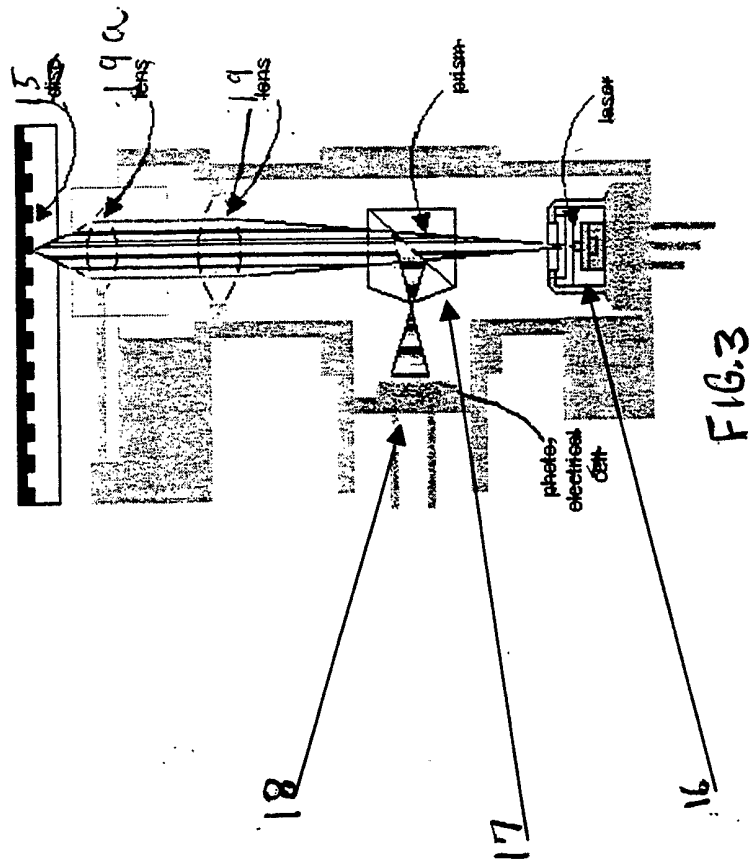


Fig. 1



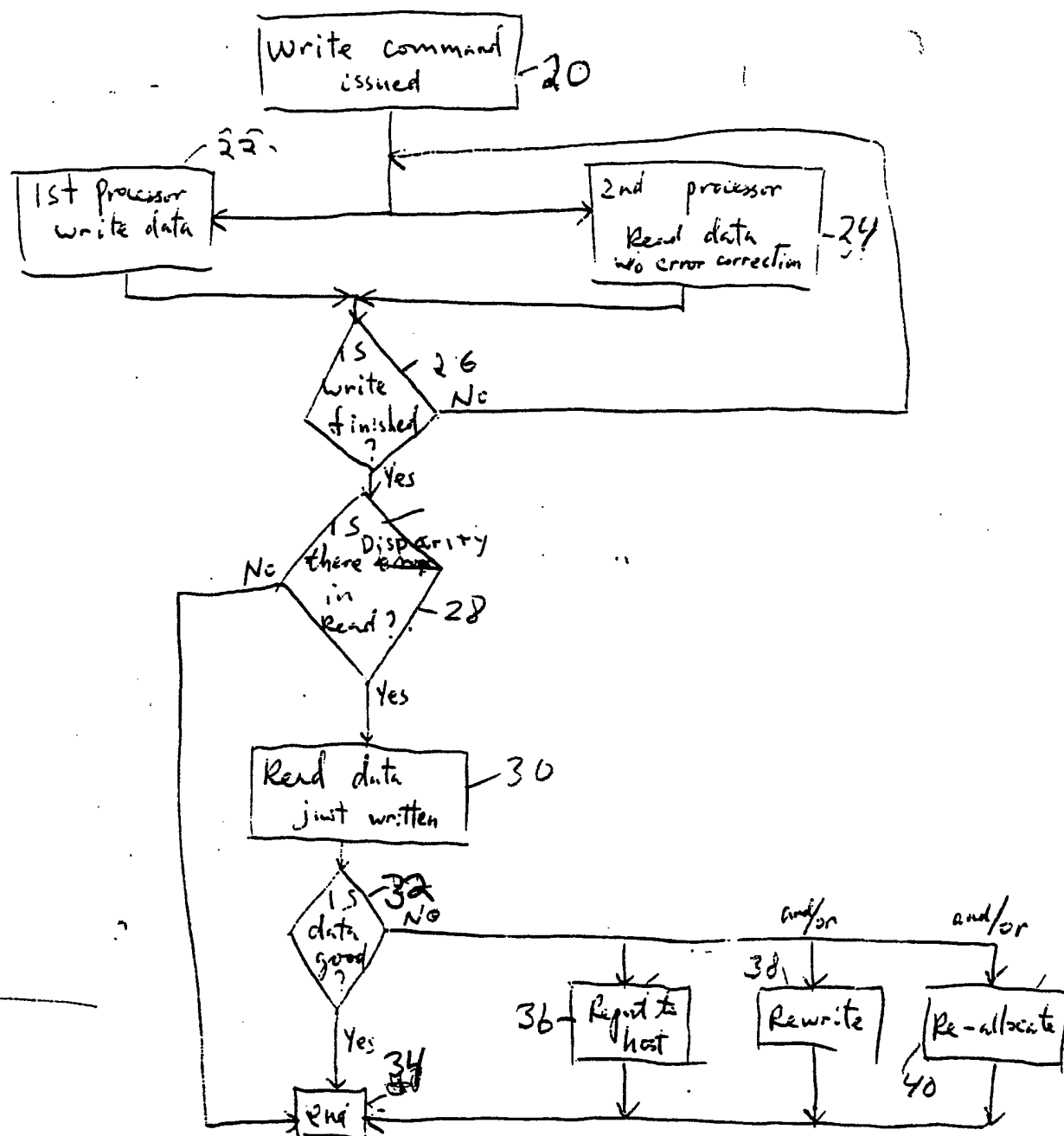
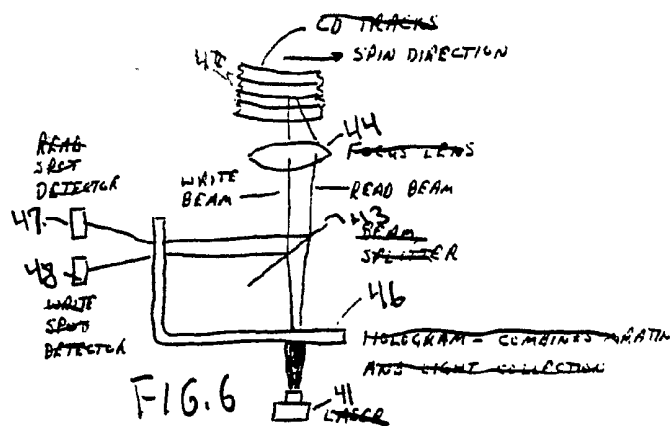
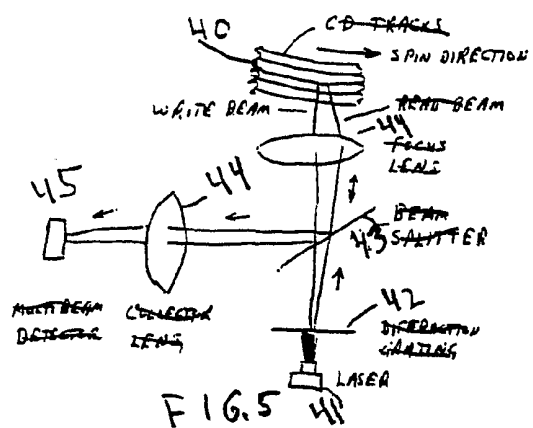


FIG. 4



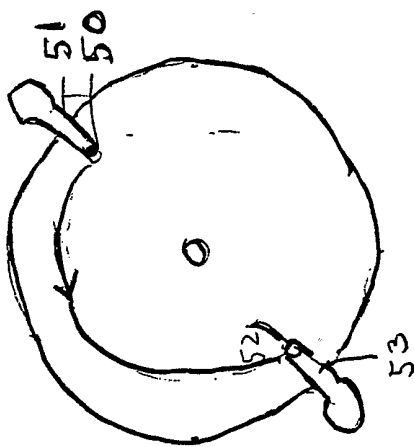


FIG. 7

INTERNATIONAL SEARCH REPORT

International Application No

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A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G11B20/18 G11B27/36 G11B19/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G11B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 893 207 A (MAURY CHRISTIAN ET AL) 9 January 1990 (1990-01-09)	1-7, 9, 10
A	figures 1A, 1B, 6A, 6B	16-24
Y	column 2, line 20 - line 23	13-15
	column 3, line 4 - line 68	
	column 6, line 60 - column 7, line 31	

Y	US 5 588 007 A (MA YIPING) 24 December 1996 (1996-12-24)	13-15
	cited in the application	
A	abstract; figure 6	19-22
	column 1, line 20 - line 61	
	column 3, line 40 - column 4, line 34	
	column 5, line 1 - line 34	

	-/--	

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

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- *A* document defining the general state of the art which is not considered to be of particular relevance
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Date of the actual completion of the international search

1 October 2001

Date of mailing of the international search report

16/10/2001

Name and mailing address of the ISA

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/41266

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
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X	EP 0 404 247 A (PHILIPS NV) 27 December 1990 (1990-12-27) abstract column 1, line 29 -column 2, line 20 ---	1,5,6, 8-10
Y	EP 0 889 474 A (THOMSON BRANDT GMBH) 7 January 1999 (1999-01-07) column 2, line 32 -column 3, line 19 claims 1,4 ---	1-3,7,9, 10,13-15
P,Y	WO 01 27924 A (IOMEGA CORP) 19 April 2001 (2001-04-19) abstract column 2, line 16 -column 3, line 21 column 6, line 10 -column 7, line 6 column 8, line 4 -column 10, line 28 column 12, line 7 - line 12 figures 6,7 ---	1-3,7,9, 10, 13-15, 19-22
Y	US 4 494 226 A (HAZEL ROBERT L ET AL) 15 January 1985 (1985-01-15) column 8, line 51 -column 9, line 8 ---	19-22
A	EP 0 474 428 A (IBM) 11 March 1992 (1992-03-11) page 11, line 1 - line 26 page 11, line 39 -page 14, line 46 page 15, line 17 -page 16, line 11 figures 10,11 --- -/--	1,2,8, 13,14

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>ANONYMOUS: "Simulation of Magnetic Disk Defects by Off-Track Writing and Reading"</p> <p>IBM TECHNICAL DISCLOSURE BULLETIN,</p> <p>vol. 30, no. 2, 1 July 1987 (1987-07-01),</p> <p>pages 649-651, XP002178909</p> <p>New York, US</p> <p>the whole document</p> <p>-----</p>	<p>1,7,11,</p> <p>19,26</p>

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