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HITACHI GLOBAL STORAGE TECHNOLOGIES NETHERLANDS B.V.

UNITED STATES DISTRICT COURT

NORTHERN DISTRICT OF CALIFORNIA

HITACHI GLOBAL STORAGE TECHNOLOGIES NETHERLANDS, B.V.

Plaintiff,

v.

GS MAGIC, INC.; GS MAGICSTOR, INC.; and RIOSPRING, INC.

Defendants.

CASE NO. C04 05460 EDL

COMPLAINT FOR PATENT INFRINGEMENT

DEMAND FOR JURY TRIAL

Plaintiff Hitachi Global Storage Technologies Netherlands B.V. ("HGST-BV") brings this action against GS Magic, Inc.; GS Magicstor, Inc.; and Riospring, Inc. (collectively "Defendants") alleging that Defendants have infringed and are infringing its patents on personal knowledge as to its own activities and on information and belief as to the activities of others, as follows:

McDermott Will & Emery LLP
Attorneys At Law
Palo Alto

PARTIES

1. Plaintiff Hitachi Global Storage Technologies Netherlands B.V. is a corporation incorporated under the laws of The Netherlands having offices at Locatellikade 1, Parnassustoren 1076 AZ Amsterdam, The Netherlands.

2. Upon information and belief, defendant GS Magic, Inc. is a corporation incorporated under the laws of the People's Republic of China having offices at 30F Fuzhong International Plaza, 126 Xinhua Road Guiyang, Guizhou, 550002 P. R. China and 1490 McCandless Drive, Milpitas, California 95035 USA.

3. Upon information and belief, defendant GS Magicstor, Inc. is a corporation incorporated under the laws of the People's Republic of China having offices at No. 1 Duxin Road, Dulaying, Guiyang, Guizhou, 550017 P. R. China and 1490 McCandless Drive, Milpitas, California 95035 USA.

4. Upon information and belief, defendant Riospring, Inc. is a corporation incorporated under the laws of the State of California with offices at 1490 McCandless Drive, Milpitas, California, 95035.

JURISDICTION AND VENUE

5. This is a civil action for patent infringement arising under the patent laws of the United States, 35 U.S.C. § 271 *et seq*.

6. This Court has original jurisdiction over this action under 28 U.S.C. §§ 1331 and 1338(a).

7. Personal jurisdiction and venue in this District are proper under 28 U.S.C. §§ 1391(b), (c) and (d) and 1400(b), in that Defendants have committed acts of infringement in this judicial district, a substantial part of the events giving rise to Plaintiff's claims occurred in this judicial district, and one or more defendants reside in this judicial district.

OPERATIVE FACTS

8. On May 11, 1993, the United States Patent & Trademark Office ("USPTO") duly and properly issued United States Patent No. 5,210,660 ("'660") entitled Sectored Servo

Independent Of Data Architecture to inventor Steven R. Hetzler. A copy of the '660 patent is attached as Exhibit 1. HGST-BV is the owner of the '660 patent.

9. On August 8, 1995, the USPTO duly and properly issued United States Patent No. 5,440,474 ("'474") entitled Magnetic Recording Disk With Equally-Spaced Servo Sectors Extending Across Multiple Data Bands to inventor Steven R. Hetzler. A copy of the '474 patent is attached as Exhibit 2. HGST-BV is the owner of the '474 patent.

10. On May 25, 1997, the USPTO duly and properly issued United States Patent No. 5,615,190 ("'190") entitled Fixed-Block Architecture Embedded Servo Disk Drive Without Data Identification (ID) Regions to inventors John S. Best and Steven R. Hetzler. A copy of the '190 patent is attached as Exhibit 3. HGST-BV is the owner of the '190 patent.

11. On March 19, 1996, the USPTO duly and properly issued United States Patent No. 5,500,848 ("'848") entitled Sector Servo Data Recording Disk Having Data Regions Without Identification (ID) Fields to inventors John S. Best and Steven R. Hetzler. A copy of the '848 patent is attached as Exhibit 4. HGST-BV is the owner of the '848 patent.

12. Upon information and belief, GS Magic, Inc.'s activities include the development manufacture, importation, use, or offer for sale of hard disk drives ("HDDs"), including but not limited to one inch form factor HDDs, an example of which is the GS Magicstor 2.2GB GS1022C.

13. Upon information and belief, GS Magicstor, Inc.'s activities include the development, manufacture, importation, use, or offer for sale of HDDs, including but not limited to one inch form factor HDDs, an example of which is the GS Magicstor 2.2GB GS1022C.

14. Upon information and belief, Riospring, Inc.'s activities include the development, use and/or importation of HDDs, including but not limited to one inch form factor HDDs such as the GS Magicstor 2.2GB GS1022C.

15. Upon information and belief, Defendants have and continue to make, use, sell, offer to sell, and/or import into the United States HDDs, including but not limited to one inch form factor HDDs, an example of which is the GS Magicstor 2.2GB GS1022C, that practice one or more claims of the '660, '474, '190, and the '848 patents (collectively the "Patents-in-Suit").

16. Upon information and belief, Defendants have infringed, and continue to infringe, the Patents-in-Suit by making, using, selling, offering to sell, and/or importing into the United States HDDs that practice the Patents-in-Suit, including but not limited to one inch form factor HDDs, an example of which is the GS Magicstor 2.2GB GS1022C.

17. Upon information and belief, Defendants GS Magic Inc., GS Magicstor, Inc., and Riospring, Inc. continue to infringe despite their knowledge of the patents at issue.

18. Upon information and belief, Defendants GS Magic Inc., GS Magicstor, Inc., and Riospring, Inc. induce infringement by actively inducing distributors, retailers, and/or end users to infringe the patents at issue in the United States. For example, one such distributor is Wintec Industries, Inc. whose activities include the importation, offer for sale, and/or sale of HDDs supplied by GS Magic, Inc. and/or GS Magicstor, Inc., including but not limited to the GS Magicstor 2.2GB GS1022C.

19. Upon information and belief, Defendants GS Magic Inc. and GS Magicstor, Inc. contributorily infringe the patents at issue by offering to sell, selling, and/or importing into the United States the previously identified HDDs knowing that they include and/or constitute material components that are not suitable for substantial noninfringing use.

McDermott Will & Emery LLP
Attorneys At Law
Palo Alto

<u>COUNT ONE: INFRINGEMENT OF THE '660 PATENT</u>

20. HGST-BV incorporates by reference paragraphs 1-19 of this Complaint as though fully and completely set forth herein.

21. Defendants have infringed and continue to infringe at least one claim of the '660 patent, either directly or indirectly through acts of contributory infringement or inducement of infringement, by making, using, selling, offering for sale, or importing into the United States HDDs, including but not limited to one inch form factor HDDs, such as GS Magicstor's 2.2GB GS1022C, in violation of 35 U.S.C. § 271 *et seq.*

22. Defendants will continue to infringe the '660 patent unless enjoined by this Court.

23. HGST-BV has suffered damages as a result of Defendants infringement of the '660 patent and will continue to suffer damages in the future unless preliminarily and permanently enjoined from infringing the same.

24. HGST-BV is informed and believes, and thereon alleges, that Defendants infringement of the '660 patent has been and continues to be willful.

COUNT TWO: INFRINGEMENT OF THE '474 PATENT

25. HGST-BV incorporates by reference paragraphs 1-24 of this Complaint as though fully and completely set forth herein.

26. Defendants have infringed and continue to infringe at least one claim of the '474 patent, either directly or indirectly through acts of contributory infringement or inducement of infringement, by making, using, selling, offering for sale, or importing into the United States HDDs, including but not limited to one inch form factor HDDs, such as GS Magicstor's 2.2GB GS1022C, in violation of 35 U.S.C. § 271 *et seq.*

27. Defendants will continue to infringe the '474 patent unless enjoined by this Court.

28. HGST-BV has suffered damages as a result of Defendants infringement of the '474 patent and will continue to suffer damages in the future unless preliminarily and permanently enjoined from infringing the same.

29. HGST-BV is informed and believes, and thereon alleges, that Defendants infringement of the '474 patent has been and continues to be willful.

COUNT THREE: INFRINGEMENT OF THE '190 PATENT

30. HGST-BV incorporates by reference paragraphs 1-29 of this Complaint as though fully and completely set forth herein.

31. Defendants have infringed and continue to infringe at least one claim of the '190 patent, either directly or indirectly through acts of contributory infringement or inducement of infringement, by making, using, selling, offering for sale, or importing into the United States HDDs, including but not limited to one inch form factor HDDs, such as GS Magicstor's 2.2GB GS1022C, in violation of 35 U.S.C. § 271 *et seq.*

32. Defendants will continue to infringe the '190 patent unless enjoined by this Court.

33. HGST-BV has suffered damages as a result of Defendants infringement of the '190 patent and will continue to suffer damages in the future unless preliminarily and permanently enjoined from infringing the same.

34. HGST-BV is informed and believes, and thereon alleges, that Defendants infringement of the '190 patent has been and continues to be willful.

COUNT FOUR: INFRINGEMENT OF THE '848 PATENT

35. HGST-BV incorporates by reference paragraphs 1-34 of this Complaint as though fully and completely set forth herein.

36. Defendants have infringed and continue to infringe at least one claim of the '848 patent, either directly or indirectly through acts of contributory infringement or inducement of infringement, by making, using, selling, offering for sale, or importing into the United States HDDs, including but not limited to one inch form factor HDDs, such as GS Magicstor's 2.2GB GS1022C, in violation of 35 U.S.C. § 271 *et seq.*

37. Defendants will continue to infringe the '848 patent unless enjoined by this Court.

38. HGST-BV has suffered damages as a result of Defendants infringement of the '848 patent and will continue to suffer damages in the future unless preliminarily and permanently enjoined from infringing the same.

39. HGST-BV is informed and believes, and thereon alleges, that Defendants infringement of the '848 patent has been and continues to be willful.

PRAYER FOR RELIEF

WHEREFORE, Plaintiff HGST-BV respectfully requests the Court to grant it the following relief:

a) judgment against Defendants as to infringement of the Patents-in-Suit;

b) a permanent injunction precluding Defendants, their directors, officers, employees, agents, parents, subsidiaries, affiliates, and all persons in active concert of participation with them from further acts of infringement of the Patents-in-Suit;

c) judgment against Defendants under 35 U.S.C. § 284 for money damages sustained as a result of Defendants' infringement of the Patents-in-Suit;

d) judgment trebling the damages under 35 U.S.C. § 284 as a result of Defendants' willful and deliberate infringement of the Patents-in-Suit;

e) prejudgment interest under 35 U.S.C. § 284 from the date of each act of infringement of the Patents-in-Suit by Defendants to the day a damages judgment is entered, and a further award of post-judgment interest, under 28 U.S.C. § 1961, continuing until such judgment is paid, at the maximum rate allowed by law;

f) that this be declared an exceptional case under 35 U.S.C. § 285, and that Plaintiff HGST-BV be awarded its costs and attorney fees; and,

g) such other and further relief as this Court finds just and proper.

Dated: December 27, 2004

Respectfully submitted,

MCDERMOTT WILL & EMERY LLP

By: [signature]

Daniel E. Alberti (State Bar No. 68620)
Attorney for Plaintiff
HITACHI GLOBAL STORAGE TECHNOLOGIES NETHERLANDS B.V.

DEMAND FOR JURY TRIAL

Pursuant to Rule 38(b) of the Federal Rules of Civil Procedure and Rule 3-6(a) of the Local Rules of the United States District Court for the Northern District of California, Plaintiff Hitachi Global Storage Technologies Netherlands B.V. demands a trial by jury.

Dated: December 27, 2004

Respectfully submitted,

MCDERMOTT WILL & EMERY LLP

By: ______________________
Daniel E. Alberti (State Bar No. 68620)
Attorney for Plaintiff
HITACHI GLOBAL STORAGE TECHNOLOGIES B.V.

WDC99 1021977-1.068041.0013

EXHIBIT 1

US005210660A

United States Patent [19]

Hetzler

[11] **Patent Number: 5,210,660**

[45] **Date of Patent: May 11, 1993**

[54] **SECTORED SERVO INDEPENDENT OF DATA ARCHITECTURE**

[75] Inventor: **Steven R. Hetzler**, Sunnyvale, Calif.

[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

[21] Appl. No.: **466,194**

[22] Filed: **Jan. 17, 1990**

[51] **Int. Cl.**^{5} **G11B 5/012**

[52] **U.S. Cl.** **360/51**; 360/77.08; 360/48; 369/47

[58] **Field of Search** 369/47, 48, 49, 58, 369/32, 44.34, 44.25, 44.26, 109, 111, 275.1, 275.2, 275.3, 275.4, 124; 360/77.08, 77.11, 77.06, 77.02, 135, 40, 53, 48, 47, 51, 72.2

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,016,603	4/1977	Ottesen	360/72.2
4,135,217	1/1979	Jacques et al.	360/77
4,630,140	12/1986	Sugimura et al.	360/47
4,823,212	4/1989	Knowles et al.	360/77.08
4,841,498	6/1989	Sugimura et al.	360/53
4,933,786	6/1990	Wilson	360/78.14

FOREIGN PATENT DOCUMENTS

0278006	7/1987	European Pat. Off.	
1-19567(A)	1/1989	Japan	360/77.08

OTHER PUBLICATIONS

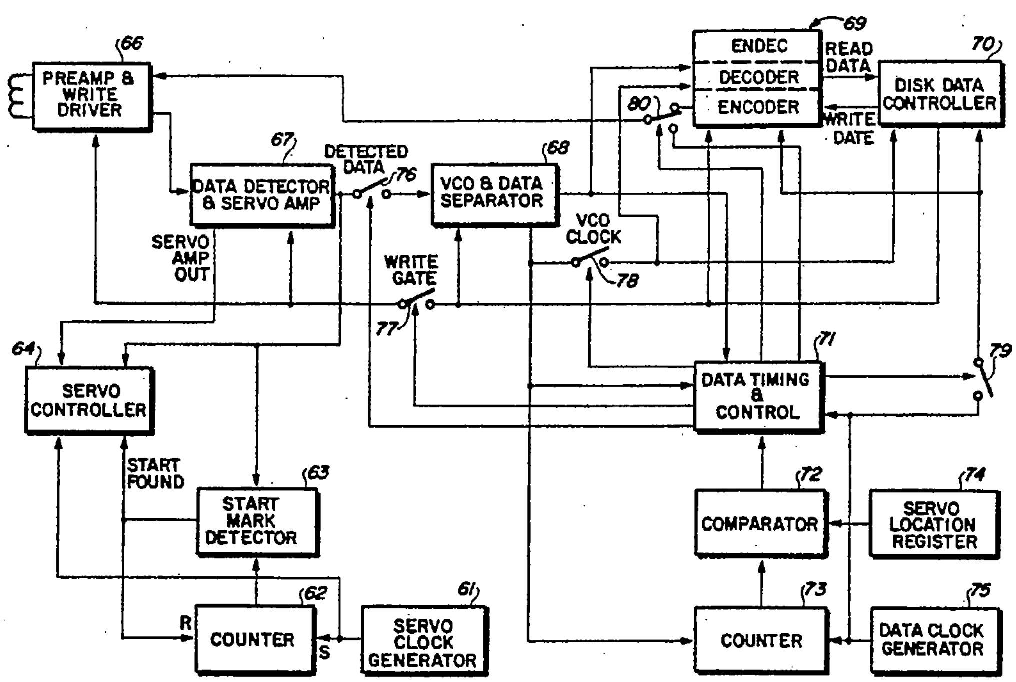
"Servo Zones Embedded In Data Tracks Solve Old, But Create New Problems." Brett Smith, Spring 1988, pp. 45, 46 and 48.

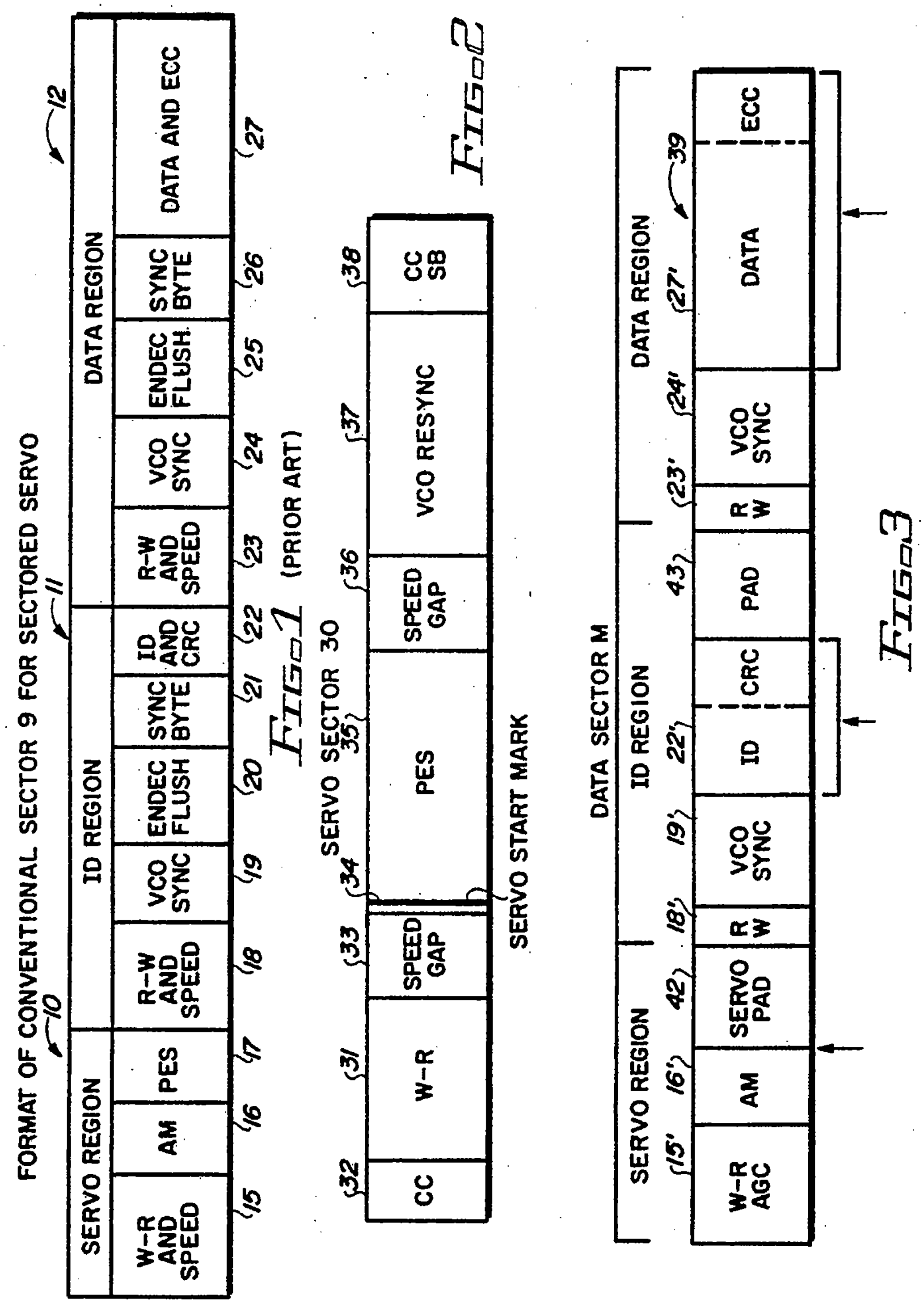
Primary Examiner—Aristotelis Psitos
Assistant Examiner—Muhammad Edun
Attorney, Agent, or Firm—Henry E. Otto, Jr.; Thomas R. Berthold

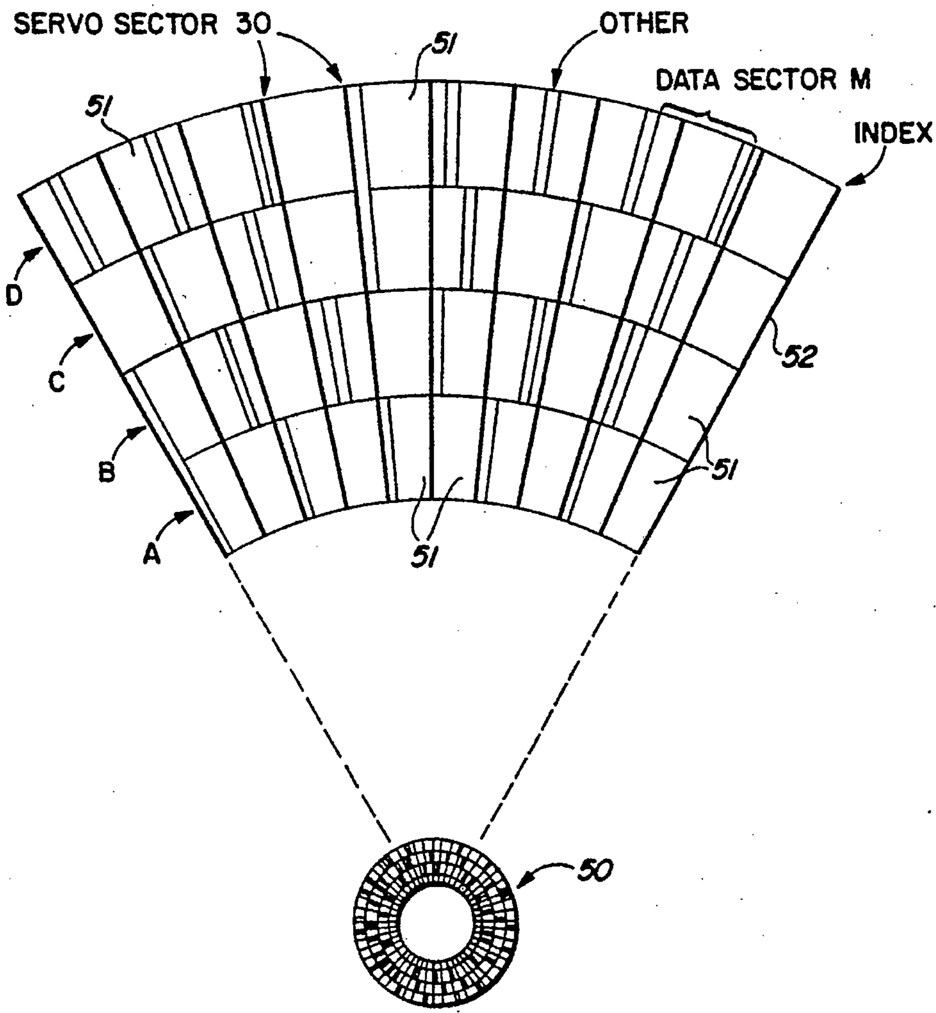
[57] **ABSTRACT**

A data recording apparatus, such as a disk drive or tape drive is described wherein servo sectors written on a disk (or servo sections written on a tape) are equally spaced on a given track and read during seek, settle and track following operations. An algorithm is used to determine the allowable time separation between servo sectors (or sections) on a track and lengths of associated data sections, such as data sectors or variable length records, that may be accommodated on the disk or tape in such manner that each of the servo sectors (or sections) equally spaced on a given track is located within a data field of a data sector or within an identification region or immediately after an address indicating mark (such as address mark or index mark). The rate at which the servo sector (or section) is sampled is constant and independent of the number and lengths of the data sections. As a result of this independent relationship, this technique is suitable for CLD recording, to banded disks using sectored servo as in conventional FBA, and also even to non-sectored architectures, such as count-key-data (CKD), wherein the data is written in records of variable length, and to tape drives formatted in FBA or CKD.

14 Claims, 3 Drawing Sheets




FORMAT OF CONVENTIONAL SECTOR 9 FOR SECTORED SERVO
SERVO REGION
ID REGION
DATA REGION
W-R AND SPEED
AM
PES
R-W AND SPEED
VCO SYNC
ENDEC FLUSH
SYNC BYTE
ID AND CRC
R-W AND SPEED
VCO SYNC
ENDEC FLUSH
SYNC BYTE
DATA AND ECC
FIG. 1 (PRIOR ART)
SERVO SECTOR 30
CC
W-R
SPEED GAP
PES
SPEED GAP
VCO RESYNC
CC SB
SERVO START MARK
FIG. 2
DATA SECTOR M
SERVO REGION
ID REGION
DATA REGION
W-R AGC
AM
SERVO PAD
R W
VCO SYNC
ID
CRC
PAD
R W
VCO SYNC
DATA
ECC
FIG. 3



BAND	M	N:M
D	50	6:5
C	40	3:2
B	36	5:3
A	30	2:1

N = SERVO SAMPLES PER REV. = 60
M = NO. OF DATA SECTORS

FIG. 4

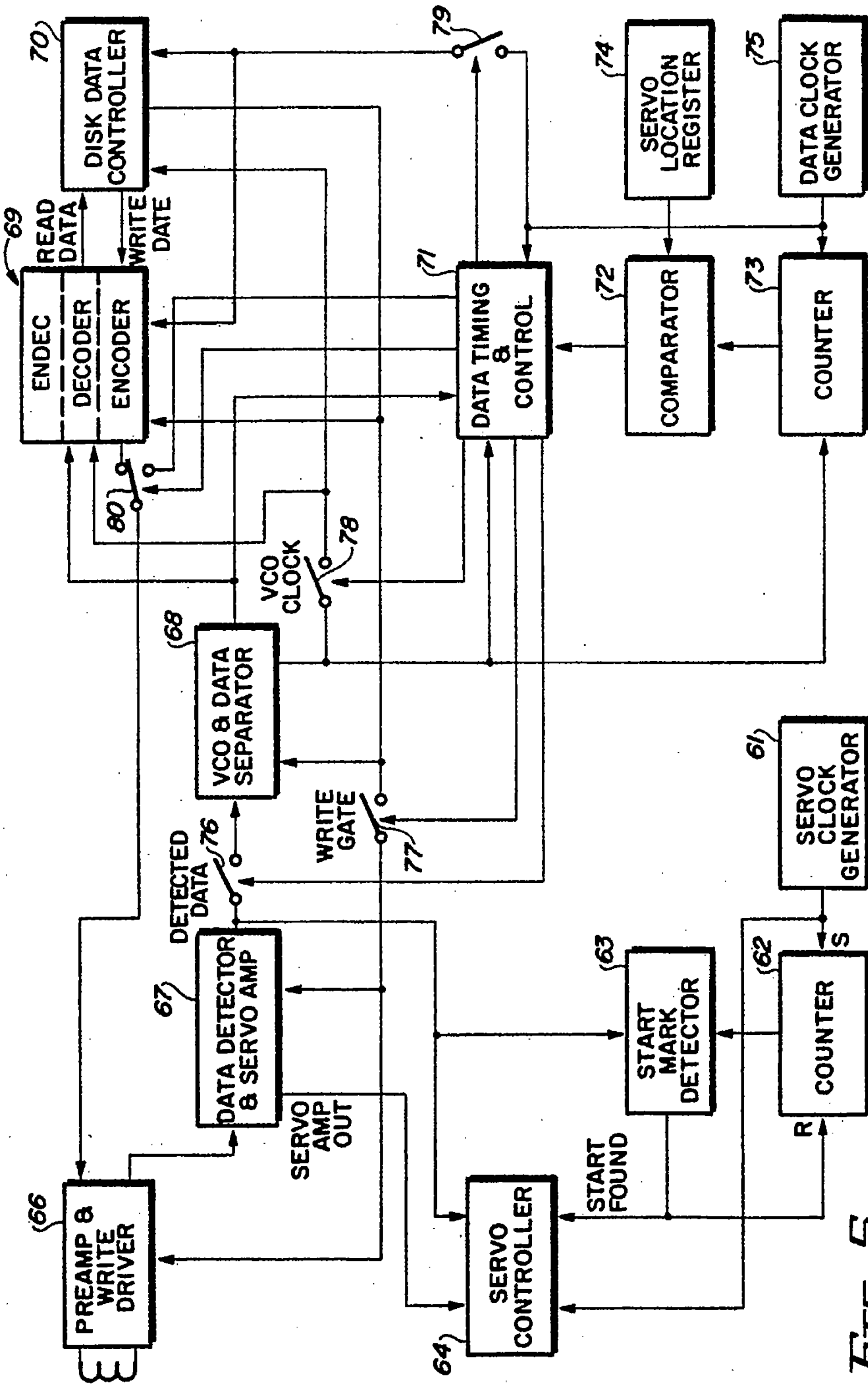

DISK DATA CONTROLLER
70
READ DATA
WRITE DATE
69
ENDEC
DECODER
ENCODER
80
79
DATA TIMING & CONTROL
71
SERVO LOCATION REGISTER
74
DATA CLOCK GENERATOR
75
COMPARATOR
72
COUNTER
73
VCO CLOCK
78
VCO & DATA SEPARATOR
68
WRITE GATE
77
DETECTED DATA
76
DATA DETECTOR & SERVO AMP
67
SERVO AMP OUT
PREAMP & WRITE DRIVER
66
SERVO CONTROLLER
64
START FOUND
START MARK DETECTOR
63
COUNTER
62
S
R
SERVO CLOCK GENERATOR
61

FIG. 5

SECTORED SERVO INDEPENDENT OF DATA ARCHITECTURE

CROSS-REFERENCE TO RELATED APPLICATION

The present invention is related to application U.S. Ser. No. 07/466,195 entitled "Disk File or Tape Drive With High Servo Sample Rate", filed concurrently herewith and assigned to the assignee of the present invention.

FIELD OF THE INVENTION

This invention relates to methods and means for providing and sampling servo sections on a movable recording medium, and more particularly relates to such a method and means wherein the rate at which the servo sectors are sampled on a disk file or servo sections are sampled on a tape drive is independent of the data architecture used.

BACKGROUND OF THE INVENTION

The above-referenced related application discloses a method and means for increasing the servo sector sampling rate in a disk formatted in a fixed block architecture (FBA), such increase being effected with a minimal increase in the overhead (non-data) regions. The disk has the prior art conventional servo sectors which contain all servo and associated overhead information. However, micro servo sectors are inserted in the data fields between the conventional servo sectors to provide short bursts of servo information. These micro servo sectors contain a small portion of the overhead information, only sufficient to provide position information and to control the temporary interruption and restoration of the write current and the data stream and clock input to a data encoder/decoder. Because the servo bursts are short, no resynchronization of the VCO is necessary after each burst. These micro sector bursts are used only during settling (since they contain only position error signal data) and also preferably during seek (if an abbreviated Gray code is used); and the conventional sector servo bursts are used during read and write track following. This technique desirably provides high sample rates with minimal overhead in disk files using a sectored servo system, such as used in low end disk files with FBA format.

Several techniques, now becoming increasingly popular to increase the areal density in sectored disk files, are constant linear density (CLD) recording and banded recording. In CLD recording, the data rate for a given track depends upon its radius. Banded recording is somewhat similar, except that the data rate is constant within a given band of radii, but varies from band to band to minimize the range of linear densities. It follows, then, that if implemented in sectored servo, the number of sectors and hence of servo samples would increase progressively from the innermost to the outermost bands, and thus require the servo system to adjust to the differing sample rates. Also, seeks across bands and settles at band edges would require constant updating of the sample rate, and timing of the servo samples would vary.

There is a need for a recording technique, transparent to the user, useful for both non-sectored and sectored disk and tape formats, wherein servo sample rate is constant and is independent of the data architecture used and limited only by the total area of the disk devoted to servo information.

SUMMARY OF THE INVENTION

Toward this end, and according to the invention, a method and means is described wherein servo sectors written on a disk (or servo sections written on a tape) are equally spaced on a given track and read during seek, settle and track following operations. An algorithm is used to determine the allowable time separation between servo sectors (or sections) on a track and lengths of associated data sections, such as data sectors or variable length records, that may be accommodated on the disk or tape in such manner that each of the servo sectors (or sections) equally spaced on a given track is located within a data field of a data sector or within an identification region or immediately after an address indicating mark (such as address mark or index mark). The rate at which the servo sector (or section) is sampled is constant and independent of the number and lengths of the data sections. As a result of this independent relationship, this technique is suitable for CLD recording, to banded disks using sectored servo as in conventional FBA, and also even to non-sectored architectures, such as count-key-data (CKD), wherein the data is written in records of variable length, and to tape drives formatted in FBA or CKD.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram, not to scale, showing the regions and fields of a typical prior art data sector for a track on a disk file formatted for conventional sectored FBA;

FIG. 2 is a diagram, also not to scale, of a servo sector according to the invention;

FIG. 3 is a diagram, also not to scale, of a data sector into which at selectable locations the servo sector may be inserted;

FIG. 4 is a diagram of a portion of a disk formatted in banded FBA depicting the constant sampling rate for all bands, the varied numbers of data sectors per band, and the servo sector locations in the respective bands; and

FIG. 5 is a block diagram showing the circuitry for implementing the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

I. Introduction—Description of Prior Art Servo Sector

As illustrated in FIG. 1, a typical prior art data sector 9 for a track on a FBA-formatted disk comprises a servo region 10, an identification (ID) region 11, and a data region 12. Write-read and speed field 15 allows time for the drive electronics to switch from write to read. Address mark (AM) field 16 is an asynchronous, absolute timing reference that identifies the beginning of the servo sector and provides the basis for locating the other fields. Position error signal (PES) field 17 contains the information needed to determine the track position of the recording head.

In ID region 11, read-write and speed field 18 allows the time needed to insure that PES field 17 is not overwritten and that sufficient time is provided for the write current to rise to its full value. VCO synchronization (VCO sync) field 19 is required to give the variable frequency read clock sufficient time to phase lock to the upcoming ID and CRC field 22. Encoder/decoder (ENDEC) flush field 20 indicates the number of bits the read channel decoder must receive in order to put it into a known state called ENDEC flush. Sync byte 21 indicates the sync byte needed to align the read bytes on current byte boundaries. ID and CRC field 22 includes as the ID portion a sector identifier and bad sector flag and as the CRC portion a cyclic redundancy check for errors in the reading of the ID.

In data region 12, fields 23–26 correspond to the ID fields 18–21, respectively. However, the function of sync byte field 26 is to tell the controller when the VCO synchronization and ENDEC flush end and the real data, which is contained in field 27, begins. Data and ECC field 27 stores the user data together with the error correction code. Each data region in a conventional sector servo system is completely independent of data regions in the other data sectors.

For a more detailed description of the regions 10–12 and fields 15–27, the reader is referred to the referenced related application.

II. Description of the Invention

Sector Servo System for Banded Recording on Disk

As illustrated in FIG. 2, servo sector 30, in accordance with the invention, differs significantly from the conventional sector 9. Sector 30 comprises a read-write field 31 having a code constraint (CC) portion 32 and a speed gap 33 which together provide the write-recovery function of field 15 of FIG. 1. The code constraint 32 consists of bits to prevent the decaying write current from writing a transition too close to the last data transition. Gap 33, which is to account for timing slop caused by variations in spindle speed of the disk drive motor, is inserted between field 31 and a servo start mark 34.

Mark 34 is at the leading end of the position error signal (PES) field 35 and marks the start of servo sampling. Between the end of PES field 35 and an optional VCO sync field 37 is a gap 36, again to account for variations in spindle speed. Following field 37 (or gap 36 if 37 is not used) is a field 38 containing a coding constraint and sync bits which, for example, for a (2,7) code would be 00. Each of the fields 32,37,38 are completely written during a write operation; fields 31 and 36 are partially written during a write operation; and fields 33 and 35 are written only during a servo write operation.

It will thus be seen that each servo sector 30 consists solely of bits in PES field 35 containing position information and to each side thereof bits in fields for controlling the interruption and restoration of the writing and reading of data.

FIG. 3 illustrates the various regions or fields on a typical track 39 of a data sector M that may be used to implement the invention. The servo sector 30 is not included because, in accordance with the invention, it may be inserted anywhere within any of the locations indicated by the vertical arrows in FIG. 3.

As illustrated, each track 39 preferably contains the following fields: write-read recovery and AGC field 15'; pad fields 42,43, which compensate for timing slop; and fields 16', 18', 19', 22', 23', 24' and 27' which, with 15', are essentially similar to the corresponding unprimed fields in conventional sector servo 9 of FIG. 1.

Servo sectors 30 are written at the factory and are inserted either anywhere within the data field 27' or at certain other prescribed positions in each data sector M, such as the ID/CRC field 22' or ECC portion of field 27'. However, fields 22' and said ECC portion of field 27' are so small compared with the length of the data portion of field 27' that only a small gain in number of permissible sample positions would be achieved. As a practical matter, therefore, the servo sectors 30 preferably should be inserted anywhere in the data portion of field 27' or else immediately following AM 16'.

The servo sectors 30 should not be inserted in the sync fields 19' or 24' because the VCO is then attempting a phase or frequency lock, resulting in an unpredictable drift over a servo sample. Nor should servo sectors 30 be inserted in fields 15', 18' or 23' which are required for channel recovery or in pad fields 42,43 used to accommodate timing slop.

It will be apparent that, if the servo samples occur at the AM 16', then CC field 32, W-R field 31 and gap field 33 are not required; and since pad field 42 would then follow the servo sample, VCO field 37 and CCSB field 38 are not required either. Although eliminating these fields by starting the servo samples at AM 16' desirably lowers the overhead, it probably is not sufficient enough to offset the advantage of having all the servo sectors be of identical length. In banded recording, especially, all servo sectors should be identical so that the servo system will operate independently of the banding.

FIG. 4 depicts a disk 50 formatted in FBA as banded sectors. According to an important feature of the invention, servo sectors 30 in each respective band A-D are written at equally circumferentially spaced intervals and are sampled (i.e., read) during seek, settle and track following operations. An allowable number of servo sectors per revolution and the lengths of associated data regions 51 on disk 50 is calculated such that each of the equally spaced servo sectors 30 on a given track is located anywhere within either a data field 27' of a data region 51 or an identification region 22' or immediately after an index mark 52 or address mark 16' in a data sector M. As shown in FIGS. 3 and 4, each data sector M extends from the leading end of each "other" fields (which are the overhead fields) to the end of the adjacent data region 51.

According to an important feature of the invention, it is not necessary for each servo sector 30 to start at the AM 16' or index mark 52 for every data sector M or that the positions of the servo sectors be the same for every data sector. However, formatting will be simplified, if as illustrated in FIG. 4, the first servo sector in each band starts at the common radial index 52 and each succeeding servo sector in such band is initiated at successive locations in equally spaced time increments from said index. Thus, in disk 50 the data in each concentric band A-D is clocked at the same data rate but the data rates and number of data sectors M vary from band to band.

Not all combinations of servo sample rates and numbers of data sectors M per band are permissible. Permissible combinations are those where the ratio between the number of servo samples N per revolution and the number of data sectors M in a particular band A, B, C or D reduces to a ratio of small integers. For example, assume there are 60 servo samples N per revolution; that bands A, B, C and D have 30, 36, 40 and 50 data sectors M per band, respectively; and that all servo samples are initiated at index 52. As noted in FIG. 4, the ratios of servo samples N to data sectors M in each band are 2:1, 5:3, 3:2 and 6:5 starting from innermost band A. Note that in each case the servo samples line up either at the AM position 16' or within the data regions 51 for all sectors in all bands.

Relatively prime ratios of servo samples N to data sectors M, such as 60/31, are not desirable since they are likely to violate the placement constraints. The AM 16' position tends to fall near the middle of the gap between data fields 27'; hence, the number of allowed combinations would be quite high. If the track does not have VCO or AGC sync fields, there are few servo placement restrictions because only the AM and gap fields need be avoided; and in such case nearly any ratio of servo sample N to data sectors M should be permissible, except the larger integer in either the numerator or denominator of said ratio preferably does not exceed twice the reciprocal of those portions of each track not devoted to data fields or identification fields of the data sectors.

The manner in which permissible combinations of servo samples and data sectors is computed is described in the Appendix attached hereto.

III. Implementation of the Invention

The servo system is initialized by locating a servo sector 30 at index mark 52 (FIG. 4). As illustrated in FIG. 5, clock generator 61 generates servo clock cycles which are counted by counter 62. When counter 62 reaches a preset terminal count corresponding to the number of servo clock cycles between each servo sector 30, it sends an enable signal to a start mark detector 63. Detector 63 then looks for the start mark 34 of a servo sector 30. When start mark 34 is located, detector 63 generates a start found signal, which is sent to a servo controller 64 and to counter 62. Counter 62 is reset by the start found signal and resumes counting. Servo controller 64 then reads the PES field 35 and other servo information, such as a track ID Gray code, based upon the known timing offsets from start mark 34. Servo controller 64 then operates in the same manner as a typical prior art servo controller using the PES to control an actuator (not shown).

In the preceding description, it has been assumed that spindle speed control of the disk drive motor is sufficiently precise to permit completely open-loop operation; i.e., the open-loop counting cycle is repeated for each servo sector 30 and all the servo samples line up at common index 52 at the end of each revolution of the disk. If speed control timing slop is unacceptable, however, it can be reduced by placing a sync bit into PES field 35 to reset a sample timer and thereby update the timer at every sample time.

Data for read and write operations is processed in the same manner as in the prior art, with switches 76–79 closed and switch 80 positioned as shown, until a servo sector 30 is encountered. Servo sector locations are known and stored in a servo location register 74. Prior knowledge of these servo locations allows data timing and control circuitry 71 to make the servo sector transparent to the data channel. Circuitry 71 allows the data channel to operate in the usual manner until it receives a servo location signal from a comparator 72. Comparator 72 generates this signal when the value presented by a counter 73 matches the value present at the output of a servo location register 74. Register 74 contains all the servo sector locations for the various sets of data sectors.

Counter 73 counts VCO clock cycles from a VCO and data separator 68 during read mode, and counts generated data clock cycles from a data clock generator 75 during write mode. This insures that the data timing and control circuitry 71 will interrupt the data stream at the proper bit boundary.

In response to the servo location signal from comparator 72, data timing and control circuitry 71 opens switches 78 and 79. This interrupts the VCO cycles and generated data clock cycles to disk data controller 70 and to ENDEC 69. This freezes the states of the disk data controller 70 and ENDEC 69, making each servo sector 30 transparent to the data channel.

Switch 77 is used only during write mode to put a preamp and write driver 66 in read mode to read a servo sector 30. Switch 76 is opened to prevent detected data from affecting the VCO 68. This has the effect of a VCO hold. Data timing and control circuitry 71 maintains switches 76–80 as positioned in FIG. 5 for a fixed time period until field 37. Switch 80 is used only during write mode to write VCO resync field 37 and code constraint field 38.

In write mode, switch 77 is closed first to enable writing of the VCO resync field 37. After field 37 is written, switch 80 is closed. In read mode, switch 76 is closed first to allow VCO 68 to resynchronize to the data. Switches 78 and 79 are closed when the VCO resync field operation is completed; i.e., is either written or read. The value in servo location register 74 is then updated with the location of the next servo sector 30. The channel again functions in the same manner as a prior art data channel until the next servo location signal is generated by comparator 72.

According to an important feature of the invention, the data and servo sectors work in concert such that the data channel is prepared for each servo sector 30 without requiring an address mark for that sector. To locate each servo sector only a servo start mark 34, which may be as short as 1 bit, is required. Each servo sector 30 can be located by open-loop timing from the previous servo sector and without any knowledge of the lengths or positions of the data sectors.

IV. Application to Constant Linear Density (CLD) Recording

It will be understood that the sector servo system for CLD recording is essentially the same as described for banded recording, except that the clock frequency changes at each track and the length of each data sector will change from track to track. The manner in which the permissible combinations of servo sample rates and number of data sectors per track is computed is by an apparent modification of the algorithm described in the Appendix for banded recording.

V. Application to Conventional FBA Format

A plurality of servo sectors are positioned and written at the factory. They are circumferentially spaced from each other on each track by an equal angle, which corresponds to a constant time separation. Since the data timing does not change in the FBA format, the allowed combinations of number of servo sectors and number of data sectors per track may be computed in the same manner as described in the Appendix for calculation of the allowed bands for banded recording.

Another approach is to choose a basic data unit that is of the same length as the length of the overhead fields. The allowed data record lengths would then be integral multiples of the data unit length. If the servo sector spacing is chosen such that the distance between adjacent servo sectors is equal to an integral multiple of the data unit length, then the servo sectors will never lie in disallowed regions.

VI. Application to CKD Format

Again, servo sectors are positioned and written at the factory. The first data record on a given track is placed to start at an index mark, like 52. If the next servo sector lies within the write-read recovery area, pad bits are added to the end of the record to insure that the next servo sector lies in the data region. If the next servo sector lies within a disallowed field at the start of the next data record, then pad bits are added to the end of the current record to align the next address mark with the next servo sector. This process is repeated for all sectors on the track. The controller generates the pad bits during a write operation and extracts the pad bits during a read operation, thus making said operations transparent to the host.

VII. Application to Tape Drives

While the invention has been illustrated as applied to disk drives, it will be apparent that the invention is equally applicable to tape drives. In both, the rate at which servo sectors for disk or servo sections for tape are sampled is independent of whether the disk or tape is formatted in FBA or CKD architecture.

In a tape drive, the allowable time separation between servo sections on a track and lengths of associated data sections on the tape is established such that at least some of the equally spaced servo sections on a given track are located within a data field of a data section and the rate at which the servo sections are sampled is independent of the data architecture used. Like the disk embodiments, the reading of a servo section is initiated based upon open-loop timing from the preceding servo section. The first servo section on each track commences at one common track index and each succeeding servo section is initiated at successive locations in equally spaced time increments from said index. Each servo section consists solely of bits containing position information and to each side thereof bits for controlling the interruption and restoration of the writing and reading of data. The ratio of servo sections to data sections is other than 1:1. At least some servo sections are located anywhere within a data field in a data section. At least some others of the equally spaced servo sections are within an identification field or immediately after an address indicating mark.

For a FBA formatted tape, the ratio of the time separation between data sections to the time separation between servo sections should again reduce to a ratio of small integers. For a CKD formatted tape, it will be necessary to add pad bits as described in Section VI.

As hereinafter used in the claims, the term "moving medium" is intended, unless otherwise indicated, to generically define either a magnetic, magneto-optical or optical disk or a magnetic or optical tape; the term "servo sections" is intended generically to cover servo sectors for disk files and servo sections for tape drives; and the term "data sections" is intended to generically define the data sectors for FBA and CLD formats and the variable length records for CKD format.

In the disk embodiments, the allowable number of servo sectors per revolution was calculated for each track or band of tracks. It will be apparent, however, that in view of the constant rotational speed of the disk, the time between each servo sector is constant. Hence, in both the disk and tape embodiments, the allowable time separation between servo sectors on a track is calculated, though in the disk embodiment this was expressed as allowable number of servo sectors on a track.

While the invention has been shown and described with respect to preferred embodiments thereof, it will be understood by those skilled in the art that changes in form and detail may be made in these embodiments without departing from the scope and teaching of the invention. Accordingly, the method and means herein disclosed are to be considered merely as illustrative, and the invention is to be limited only as specified in the claims.

APPENDIX

Computation of Permissible Servo Sample to Data Sector Combinations for Banded Recording in FBA Format

Assuming initially that the allowable linear density as a function of radius is known, the various fields are broken down into those portions which scale with linear density and those which do not. All references to bits are in message (non-encoded) bits; and the linear density units are kbpmm (kilobits per millimeter), also message bits. Assume further that

- DB=number of data bits per sector (same for all bands for banded recording)
- SB=number of servo bits (data rate dependent portion)
- SF=fixed length portion of servo in μs
- OB=number of bits in other fields (data rate dependent portion)
- OF=fixed length portion of other fields in μs
- P=rotational period in μs (i.e., 1/rpm)
- M=number of data sectors in a band
- N=number of servo samples per revolution
- ld(r)=linear density in kbpmm, where r is the radius in mm
- OH=fixed overhead

The minimum allowable ID radius for a band is then given by:

$$\text{bits} = \frac{(M \times (DB + OB) + N \times SB)}{1000}$$

$$OH = M \times OF + N \times SF$$

$$r = \frac{\text{bits}/ld(r)}{2\pi\left(1 - \frac{OH}{P}\right)}$$

$$rld(r) = \frac{\text{bits}}{2\pi\left(1 - \frac{OH}{P}\right)}$$

Where ld(r) is a constant,

$$ld(r) = B,$$

$$r = \frac{\text{bits}}{2B\pi\left(1 - \frac{OH}{P}\right)}$$

and where ld(r) is linear:

$$ld(r) = Ar + B,$$

$$r = \frac{-B + \sqrt{B^2 + \frac{4A\text{bits}}{2B\pi\left(1 - \frac{OH}{P}\right)}}}{2A}$$

Usually the linear density decreases with increased radius, therefore A<0 and B>0. In this case, the positive root of the quadratic yields the smaller radius (the negative root occurs where the decreasing linear density is compensated for by the increasing circumference of the track).

Once the minimum allowable ID radius has been computed, the actual relationship between the positions of servo sectors **30** and data sectors M must be computed to determine if the band is valid; i.e., that the servo samples N occur only in the allowed positions.

To determine the allowed bands:

1. Choose a servo sample rate. (For example, 60.)
2. Compute the band with the greatest number of data sectors, whose minimum allowable ID radius is less than or equal to the disk ID. (For example, assume the result is 31 data sectors.)
3. Starting with this band, check to see if it is valid. If not, decrease the sector count by 1 and repeat. (Thus, decrease from 31 to 30.) Note that if the sector count goes to 0 without success, there is no allowable ID band under these conditions.
4. Start with the first band whose minimum allowable ID radius is greater than the disk ID. (This could be 30 data sectors as a result of the example used for step 3.)
5. See if the band is valid, if so, add it to the list. Increase the sector count by 1 and repeat until the minimum allowable ID radius is greater than or equal to the disk OD. (Again, using the example from the prior steps, step 5 could give the following numbers of data sectors per band: 30, 35, 36, 40, 42, 45, 48, 50 and 54, of which for simplified illustration only four, A–D, are shown in FIG. 4.)

We claim:

1. A fixed block architecture disk drive comprising:

a rotatable, rigid magnetic recording disk having a plurality of concentric tracks divided into angular sectors of fixed blocks, each block containing a data field for the recording of magnetically written data, and a plurality of generally equally angularly spaced servo sectors containing servo position information extending in a generally radially straight line across the tracks, at least some of the servo sectors being located within the data fields and splitting the data fields into at least two portions;

a head for writing data to and reading data from the data fields in the fixed blocks, and for reading servo position information from the servo sectors;

an actuator attached to the head for positioning the head across the tracks and for following specific tracks, the actuator being responsive to servo position information read by the head at an essentially constant servo sample rate determined by the rotational speed of the disk and the angular spacing of the servo sectors;

means coupled to the head for clocking write data to and read data from the data fields at an essentially constant data rate for all tracks;

means coupled to the head and responsive to a clock signal from the data clocking means for encoding data to and decoding data from the head; and

means coupled to the encoding and decoding means for stopping the transfer of data to and from the encoding and decoding means when the head is reading servo position information from the servo sectors located within the data fields.

2. The disk drive according to claim **1** wherein the data stopping means comprises means for interrupting the essentially constant data rate clock signal to the encoding and decoding means.

3. The disk drive according to claim **1** further comprising:

means for storing values representing the locations for servo sectors located within the data fields;

a counter coupled to the data clocking means for counting the number of clock cycles;

means coupled to the counter and the servo sector location value storing means for comparing the count value with a stored servo sector location value; and

wherein the means for stopping the data transfer is responsive to the comparing means.

4. The disk drive according to claim **3** wherein the servo sector location value storing means comprises a register located off the disk.

5. A banded recording, fixed block architecture disk drive comprising:

a rotatable, rigid magnetic recording disk having a plurality of radially spaced bands containing the fixed blocks for the recording of magnetically written data, and a plurality of generally equally angularly spaced servo sectors containing servo position information, each servo sector extending in a generally radially straight line across the bands;

a head for writing data to and reading data from data fields located in the fixed blocks of each of the bands, and for reading servo position information from the servo sectors;

means coupled to the head for clocking write data to and read data from the data fields at a plurality of data rates, each data rate having a unique value corresponding to the band in which the head is located; and

an actuator attached to the head for positioning the head across the bands and within each of the bands, the actuator being responsive to servo position information read by the head at a constant servo sample rate regardless of the band in which the head is located or the corresponding rate at which the data is clocked, said constant servo sample rate being determined by the rotational speed of the disk and the angular spacing of the servo sectors.

6. The disk drive according to claim **5** wherein the disk has a radial index mark common to all the bands and extending across the bands in a generally radially straight line, and wherein the first servo sector is located at the common radial index mark.

7. The disk drive according to claim **5** wherein the servo sectors on the disk are located within the data fields of at least one of the bands.

8. The disk drive according to claim **7** wherein the servo sectors located within the data fields of at least one of the bands split each of the data fields into at least two portions of substantially different circumferential lengths.

9. The disk drive according to claim 5 wherein the number of data fields in a band varies from band to band, and wherein if the number of data fields within each band is represented by the variable M and the number of servo sectors on the disk is represented by the constant N, then the ratio of M to N for each band is equal to a ratio of two integers, each integer being between 1 and 12.

10. The disk drive according to claim 5 wherein at least one of the servo sectors in at least one of the bands is located within an identification field associated with one of the fixed blocks.

11. The disk drive according to claim 5 further comprising means coupled to the head for interrupting the reading and writing of data by the head when the servo position information from the servo sectors located within the data fields is being read by the head.

12. The disk drive according to claim 5 further comprising:

means for storing values representing the servo sector locations;

a counter coupled to the data clocking means for counting the number of clock cycles; and

means coupled to the counter and the servo sector location value storing means for interrupting the reading and writing of data by the head when the counter reaches a value corresponding to a stored location value, whereby servo position information may be read by the head during the period of the interruption.

13. The disk drive according to claim 12 further comprising means coupled to the head and responsive to a clock signal from the data clocking means for encoding and decoding data, and wherein the interrupting means includes means for interrupting the clock signal to the encoding and decoding means, whereby the state of the encoding and decoding means is frozen during the period the servo position information is read by the head.

14. The disk drive according to claim 12 wherein the servo sector location value storing means comprises a register located off the disk.

* * * * *

EXHIBIT 2

US005440474A

United States Patent [19]

Hetzler

[11] **Patent Number: 5,440,474**

[45] **Date of Patent: * Aug. 8, 1995**

[54] **MAGNETIC RECORDING DISK WITH EQUALLY-SPACED SERVO SECTORS EXTENDING ACROSS MULTIPLE DATA BANDS**

[75] Inventor: **Steven R. Hetzler**, Sunnyvale, Calif.

[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

[*] Notice: The portion of the term of this patent subsequent to May 11, 2010 has been disclaimed.

[21] Appl. No.: **150,939**

[22] Filed: **Nov. 10, 1993**

Related U.S. Application Data

[63] Continuation of Ser. No. 58,348, May 5, 1993, Pat. No. 5,285,327, which is a continuation of Ser. No. 466,194, Jan. 17, 1990, Pat. No. 5,210,660.

[51] **Int. Cl.⁶** **G11B 5/09**; G11B 5/596

[52] **U.S. Cl.** **360/135**; 360/48; 360/77.08; 369/44.26; 369/275.3

[58] **Field of Search** 360/51, 135, 77.08, 360/48, 77.05, 78.04, 77.08, 46, 77.02; 364/602, 275.3; 369/59, 32, 44.26; 395/425; 371/37.1, 40.1

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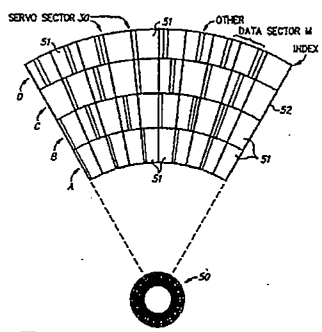
Primary Examiner—W. R. Young
Assistant Examiner—Patrick Wamsley
Attorney, Agent, or Firm—Thomas R. Berthold

[57] **ABSTRACT**

A magnetic recording disk has servo sectors that are generally equally spaced on a given track and read during seek, settle, and track-following operations. An algorithm is used to determine the allowable time separation between servo sectors on a track and lengths of associated data sections that may be accommodated on the disk. In such a manner, the servo sectors are equally spaced on a given track and may be located within a data field of a data sector, within an identification region, or immediately after an address indicating mark (such as an address mark or an index mark). The rate at which the servo sectors are sampled is constant and independent of the number and lengths of the data sections. As a result of this independent relationship, this technique is suitable for a banded recording disk using sectored servo. The banded magnetic recording disk with multiple radially-spaced data bands has generally equally angularly-spaced servo sectors extending across the bands to provide a constant servo sample rate independent of the data rate.

6 Claims, 3 Drawing Sheets



BAND	M	N:M
D	50	6:5
C	40	3:2
B	36	5:3
A	30	2:1

N=SERVO SAMPLES PER REV.=60
N=NO. OF DATA SECTORS

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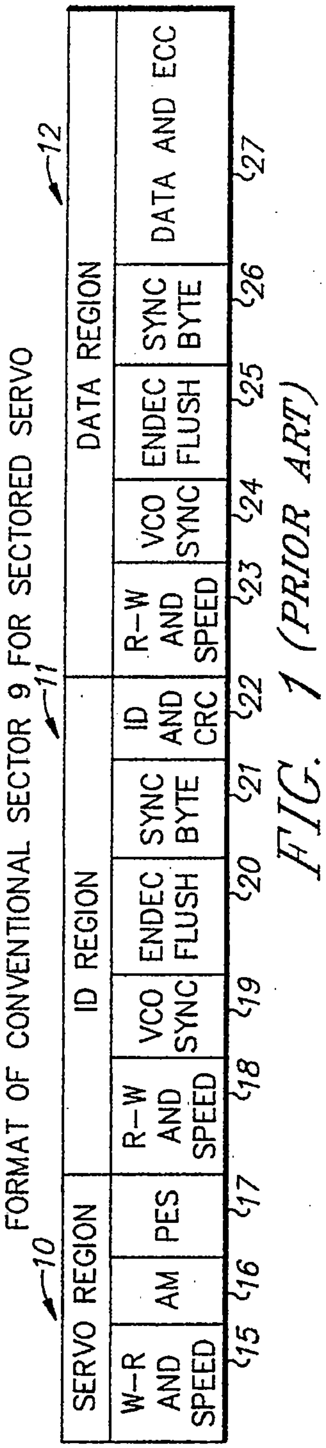


FIG. 1 (PRIOR ART)

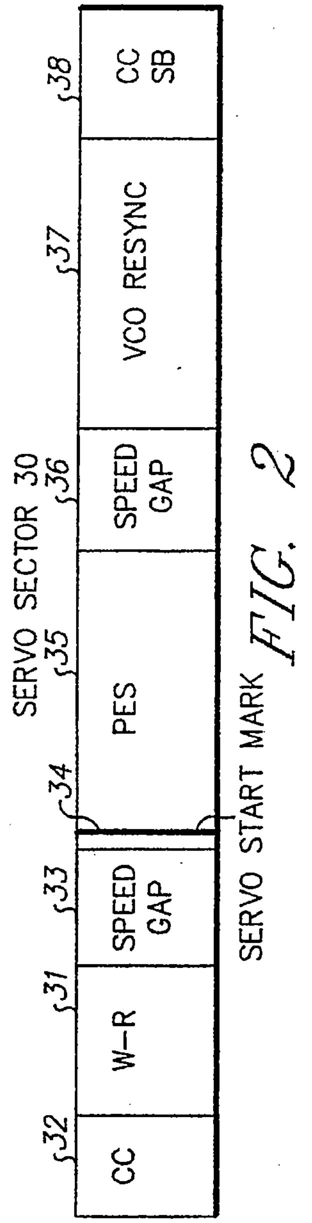


FIG. 2

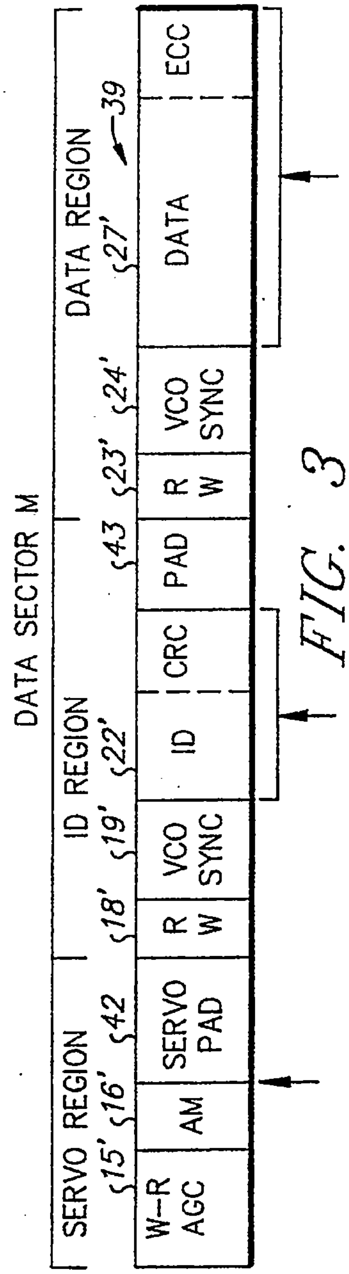
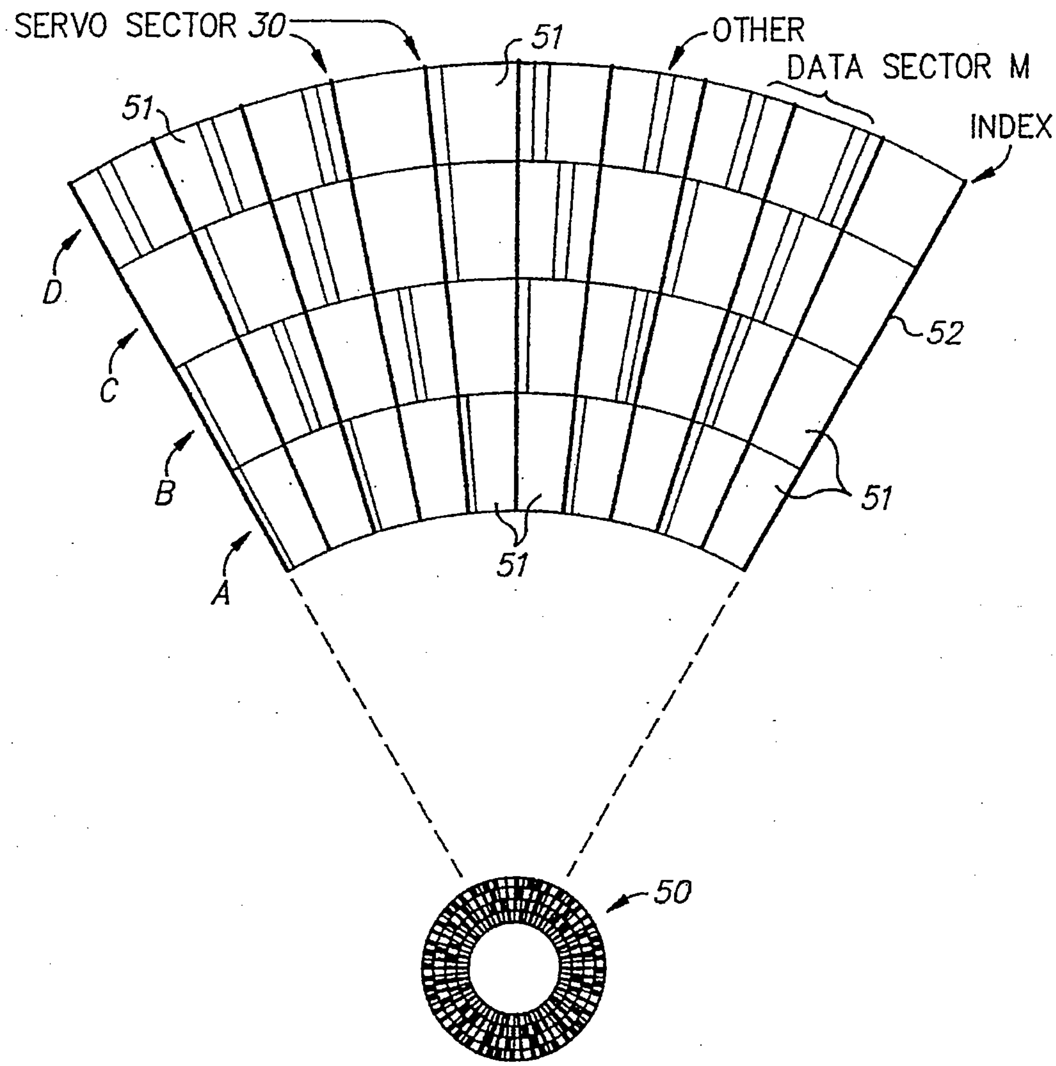


FIG. 3



BAND	M	N:M
D	50	6:5
C	40	3:2
B	36	5:3
A	30	2:1

N=SERVO SAMPLES PER REV.=60
N=NO. OF DATA SECTORS

FIG. 4

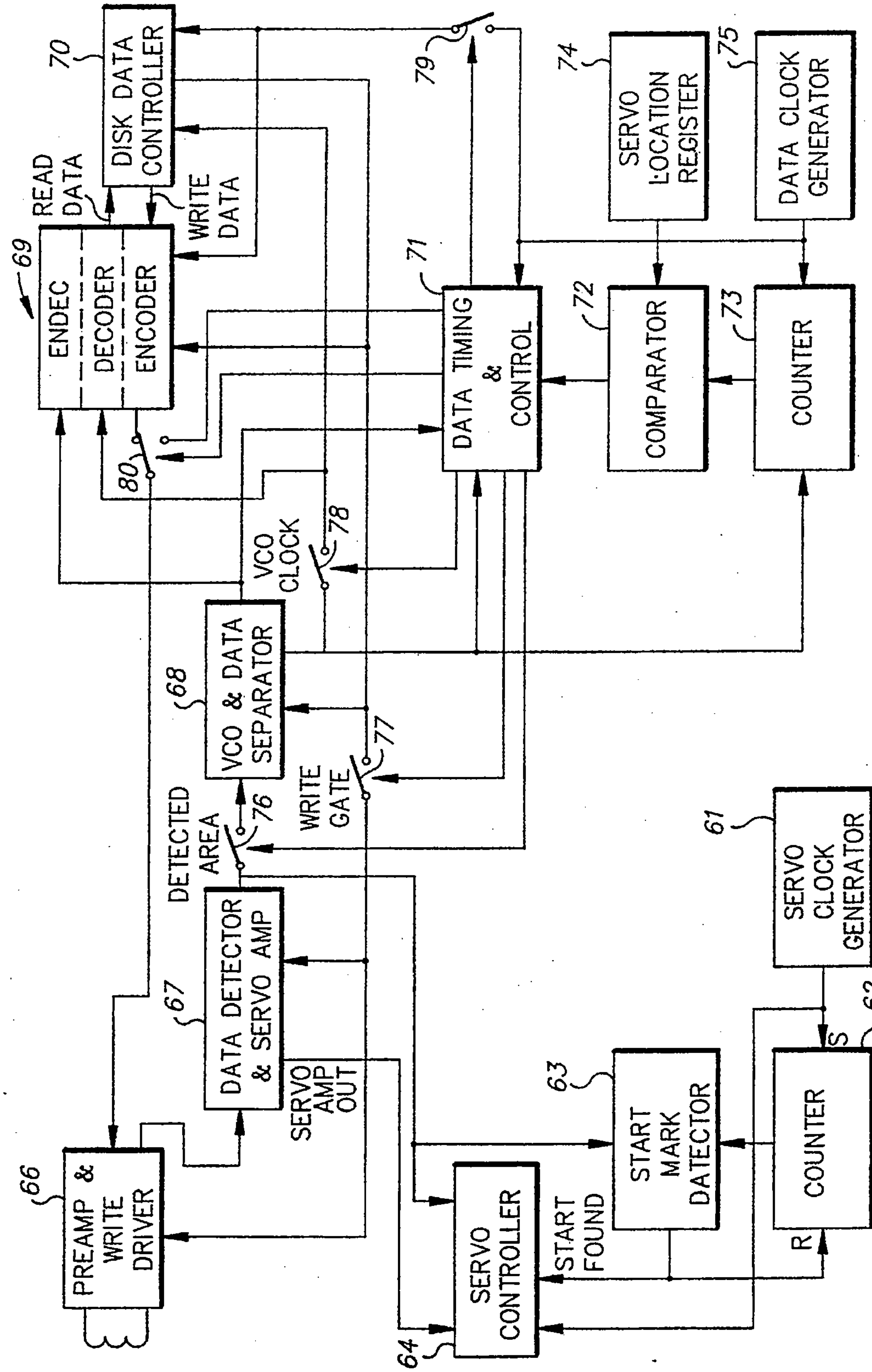

70
DISK DATA CONTROLLER
READ DATA
WRITE DATA
69
ENDEC
DECODER
ENCODER
79
74
SERVO LOCATION REGISTER
75
DATA CLOCK GENERATOR
71
DATA TIMING & CONTROL
72
COMPARATOR
73
COUNTER
80
VCO CLOCK
78
68
VCO & DATA SEPARATOR
77
WRITE GATE
76
DETECTED AREA
67
DATA DETECTOR & SERVO AMP
SERVO AMP OUT
66
PREAMP & WRITE DRIVER
61
SERVO CLOCK GENERATOR
62
S
COUNTER
R
63
START MARK DATECTOR
START FOUND
64
SERVO CONTROLLER

FIG. 5

MAGNETIC RECORDING DISK WITH EQUALLY-SPACED SERVO SECTORS EXTENDING ACROSS MULTIPLE DATA BANDS

RELATED APPLICATIONS

This is a continuation of application Ser. No. 08/058,348, filed May 5, 1993, now U.S. Pat. No. 5,285,327, which is a continuation of application Ser. No. 07/466,194, filed Jan. 17, 1990, now U.S. Pat. No. 5,210,660.

The present invention is related to application Ser. No. 07/466,195, filed Jan. 17, 1990, now U.S. Pat. No. 5,073,834.

FIELD OF THE INVENTION

This invention relates to methods and means for providing and sampling servo sections on a movable recording medium, and more particularly relates to such a method and means wherein the rate at which the servo sectors are sampled on a disk file or servo sections are sampled on a tape drive is independent of the data architecture used.

BACKGROUND OF THE INVENTION

The above-referenced related application discloses a method and means for increasing the servo sector sampling rate in a disk formatted in a fixed block architecture (FBA), such increase being effected with a minimal increase in the overhead (non-data) regions. The disk has the prior art conventional servo sectors which contain all servo and associated overhead information. However, micro servo sectors are inserted in the data fields between the conventional servo sectors to provide short bursts of servo information. These micro servo sectors contain a small portion of the overhead information, only sufficient to provide position information and to control the temporary interruption and restoration of the write current and the data stream and clock input to a data encoder/decoder. Because the servo bursts are short, no resynchronization of the VCO is necessary after each burst. These micro sector bursts are used only during settling (since they contain only position error signal data) and also preferably during seeking (if an abbreviated Gray code is used); and the conventional sector servo bursts are used during read and write track following. This technique desirably provides high sample rates with minimal overhead in disk files using a sectored servo system, such as low end disk files with FBA format.

Two techniques, now becoming increasingly popular to increase the areal density in sectored disk files, are constant to linear density (CLD) recording and banded recording. In CLD recording, the data rate for a given track depends upon its radius. Banded recording is somewhat similar, except that the data rate is constant within a given band of radii, but varies from band to band to minimize the range of linear densities. It follows, then, that if implemented in sectored servo, the number of sectors and hence of servo samples would increase progressively from the innermost to the outermost bands, and thus require the servo system to adjust to the differing sample rates. Also, seeks across bands and settles at band edges would require constant updating of the sample rate, and timing of the servo samples would vary.

There is a need for a recording technique, transparent to the user, useful for both non-sectored and sectored disk and tape formats, wherein the servo sample rate is constant and is independent of the data architecture used and limited only by the total area of the disk devoted to servo information.

SUMMARY OF THE INVENTION

Toward this end, and according to the invention, a method and means is described wherein servo sectors written on a disk (or servo sections written on a tape) are equally spaced on a given track and read during seek, settle and track following operations. An algorithm is used to determine the allowable time separation between servo sectors (or sections) on a track and lengths of associated data sections, such as data sectors or variable length records, that may be accommodated on the disk or tape in such manner that each of the servo sectors (or sections) equally spaced on a given track is located within a data field of a data sector or within an identification region or immediately after an address indicating mark (such as address mark or index mark). The rate at which the servo sector (or section) is sampled is constant and independent of the number and lengths of the data sections. As a result of this independent relationship, this technique is suitable for CLD recording, to banded disks using sectored servo as in conventional FBA, and also even to non-sectored architectures, such as count-key-data (CKD), wherein the data are written in records of variable length, and to tape drives formatted in FBA or CKD.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram, not to scale, showing the regions and fields of a typical prior art data sector for a track on a disk file formatted for conventional sectored FBA;

FIG. **2** is a diagram, also not to scale, of a servo sector according to the invention;

FIG. **3** is a diagram, also not to scale, of a data sector into which at selectable locations the servo sector may be inserted;

FIG. **4** is a diagram of a portion of a disk formatted in banded FBA depicting the constant sampling rate for all bands, the varied numbers of data sectors per band, and the servo sector locations in the respective bands; and

FIG. **5** is a block diagram showing the circuitry for implementing the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

I. Introduction—Description of Prior Art Servo Sector

As illustrated in FIG. **1**, a typical prior art data sector **9** for a track on a FBA-formatted disk comprises a servo region **10**, an identification (ID) region **11**, and a data region **12**. Write-read and speed field **15** allows time for the drive electronics to switch from write to read. Address mark (AM) field **16** is an asynchronous, absolute timing reference that identifies the beginning of the servo sector and provides the basis for locating the other fields. Position error signal (PES) field **17** contains the information needed to determine the track position of the recording head.

In ID region **11**, read-write and speed field **18** allows the time needed to insure that PES field **17** is not overwritten and that sufficient time is provided for the write current to rise to its full value. VCO synchronization (VCO sync) field **19** is required to give the variable frequency read clock sufficient time to phase lock to the upcoming ID and CRC field **22**. Encoder/decoder

(ENDEC) flush field 20 indicates the number of bits the read channel decoder must receive in order to put it into a known state called ENDEC flush. Sync byte 21 indicates the sync byte needed to align the read bytes on current byte boundaries. ID and CRC field 22 includes as the ID portion a sector identifier and bad sector flag and as the CRC portion a cyclic redundancy check for errors in the reading of the ID.

In data region 12, fields 23–26 correspond to the ID fields 18–21, respectively. However, the function of sync byte field 26 is to tell the controller when the VCO synchronization and ENDEC flush end and the real data, which are contained in field 27, begins. Data and ECC field 27 stores the user data together with the error correction code. Each data region in a conventional sector servo system is completely independent of data regions in the other data sectors.

For a more detailed description of the regions 10–12 and fields 15–27, the reader is referred to the referenced related application.

II. Description of the Invention

Sector Servo System for Banded Recording on Disk

As illustrated in FIG. 2, servo sector 30, in accordance with the invention, differs significantly from the conventional sector 9. Sector 30 comprises a read-write field 31 having a code constraint (CC) portion 32 and a speed gap 33 which together provide the write-recovery function of field 15 of FIG. 1. The code constraint 32 consists of bits to prevent the decaying write current from writing a transition too close to the last data transition. Gap 33, which is to account for timing slop caused by variations in spindle speed of the disk drive motor, is inserted between field 31 and a servo start mark 34.

Mark 34 is at the leading end of the position error signal (PES) field 35 and marks the start of servo sampling. Between the end of PES field 35 and an optional VCO sync field 37 is a gap 36, again to account for variations in spindle speed. Following field 37 (or gap 36 if 37 is not used) is a field 38 containing a coding constraint and sync bits which, for example, for a (2,7) code would be 00. Each of the fields 32, 37, 38 is completely written during a write operation; fields 31 and 36 are partially written during a write operation; and fields 33 and 35 are written only during a servo write operation.

It will thus be seen that each servo sector 30 consists solely of bits in PES field 35 containing position information and to each side thereof bits in fields for controlling the interruption and restoration of the writing and reading of data.

FIG. 3 illustrates the various regions or fields on a typical track 39 of a data sector M that may be used to implement the invention. The servo sector 30 is not included because, in accordance with the invention, it may be inserted anywhere within any of the locations indicated by the vertical arrows in FIG. 3.

As illustrated, each track 39 preferably contains the following fields: write-read recovery and AGC field 15'; pad fields 42, 43, which compensate for timing slop; and fields 16', 18', 19', 22', 23', 24' and 27' which, with 15', are essentially similar to the corresponding unprimed fields in conventional sector servo 9 of FIG. 1.

Servo sectors 30 are written at the factory and are inserted either anywhere within the data field 27' or at certain other prescribed positions in each data sector M, such as the ID/CRC field 22' or ECC portion of field 27'. However, fields 22' and said ECC portion of field 27' are so small compared with the length of the data portion of field 27' that only a small gain in number of permissible sample positions would be achieved. As a practical matter, therefore, the servo sectors 30 preferably should be inserted anywhere in the data portion of field 27' or else immediately following AM 16'.

The servo sectors 30 should not be inserted in the sync fields 19' or 24' because the VCO is then attempting a phase or frequency lock, resulting in an unpredictable drift over a servo sample. Nor should servo sectors 30 be inserted in fields 15', 18' or 23' which are required for channel recovery or in pad fields 42, 43 used to accommodate timing slop.

It will be apparent that, if the servo samples occur at the AM 16', then CC field 32, W-R field 31 and gap field 33 are not required; and since pad field 42 would then follow the servo sample, VCO field 37 and CCSB field 38 are not required either. Although eliminating these fields by starting the servo samples at AM 16' desirably lowers the overhead, it probably is not sufficient enough to offset the advantage of having all the servo sectors be of identical length. In banded recording, especially, all servo sectors should be identical so that the servo system will operate independently of the banding.

FIG. 4 depicts a disk 50 formatted in FBA as banded sectors. According to an important feature of the invention, servo sectors 30 in each respective band A–D are written at equally circumferentially spaced intervals and are sampled (i.e., read) during seek, settle and track following operations. An allowable number of servo sectors per revolution and the lengths of associated data regions 51 on disk 50 is calculated such that each of the equally spaced servo sectors 30 on a given track is located anywhere within either a data field 27' of a data region 51 or an identification region 22' or immediately after an index mark 52 or address mark 16' in a data sector M. As shown in FIGS. 3 and 4, each data sector M extends from the leading end of each "other" fields (which are the overhead fields) to the end of the adjacent data region 51.

According to an important feature of the invention, it is not necessary for each servo sector 30 to start at the AM 16' or index mark 52 for every data sector M or that the positions of the servo sectors be the same for every data sector. However, formatting will be simplified, if as illustrated in FIG. 4, the first servo sector in each band starts at the common radial index 52 and each succeeding servo sector in such band is initiated at successive locations in equally spaced time increments from said index. Thus, in disk 50 the data in each concentric band A–D are clocked at the same data rate but the data rates and number of data sectors M vary from band to band.

Not all combinations of servo sample rates and numbers of data sectors M per band are permissible. Permissible combinations are those where the ratio between the number of servo samples N per revolution and the number of data sectors M in a particular band A, B, C or D reduces to a ratio of small integers. For example, assume there are 60 servo samples N per revolution; that bands A, B, C and D have 30, 36, 40 and 50 data sectors M per band, respectively; and that all servo samples are initiated at index 52. As noted in FIG. 4, the ratios of servo samples N to data sectors M in each band are 2:1, 5:3, 3:2 and 6:5 starting from innermost band A. Note that in each case the servo samples line up either at the AM position **16'** or within the data regions **51** for all sectors in all bands.

Relatively prime ratios of servo samples N to data sectors M, such as 60/31, are not desirable since they are likely to violate the placement constraints. The AM **16'** position tends to fall near the middle of the gap between data fields **27'**; hence, the number of allowed combinations would be quite high. If the track does not have VCO or AGC sync fields, there are few servo placement restrictions because only the AM and gap fields need be avoided; and in such case nearly any ratio of servo sample N to data sectors M should be permissible, except the larger integer in either the numerator or denominator of said ratio preferably does not exceed twice the reciprocal of those portions of each track not devoted to data fields or identification fields of the data sectors.

The manner in which permissible combinations of servo samples and data sectors is computed is described in the Appendix attached hereto.

III. Implementation of the Invention

The servo system is initialized by locating a servo sector **30** at index mark **52** (FIG. **4**). As illustrated in FIG. **5**, clock generator **61** generates servo clock cycles which are counted by counter **62**. When counter **62** reaches a preset terminal count corresponding to the number of servo clock cycles between each servo sector **30**, it sends an enable signal to a start mark detector **63**. Detector **63** then looks for the start mark **34** of a servo sector **30**. When start mark **34** is located, detector **63** generates a start found signal, which is sent to a servo controller **64** and to counter **62**. Counter **62** is reset by the start found signal and resumes counting. Servo controller **64** then reads the PES field **35** and other servo information, such as a track ID Gray code, based upon the known timing offsets from start mark **34**. Servo controller **64** then operates in the same manner as a typical prior art servo controller using the PES to control an actuator (not shown).

In the preceding description, it has been assumed that spindle speed control of the disk drive motor is sufficiently precise to permit completely open-loop operation; i.e., the open-loop counting cycle is repeated for each servo sector **30** and all the servo samples line up at common index **52** at the end of each revolution of the disk. If speed control timing slop is unacceptable, however, it can be reduced by placing a sync bit into PES field **35** to reset a sample timer and thereby update the timer at every sample time.

Data for read and write operations are processed in the same manner as in the prior art, with switches **76–79** closed and switch **80** positioned as shown, until a servo sector **30** is encountered. Servo sector locations are known and stored in a servo location register **74**. Prior knowledge of these servo locations allows data timing and control circuitry **71** to make the servo sector transparent to the data channel. Circuitry **71** allows the data channel to operate in the usual manner until it receives a servo location signal from a comparator **72**. Comparator **72** generates this signal when the value presented by a counter **73** matches the value present at the output of a servo location register **74**. Register **74** contains all the servo sector locations for the various sets of data sectors.

Counter **73** counts VCO clock cycles from a VCO and data separator **68** during read mode, and counts generated data clock cycles from a data clock generator

75 during write mode. This insures that the data timing and control circuitry **71** will interrupt the data stream at the proper bit boundary.

In response to the servo location signal from comparator **72**, data timing and control circuitry **71** opens switches **78** and **79**. This interrupts the VCO cycles and generated data clock cycles to disk data controller **70** and to ENDEC **69**. This freezes the states of the disk data controller **70** and ENDEC **69**, making each servo sector **30** transparent to the data channel.

Switch **77** is used only during write mode to put a preamp and write driver **66** in read mode to read a servo sector **30**. Switch **76** is opened to prevent detected data from affecting the VCO **68**. This has the effect of a VCO hold. Data timing and control circuitry **71** maintains switches **76–80** as positioned in FIG. **5** for a fixed time period until field **37**. Switch **80** is used only during write mode to write VCO resync field **37** and code constraint field **38**.

In write mode, switch **77** is closed first to enable writing of the VCO resync field **37**. After field **37** is written, switch **80** is closed. In read mode, switch **76** is closed first to allow VCO **68** to resynchronize to the data. Switches **78** and **79** are closed when the VCO resync field operation is completed; i.e., is either written or read. The value in servo location register **74** is then updated with the location of the next servo sector **30**. The channel again functions in the same manner as a prior art data channel until the next servo location signal is generated by comparator **72**.

According to an important feature of the invention, the data and servo sectors work in concert such that the data channel is prepared for each servo sector **30** without requiring an address mark for that sector. To locate each servo sector only a servo start mark **34**, which may be as short as 1 bit, is required. Each servo sector **30** can be located by open-loop timing from the previous servo sector and without any knowledge of the lengths or positions of the data sectors.

IV. Application to Constant Linear Density (CLD) Recording

It will be understood that the sector servo system for CLD recording is essentially the same as described for banded recording, except that the clock frequency changes at each track and the length of each data sector will change from track to track. The manner in which the permissible combinations of servo sample rates and number of data sectors per track is computed is by an apparent modification of the algorithm described in the Appendix for banded recording.

V. Application to Conventional FBA Format

A plurality of servo sectors are positioned and written at the factory. They are circumferentially spaced from each other on each track by an equal angle, which corresponds to a constant time separation. Since the data timing does not change in the FBA format, the allowed combinations of number of servo sectors and number of data sectors per track may be computed in the same manner as described in the Appendix for calculation of the allowed bands for banded recording.

Another approach is to choose a basic data unit that is of the same length as the length of the overhead fields. The allowed data record lengths would then be integral multiples of the data unit length. If the servo sector spacing is chosen such that the distance between adjacent servo sectors is equal to an integral multiple of the data unit length, then the servo sectors will never lie in disallowed regions.

VI. Application to CKD Format

Again, servo sectors are positioned and written at the factory. The first data record on a given track is placed to start at an index mark, like 52. If the next servo sector lies within the write-read recovery area, pad bits are added to the end of the record to insure that the next servo sector lies in the data region. If the next servo sector lies within a disallowed field at the start of the next data record, then pad bits are added to the end of the current record to align the next address mark with the next servo sector. This process is repeated for all sectors on the track. The controller generates the pad bits during a write operation and extracts the pad bits during a read operation, thus making said operations transparent to the host.

VII. Application to Tape Drives

While the invention has been illustrated as applied to disk drives, it will be apparent that the invention is equally applicable to tape drives. In both, the rate at which servo sectors for disk or servo sections for tape are sampled is independent of whether the disk or tape is formatted in FBA or CKD architecture.

In a tape drive, the allowable time separation between servo sections on a track and lengths of associated data sections on the tape is established such that at least some of the equally spaced servo sections on a given track are located within a data field of a data section and the rate at which the servo sections are sampled is independent of the data architecture used. Like the disk embodiments, the reading of a servo section is initiated based upon open-loop timing from the preceding servo section. The first servo section on each track commences at one common track index and each succeeding servo section is initiated at successive locations in equally spaced time increments from said index. Each servo section consists solely of bits containing position information and to each side thereof bits for controlling the interruption and restoration of the writing and reading of data. The ratio of servo sections to data sections is other than 1:1. At least some servo sections are located anywhere within a data field in a data section. At least some others of the equally spaced servo sections are within an identification field or immediately after an address indicating mark.

For a FBA formatted tape, the ratio of the time separation between data sections to the time separation between servo sections should again reduce to a ratio of small integers. For a CKD formatted tape, it will be necessary to add pad bits as described in Section VI.

As hereinafter used in the claims, the term "moving medium" is intended, unless otherwise indicated, to generically define either a magnetic, magneto-optical or optical disk or a magnetic or optical tape; the term "servo sections" is intended generically to cover servo sectors for disk files and servo sections for tape drives; and the term "data sections" is intended to generically define the data sectors for FBA and CLD formats and the variable length records for CKD format.

In the disk embodiments, the allowable number of servo sectors per revolution was calculated for each track or band of tracks. It will be apparent, however, that in view of the constant rotational speed of the disk, the time between each servo sector is constant. Hence, in both the disk and tape embodiments, the allowable time separation between servo sectors on a track is calculated, though in the disk embodiment this was expressed as allowable number of servo sectors on a track.

While the invention has been shown and described with respect to preferred embodiments thereof, it will be understood by those skilled in the art that changes in form and detail may be made in these embodiments without departing from the scope and teaching of the invention. Accordingly, the method and means herein disclosed are to be considered merely as illustrative, and the invention is to be limited only as specified in the claims.

APPENDIX

Computation of Permissible Servo Sample to Data Sector Combinations for Banded Recording in FBA Format

Assuming initially that the allowable linear density as a function of radius is known, the various fields are broken down into those portions which scale with linear density and those which do not. All references to bits are in message (non-encoded) bits; and the linear density units are kbpmm (kilobits per millimeter), also message bits. Assume further that

- DB=number of data bits per sector (same for all bands for banded recording)
- SB=number of servo bits (data rate dependent portion)
- SF=fixed length portion of servo in μs
- OB=number of bits in other fields (data rate dependent portion)
- OF=fixed length portion of other fields in μs
- P=rotational period in μs (i.e., 1/rpm)
- M=number of data sectors in a band
- N=number of servo samples per revolution
- ld(r)=linear density in kbpmm, where r is the radius in mm
- OH=fixed overhead

The minimum allowable ID radius for a band is then given by:

$$\text{bits} = \frac{(M \times (DB + OB) + N \times SB)}{1000}$$

$$OH = M \times OF + N \times SF$$

$$r = \frac{\text{bits}/ld(r)}{2\pi\left(1 - \frac{OH}{P}\right)}$$

$$rld(r) = \frac{\text{bits}}{2\pi\left(1 - \frac{OH}{P}\right)}$$

Where ld(r) is a constant,

$$ld(r) = B,$$

$$r = \frac{\text{bits}}{2B\pi\left(1 - \frac{OH}{P}\right)}$$

and where ld (r) is linear:

$$ld(r) = Ar + B.$$

-continued

$$r = \frac{-B + \sqrt{B^2 + \frac{4A\text{bits}}{2B\pi\left(1 - \frac{OH}{P}\right)}}}{2A}$$

Usually the linear density decreases with increased radius, therefore A<0 and B>0. In this case, the positive root of the quadratic yields the smaller radius (the negative root occurs where the decreasing linear density is compensated for by the increasing circumference of the track).

Once the minimum allowable ID radius has been computed, the actual relationship between the positions of servo sectors **30** and data sectors M muse be computed to determine if the band is valid; i.e., that the servo samples N occur only in the allowed positions.

To determine the allowed bands:

1. Choose a servo sample rate. (For example, 60.)

2. Compute the band with the greatest number of data sectors, whose minimum allowable ID radius is less than or equal to the disk ID. (For example, assume the result is 31 data sectors.)

3. Starting with this band, check to see if it is valid. If not, decrease the sector count by 1 and repeat. (Thus, decrease from 31 to 30.) Note that if the sector count goes to 0 without success, there is no allowable ID band under these conditions.

4. Start with the first band whose minimum allowable ID radius is greater than the disk ID. (This could be 30 data sectors as a result of the example used for step 3.)

5. See if the band is valid, if so, add it to the list. Increase the sector count by 1 and repeat until the minimum allowable ID radius is greater than or equal to the disk OD. (Again, using the example from the prior steps, step 5 could give the following numbers of data sectors per band: 30, 35, 36, 40, 42, 45, 48, 50 and 54, of which for simplified illustration only four, A–D, are shown in FIG. 4.)

We claim:

1. A magnetic recording disk, the magnetic recording surface of the disk being divided into a plurality of radially-spaced bands, each band comprising a plurality of concentric data tracks, all of the data tracks in each band being divided into the same number of data sectors, the number of data sectors in a data track of each band being different from the number of data sectors in a data track in the other band or bands, but each data sector in each band containing the same number of data bits, the magnetic recording surface also having formed on it a plurality of generally equally angularly-spaced servo sectors extending generally radially across the bands, wherein some of the servo sectors are located within some of the data sectors.

2. The disk according to claim **1** wherein some of the servo sectors located within some of the data sectors split those data sectors into at least two portions of substantially different circumferential lengths.

3. A magnetic recording disk, the magnetic recording surface of the disk having (a) a plurality of radially-spaced bands, each band comprising a plurality of concentric data tracks: (b) a plurality of data sectors in each data track of each band, the number of data sectors per data track being the same for all data tracks in a band and different from the number of data sectors per data track in the other band or bands, but each data sector in each band containing the same number of data bits; and (c) a plurality of generally equally angularly-spaced servo sectors, each of the servo sectors extending generally radially across the bands with at least one of the servo sectors being located within one of the data sectors of one of the bands and splitting that data sector into multiple portions.

4. The disk according to claim **3** wherein the magnetic recording surface of the disk also has (d) a radial index mark, the index mark being common to all the bands and extending across the bands in a generally radial direction, and wherein the first servo sector is located at the common radial index mark.

5. The disk according to claim **3** wherein at least one of the servo sectors located within one of the data sectors splits that data sector into at least two portions of substantially different circumferential lengths.

6. The disk according to claim **3** wherein if the number of data sectors within each band is represented by the variable M and the number of servo sectors is represented by the constant N, then the ratio of M to N for each band is equal to a ratio of two integers, each integer being within the range of 1 to 12.

* * * * *

EXHIBIT 3

US005615190A

United States Patent [19]

Best et al.

[11] **Patent Number: 5,615,190**

[45] **Date of Patent: Mar. 25, 1997**

[54] **FIXED- BLOCK ARCHITECTURE EMBEDDED SERVO DISK DRIVE WITHOUT DATA IDENTIFICATION (ID) REGIONS**

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[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

[21] Appl. No.: **469,066**

[22] Filed: **Jun. 6, 1995**

Related U.S. Application Data

[60] Continuation of Ser. No. 218,546, Mar. 28, 1994, abandoned, which is a division of Ser. No. 82,826, Jun. 23, 1993, Pat. No. 5,500,848, which is a continuation of Ser. No. 727,680, Jul. 10, 1991, abandoned.

[51] **Int. Cl.**[6] **G11B 7/00**

[52] **U.S. Cl.** **369/58**; 369/275.3; 369/48

[58] **Field of Search** 369/54, 58, 48, 369/32, 44.26, 275.3; 360/48, 51, 77.08, 77.04

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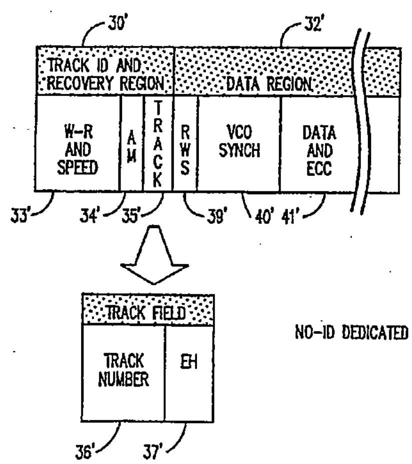
Primary Examiner—Nabil Hindi
Attorney, Agent, or Firm—Thomas R. Berthold; David J. Kappos

[57] **ABSTRACT**

A data recording disk drive is provided with a fixed block architecture sector format that eliminates the ID region. The servo region contains sector identification information in the form of a start-of-track indicating mark recorded in a selected sector of each track and a start-of sector indicating mark recorded in each sector. A full track number identifier is encoded in the position field within the servo region of each sector. A look-up table is built at format time to map bad sectors out of the disk drive. The table contains entries for each cluster of contiguous bad sectors, and is searched at runtime to provide conversion of logical sector location identifiers to physical sector location identifiers.

26 Claims, 4 Drawing Sheets



NO-ID DEDICATED SERVO SECTOR FORMAT

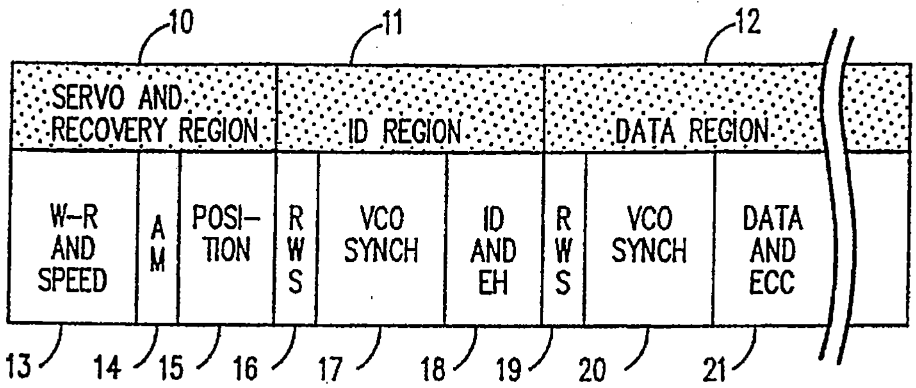


FIG. 1A: PRIOR ART SECTOR SERVO SECTOR FORMAT

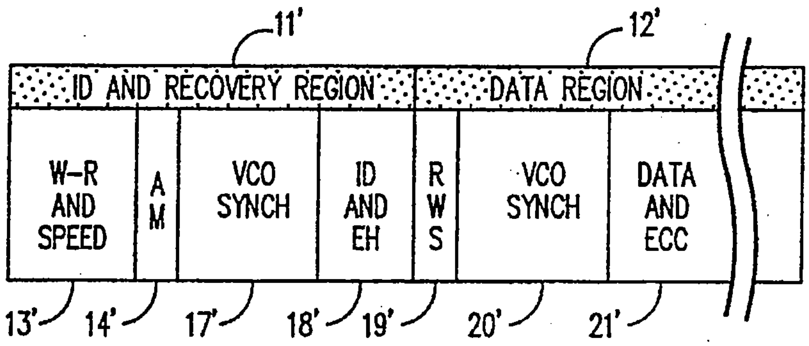


FIG. 1B: PRIOR ART DEDICATED SERVO SECTOR FORMAT

Bad Sector List							
Physical Sector	3	5	6	9	10	11	13
Logical to Physical Mapping							
Logical Sector	1	2	3	4	5	6	7
Physical Sector	1	2	4	7	8	12	14
Look-up Table							
Logical Sector	3	4	6	7			
Offset	1	3	6	7			

FIG. 3: EXAMPLE OF LOOK-UP TABLE CREATION

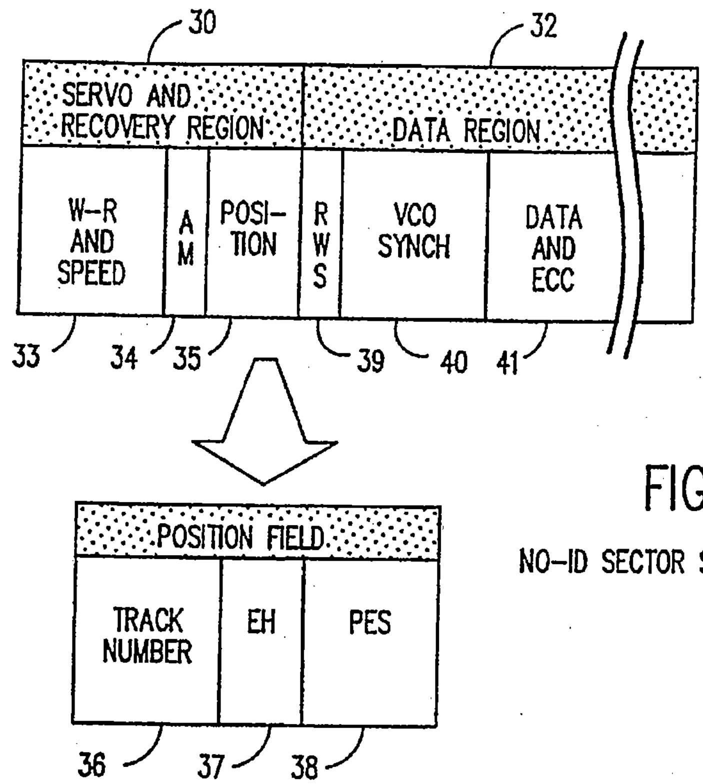


FIG. 2A:

NO-ID SECTOR SERVO SECTOR FORMAT

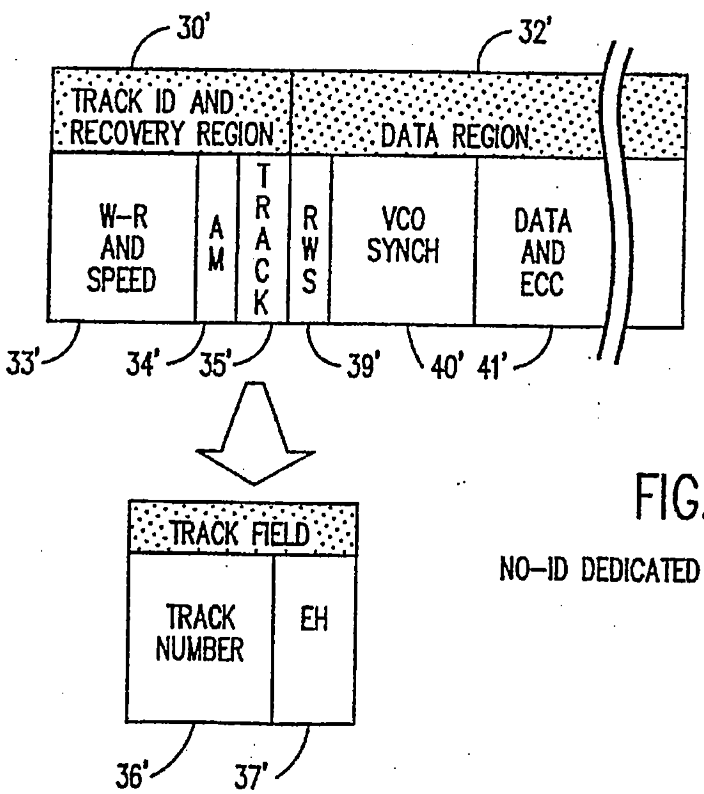


FIG. 2B:

NO-ID DEDICATED SERVO SECTOR FORMAT

```
static int tl[MAXBAD];            /*lookup table: logical #*/
static int to[MAXBAD];            /*lookup table: offset*/
static int nt = 0;                /*number table entries*/

void build(b,nbad)                /*build bad sector table*/
int b[MAXBAD];                    /*physical bad sectors*/
int nbad;                         /*number of bad sectors found*/
{
  int bad;

  bad = 0;                        /*bad sector counter*/
  nt = 0;                         /*table index counter*/

  tl[nt] = b[bad];                /*first entry*/
  to[nt] = 1;                     /*offset starts at 1*/
  bad++;                          /*next bad sector*/
  while (b[bad] == b[bad-1]+1) {  /*while adjacent sectors*/
    to[nt]++;                     /*increment offset*/
    bad++;                        /*next sector*/
 }

 while (bad < nbad) {
   nt++;                          /*next table entry*/
   tl[nt] = b[bad] - to[nt-1];    /*will be next entry*/
   to[nt] = to[nt-1] + 1;         /*starting offset*/
   bad++;                         /*next bad sector*/
   if (bad == nbad) break;        /*end of the list*/
   while (b[bad] == b[bad-1]+1) { /*while adjacent sectors*/
     to[nt]++;                    /*increment offset*/
     bad++;                       /*next sector*/
     if (bad == nbad) break;      /*end of the list*/
   }
 }
 nt++;                            /*nt is now # elements*/
 if ((nt & 1) == 0) {             /*table should be odd*/
   tl[nt] = 32767;                /*max allowed value*/
   nt++;
 }
} /* build */
```

FIG. 4: Look-up Table Generation Algorithm in C.

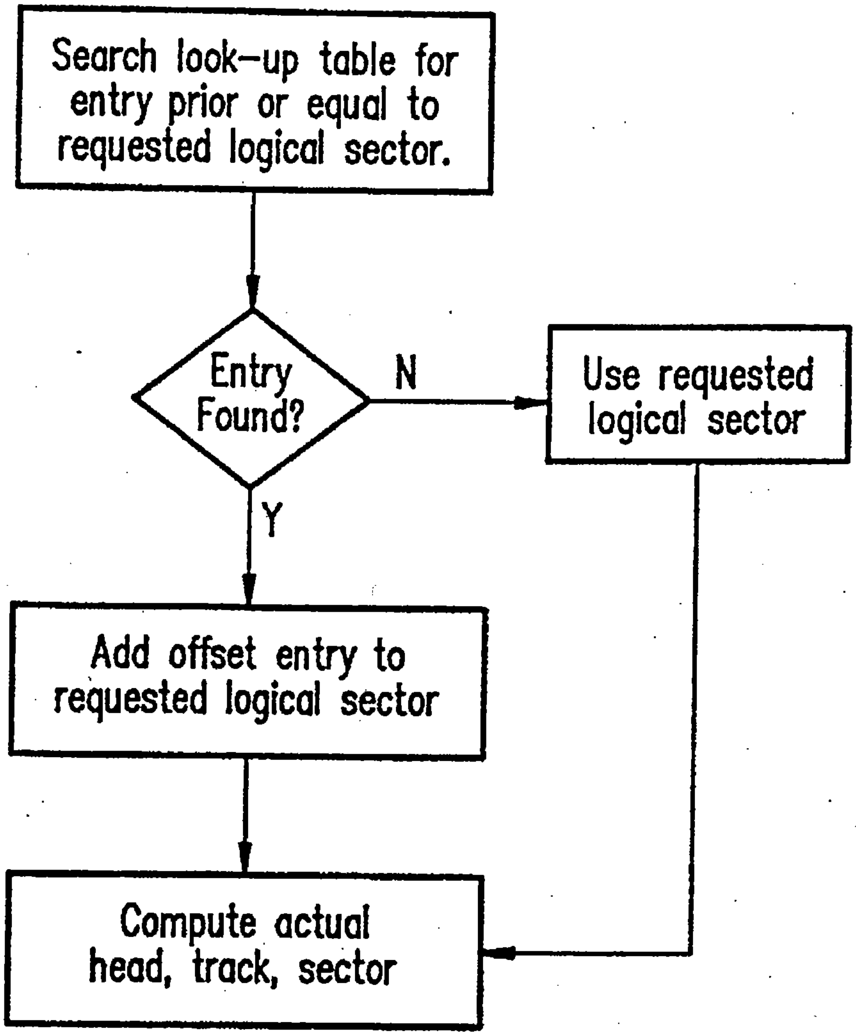


FIG. 5: Logical-to-Physical Sector Conversion Algorithm

FIXED- BLOCK ARCHITECTURE EMBEDDED SERVO DISK DRIVE WITHOUT DATA IDENTIFICATION (ID) REGIONS

This is a continuation of application Ser. No. 08/218,546 filed on Mar. 28, 1994 now abandoned which is a division of application Ser. No. 08/082,826 filed on Jun. 23, 1993 now U.S. Pat. No. 5,500,848 which is a continuation of application Ser. No. 08/727,680 filed Jul. 10, 1991 now abandoned.

BACKGROUND OF THE INVENTION

All disk drives require some means of determining the radial position of the READ-WRITE heads over the disks so that the heads can be accurately positioned over any desired track. Typically this is accomplished by placing servo information on one or more of the disk surfaces for reading by magnetic or optical heads. Some disk drives, known as dedicated servo drives, contain servo information only on a dedicated surface of one disk in the disk stack. In contrast, some modern drives, known as sector servo drives, store the servo information interspersed with the data on each disk surface. This latter approach represents the direction in which the technology is progressing and is preferred because it can be implemented at low cost and without additional componentry beyond that required to store the data and further because it provides the servo information at the data surface being accessed, thereby eliminating many mechanical and thermal sources of track misregistration. Fixed block architecture (FBA) is a common configuration used to format both dedicated servo disk drives and sector servo disk drives. In an FBA formatted disk drive, each disk track is divided into a number of equal-sized sectors, and each sector is divided into regions containing servo information, identification information(ID), and data.

A typical FBA sector servo sector format according to the prior art is illustrated in FIG. 1A. The sector is divided into three regions: servo and recovery region **10**, ID region **11**, and data region **12**. Generally, servo and recovery region **10** contains overhead associated with sectoring, as well as servo information for sector servo drives. Also, this region marks the beginning of the sector. Specifically, servo region **10** contains WRITE-to-READ recovery (W-R) and speed compensation field **13**, which is used to switch the data channel from WRITE to READ and accommodate spindle speed variations; address mark (AM) field **14**; and servo position field **15** containing a position-error-signal (PES). Data region **12** contains the user data, as well as overhead fields. READ-to-WRITE recovery (R-W) and speed field **19** performs a function like that of W-R and speed field **13**. Voltage controlled oscillator (VCO) synch field **20** is used to synchronize the read clock with the read data. Data field **21** contains the user data and associated error checking and correction (ECC) information. ID region **11** is used by the disk data controller (DDC) to identify the physical sector number. It contains R-W and speed field **16**, VCO synch field **17** and identification/error handling (ID/EH) field **18**, which contains the identification information including the logical sector number.

A typical FBA dedicated servo sector format according to the prior art is illustrated in FIG. **1B**. The data disk sector shown is divided into two regions: ID and recovery region **11'** and data region **12'**. ID and recovery region **11'** contains substantially the same information as servo and -recovery region **10** and ID region **11** of FIG. 1A, with the exception that servo position field **15** and R-W and speed field **16** are

removed. In a dedicated servo scheme, servo position field **15** is not needed because the position information is contained on a separate surface; R-W and speed field **16** is not needed because address mark field **14'** can be written whenever the succeeding VCO synch field **17'** and ID/EH field **18'** are written. Data region **12'** contains substantially the same information as data region **12** of FIG. 1A.

ID regions **11** and ID and recovery region **11'** of the prior art FBA sector formats perform two important functions. First, they uniquely identify the logical sector number of the sector in which they are located. Second, they indicate whether the sector is good or bad (that is, whether the sector can be successfully written to and read from). Unfortunately, in both the dedicated servo and sector servo scheme, the ID region requires a great deal of disk space to perform its functions. Since the disk uses the information in the ID region to perform a logical-to-physical sector conversion in order to locate the physical position on the disk corresponding to the requested logical sector, the ID region must be large enough to avoid misidentifying sectors. Furthermore, since a phase synchronous clock is typically used to read the ID/EH field, the VCO field is required; this field is typically much larger than the ID/EH field. Finally, in the sector servo scheme, due to the region transition, an R-W and speed field is required to switch the data channel from READ to WRITE and accommodate spindle speed variations.

In sum, due to overhead and accuracy requirements, the ID region of the prior art FBA sector accounts for a substantial portion of the overall sector length (typically about 4%), a portion that could otherwise be used for data storage. However, the importance of its two functions has hampered efforts to eliminate it from the FBA sector.

One approach that has been used to eliminate the ID region is to encode the ID information into the data field. This eliminates the overhead associated with synching (fields **16** and **17**), and allows the ECC to provide error checking for the ID information. However, it does not eliminate or reduce the actual ID information as contained in ID/EH field **18**. Also, it adds a minimum of one sector time to the latency during WRITE, since the disk drive controller cannot determine the good/bad sector relationship until it has read at least one sector. Further, this scheme is not well suited to compact and low-cost disk drives, where the error correction time is typically quite long, since it means a revolution may be lost in the case of a sector where any bit is bad in the entire field containing the combined ID and data. Thus, while the approach of combining the ID and data regions reduces the disk space required for ID information, this approach introduces performance penalties that restrict its usefulness.

OBJECTS OF THE INVENTION

It is therefore an object of the present invention to provide a data recording disk drive having a sector format that eliminates the need for an ID region.

It is another object of the present invention to provide a data recording disk drive having a sector format that uniquely identifies each track and each sector of a multiple track data storage medium.

It is another object of the present invention to provide a data recording disk drive having a sector format that includes information encoded in the servo region of a sector to uniquely identify the sector.

It is another object of the present invention to provide a data recording disk drive having a table for cataloging and mapping around bad sectors caused by media defects.

These and other objects will become more apparent when read in light of the following specification and drawings.

SUMMARY OF THE INVENTION

In accordance with the invention, a data recording disk drive is provided with an FBA sector architecture that eliminates the ID region while preserving its function. For disk drives implementing a sector servo scheme, the position field in the servo region of each sector is expanded to include a full track number identifier. For disk drives implementing a dedicated servo scheme, a track field is created in the servo region of each sector to include a full track number identifier. In either scheme, this enables the DDC to verify the full physical track number. The function performed by the ID/EH field is moved to the servo region in the form of a start-of-track indicating mark recorded in a selected sector of each track and a start-of-sector indicating mark recorded in each sector. The disk drive uniquely identifies a requested sector by detecting the start-of-track indicating mark and then counting start-of-sector marks to the appropriate sector.

Bad sectors are mapped out of the disk drive by means of a look-up table. At disk format time, each sector is written to and read from to determine whether it is operable or defective. Clusters of defective sectors are marked bad by recording in the look-up table the sector location identifier of the first bad sector in the cluster and the quantity of consecutive bad sectors in the cluster. During operation, the disk drive performs logical-to-physical sector conversion by searching the look-up table for an entry having a value less than or equal to the requested logical sector location identifier. If none is found, the physical sector location identifier is equal to the logical sector location identifier. If an entry is found, an offset representing the quantity of consecutive bad sectors associated with the entry is added to the logical sector location identifier to produce the physical sector location identifier. Then the physical sector location identifier is converted into an actual head, track and sector location, which is accessed by counting start-of-sector marks after a start-of-track mark on the appropriate track.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a schematic diagram illustrating a fixed block architecture sector servo sector format according to the prior art.

FIG. 1B is a schematic diagram illustrating a fixed block architecture dedicated servo sector format-according to the prior art.

FIG. 2A is a schematic diagram illustrating a fixed block architecture sector servo sector format according to the present invention.

FIG. 2B is a schematic diagram illustrating a fixed block architecture dedicated servo sector format according to the present invention.

FIG. 3 is a table illustrating a bad sector list, a logical-to-physical mapping, and a look-up table according to the present invention.

FIG. 4 is a C language procedure illustrating an algorithm for creating a look-up table according to the present invention.

FIG. 5 is a flowchart illustrating an algorithm for performing logical-to-physical sector conversion according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

IA. NO-ID FBA SECTOR SERVO SECTOR FORMAT

FIG. 2A illustrates in schematic diagram form an FBA sector servo sector according to the present invention. Servo and recovery region **30** includes W-R and speed field **33**, AM field **34** and position field **35**. Position field **35** itself includes track number subfield **36**, EH subfield **37** and PES subfield **38**. Data region **32** includes R-W and speed field **39**, VCO synch field **40** and data field **41**.

In operation, fields **33**, **34**, **39**, **40** and **41** provide substantially the same functions as fields **13**, **14**, **19**, **20** and **21** shown in prior art FIG. **1**A and described previously. Fields **16**, **17** and **18** from prior art FIG. **1**A are eliminated.

Position field **35** is expanded over position field **15** of the prior art, as shown in the lower portion of FIG. 2A. According to the preferred embodiment of the present invention, the full track number corresponding to the track on which the sector is located is recorded in track number subfield **36**. EH subfield **37** is provided as an adjunct to the full track number to ensure that the track number has been read correctly. Finally, the actual position-error-signal is encoded in PES subfield **38**. This subfield contains substantially the same information as position field **15** of prior art FIG. **1**A.

It is to be noted that both the full track number and the EH information may be recorded according to any of a variety of techniques well known to those skilled in the art of data recording disk sector formats. For instance, a gray code may be used to record the full track number because it allows the full track number to be accurately read when the disk head is off-track. The EH information may implement any of a variety of schemes well known to those skilled in the art, including error checking and correction (ECC) codes and cyclic redundancy check (CRC) codes. According to the preferred embodiment of the present invention, EH subfield **37** is implemented using CRC, an error-check-only code. CRC is chosen because it is easy to compute and because it requires a small number of bits (roughly **16**). Since CRC bits will not form a gray code, EH subfield **27** is implemented in a code that is accurately readable only when the head is on track. This implementation has no adverse impact on the present invention, since an absolutely accurate reading of the track number subfield is required only when the head is already on-track.

The No-ID sector format of the present invention provides several space saving advantages over the prior art. The track number need not be redundantly encoded in an ID region but instead is communicated to the DDC by the servo system at runtime. Servo region number subfield **36** and EH subfield **37** are substantially shorter than ID region **11** shown in prior art FIG. **1**A, since the FBA format of the present invention is able to use CRC rather than other forms of ECC and since the maximum track number is one or two orders of magnitude smaller than the maximum sector number encoded in prior art ID/EH field **18**. Since fewer bits are required to represent the track number, this quantity may be recorded at lower density, so that track number subfield **36** and EH subfield **37** can be read without a phase synchronous clock; therefore, VCO synch field **17** is not required. Finally, since no separate ID region is set up, R-W and speed field **16** is eliminated.

As discussed above, the preferred embodiment of the present invention contemplates the use of a full track number in track number subfield **36** in order to provide absolute identification of the track number for READ and WRITE operations. However, it is to be understood that the track number may be encoded according to a variety of alternative schemes. For instance, PES subfield **38** may itself assume the form of a pattern which is unique over a range of tracks, and may be used to construct the LSBs of the track number. Thus, if the PES pattern repeats every four tracks, it may be used to provide the two LSBs of the track number. Or, the MSBs of the track number may be omitted altogether and the servo electronics depended on to determine which half (or quarter, or eighth) of the disk the head is positioned over.

The application of the present invention to sector servo disk drives has been described with reference to the sector servo sector format shown in FIG. 2A. However, it should be noted that the present invention may be applied to any sector servo format fin which the track number may be encoded in the servo and recovery region. For example, instead of a fixed spacial relationship between the servo regions and data regions, a sector servo format may provide servo information at other than fixed intervals with respect to data, such as within the data region itself. Such a scheme is disclosed in U.S. Pat. No. 5,210,660. In this case, the fields in FIG. 2A may be repositioned such that servo and recovery region **30** is split into separate recovery and servo regions with the recovery region containing fields **33** and **34** and the servo region containing field **35**. The sector number and track number may then be determined in the same manner as with the sector format shown in FIG. 2A.

IB—NO-ID FBA DEDICATED SERVO SECTOR FORMAT

FIG. 2B illustrates in schematic diagram form an FBA data disk dedicated servo sector according to the present invention. Track ID and recovery region **30'** is produced by combining aspects of prior art ID and recovery region **11'** with the full track number. However, it contains no position error information analogous to that found in PES subfield **38**. Track ID and recovery region **30'** includes W-R and speed field **33'**, AM field **34'** and track field **35'**. Track field **35'** itself includes track number subfield **36'** and EH subfield **37'**. Data region **32'** assumes the same form as data region **32** in the sector servo format.

In operation, fields **33'**, **34'39'**, **40'** and **41'** provide substantially the same functions as fields **13'**, **14'**, **19'**, **20'** and **21'** shown in prior art FIG. 1B and described previously. Fields **17'** and **18'** from prior art FIG. 1B are eliminated. Track number subfield **36'** and EH subfield **37'** are identical to fields **36** and **37** in FIG. 2A. The full track number is therefore provided in the same manner as for the sector servo format, including the alternative encodement schemes discussed in section 1A. As with the sector servo format, the track number field must be accurately readable only when the head is on-track, since it is used only during read and write operations.

While FIG. 2B and the above description have focused on a dedicated servo data disk having the sector format of the present invention, it is to be noted that this sector format may also be applied to the dedicated servo disk itself. That is, track field **35'** may be encoded on the dedicated servo disk. This configuration is not the preferred embodiment, as it requires more rigorous constraints on the system mechanics. However, it has the advantage of lower overhead since field **35'** is not placed on the data surface, and thus may provide an attractive alternative that is within the scope and spirit of the present invention.

Dedicated servo systems record the head positioning information on a single magnetic recording surface, separate from the data surface(s). However, it is to be understood that there are many other types of servo systems, which for the purposes of the present invention function similarly to the dedicated servo system. These include systems such as: optical recording continuous groove systems, where the tracking information is provided by grooves in the substrate; buried servos, whether magnetically, capacitively, or otherwise encoded; optical tracking servos, where the servo information is optically encoded on a data or servo surface; and baseplate reference servo systems, where the positioning information is provided by some external reference such as an optical encoder or a stepping motor. Finally, it is worthy to note that the present invention may be readily applied to systems combining aspects of sector servo and dedicated servo.

II. LOGICAL-TO-PHYSICAL SECTOR CONVERSION

According to the prior art, physical sectors are accessed by counting actual sectors. Physical sector **0** refers to sector **0**, head **0**, track **0**. The number increases by counting sectors around a track, then switching heads, then tracks.

According to the present invention, physical sectors are accessed by counting start-of-sector indicating marks after a start-of-track indicating mark. A start-of-track indicating mark is encoded in a preselected track to provide a reference point from which to count sectors. A start-of-sector indicating mark is encoded in each sector. In operation, a requested physical sector is accessed by detecting the start-of-track indicating mark and then counting start-of-sector indicating marks until the appropriate sector is reached.

In the preferred embodiment of the present invention, the start-of-track indicating mark takes the form of a unique bit called an index mark, recorded in a preselected track number subfield **36**. AM field **34** of each sector is used as the start-of-sector indicating mark. The servo system then counts AM fields after an index mark to locate a requested sector. No additional overhead is incurred, since the servo system must locate every AM field in order to read the PES subfield. Also, the scheme requires only a small counter, since the number of sectors per track is typically less than 64, and since the sector count is reset each time an index mark is detected.

There are a number of variations on the embodiment that serve to improve error tolerance where AM field **34** is missed due to a disk defect. First, the physical sector number may be encoded into track number field **36**. Second, an open loop timer may be used to provide a timeout error if an address mark is not detected within a given time interval. Third, position fields may be counted in addition to AM fields.

III. LOOK-UP TABLE

Prior art disk drive implementations handle bad sectors via the sector ID region. According to the present invention in which the ID region has been eliminated, bad sectors are identified and mapped out of the data recording disk drive during logical-to-physical sector conversion using a look-up table. The table is created at format time, and consists of entries describing clusters of bad sectors (where a cluster is defined as a sequential group of physical bad sectors) by starting location and quantity. In operation, a requested logical sector location identifier is referenced into the table, and a corresponding entry is found describing an offset to the physical sector location identifier.

More specifically, at format time, the data recording disk drive generates a list of physical sector location identifiers for the bad sectors in the disk drive. This list may be generated using any of the various techniques known in the art for locating bad sectors. The list is held in RAM and is used to construct the look-up table. FIG. **3** illustrates in tabular form an example of a bad sector list, a logical-to-physical mapping and a look-up table according to the preferred embodiment of the present invention. The bad sector list indicates that physical sectors **3**, **5**, **6**, **9**, **10**, **11** and **13** were found to be bad at format time. The logical-to-physical mapping shows the desired mapping to be achieved by the look-up table. Logical sector **1** will be found at physical sector 1; logical sector **2** will map to physical sector **2**; logical sector **3** will map to physical sector **4** since physical sector **3** is defective, etc.

The look-up table shows the result of compressing the bad sector list in accordance with the present invention. Starting at logical sector **3**, there is a cluster of 1 bad sector; thus, sectors **3** and beyond must be offset by 1 to map into the correct physical sector. Starting at logical sector **4**, there is; a cluster of 2 bad sectors; thus, sector 4 and beyond must be offset by a total of 3 to map into the correct physical sector. Starting at logical sector **6**, there is a cluster of 3 bad sectors; thus, sectors **6** and beyond must be offset by a total of 6 to map into the correct physical sector. Finally, starting at logical sector **7**, there is a cluster of 1 bad sector; thus, sectors **7** and beyond must be offset by a total of 7 to map into the correct physical sector.

It is to be noted that the look-up table may be stored either on the boot track of the disk or in some non-volatile semiconductor memory in the data recording disk drive, such as EEPROM, FRAM, or PROM. The first column of the table must be wide enough to hold the largest physical sector number (24 bits is sufficient in most cases). The second column must be wide enough and the table long enough to hold the maximum number of bad sector clusters likely to be encountered (16 bits is sufficient in most cases).

FIG. **4** illustrates in algorithmic form a procedure for creating a look-up table according to the preferred embodiment of the present invention. The look-up table generation algorithm (shown in C programming language) processes the bad sector list as follows. First, the list of bad sectors is converted into the compact table representation. Then, the first "while" loop computes the offset for the first block by determining its size (i.e. the number of contiguous bad sectors). Next, the second "while" loop performs the same operation for all the remaining blocks, determining each offset by adding the number of sectors in the block to the total number of bad sectors prior to the block. Finally, the look-up table is adjusted to contain an odd number of entries, for ease of access by a binary search look-up routine. Of course, many other search types are possible, the use of which would obviate this final step. Also, it is worthy of note that the look-up table generation algorithm may be executed against the entire bad sector list, or, where storage or processing constraints arise, may be executed in a piecewise fashion, so that each block of bad sectors is processed as it is located.

FIG. **5** illustrates in flowchart form an algorithm for performing logical-to-physical sector conversion according to the preferred embodiment of the present invention. A READ or WRITE request, including a logical sector location identifier, is generated within the disk drive. A look-up table containing bad sector information and indices as described above is accessed and searched for the largest logical sector entry less than or equal to the requested logical sector. In the event no entry is found, the physical sector location identifier is equal to the logical sector location identifier, and the requested logical sector is accessed by computing head, track and sector number directly from the logical sector location identifier according to any of a variety of techniques well known to those skilled in the art.

If an entry is found in the look-up table, the corresponding offset is extracted from the look-up table and added to the logical sector location identifier of the requested logical sector. This sum, representing the physical sector location identifier, is used to compute the head, track and sector number corresponding to the requested logical sector.

In some implementations (e.g. SCSI), it may be desirable to allow for the relocation of bad sectors without resorting

to a complete device format operation. This feature is implemented in conjunction with the present invention by allocating a set of sectors as spares prior to an initial format operation. The spares are treated as though they are bad sectors for purposes of constructing the logical-to-physical mapping table. The spare sectors are then distinguished from bad sectors, for instance by means of a flag in the mapping table or a separate list. Relocation of a bad sector is accomplished by logically substituting one of the spare sectors in its place, shifting all the intervening sectors by one logical sector location, updating the spare sector list to reflect the use of the spare sector, and re-constructing the logical-to-physical mapping table to reflect all the above changes.

A look-up table constructed according to the preferred embodiment of the present invention as described above has the advantageous effect of placing most of the computational overhead into building the table during the format operation, leaving a simple computation to support logical-to-physical mappings during seek operations. It is to be noted that the preferred embodiment look-up table approach is maximally effective when the total number of bad sectors in the data recording disk drive is small, since this keeps the overall table size small and thus keeps the worst-case binary search of the table short. For example, a disk drive having 240K sectors and 0.1% bad sectors would require a table having less than 1000 entries. The look-up table, in cooperation with the above-described algorithm, provides a scheme that efficiently catalogues bad sectors and enables rapid calculation of the correct physical sector corresponding to a requested logical sector.

Furthermore, the No-ID scheme of the present invention is particularly well suited for use with disk drives having different heads for reading and writing, such as magneto-resistive read heads, where the heads must be moved to slightly different radial positions for reading and writing (a practice known as micro-jog). With prior art fixed block architectures, writing a data field requires prior reading of the ID field. However, it is not possible to complete a micro-jog between the two fields, so a revolution is lost in performing the micro-jog. The No-ID format of the present invention eliminates this problem since it has no ID field to be read.

While the invention has been particularly described and illustrated with reference to a preferred embodiment, it will be understood by those skilled in the art that changes in the description or illustrations may be made with respect to form or detail without departing from the spirit and scope of the invention.

Having thus described the invention, what is claimed is:

1. A fixed-block architecture embedded servo disk drive comprising:

a data recording disk having a plurality of tracks, each track being divided into a number of data regions and servo regions, the servo regions containing servo region count information, and wherein none of the tracks have, either within or outside the data regions and servo regions, identification (ID) regions containing information that uniquely identifies the data regions in the tracks;

a recording head which reads information in the servo regions and which writes and reads user data in preselected ones of the data regions; and

a disk data controller coupled to the recording head for identifying the preselected data regions based on servo region count information read by the recording head from circumferentially preceding servo regions without use of ID regions.

2. The disk drive as recited in claim **1**, wherein at least one of the data regions is split by a servo region.

3. The disk drive as recited in claim 1, wherein the servo region count information is servo region number information.

4. The disk drive as recited in claim 1, each of the tracks further including a start-of-track indicating mark, the data regions being identified based on the start-of-track indicating mark and a count of the number of servo regions.

5. The disk drive as recited in claim 1, further including a timer, responsive to detection of a servo region, which provides a timeout signal indicating failure to detect an expected servo region.

6. The disk drive as recited in claim 1, wherein the servo regions include error handling fields.

7. The disk drive as recited in claim 1, wherein the servo regions include position fields having track numbers recorded therein.

8. The disk drive as recited in claim 7, wherein the track numbers are full track numbers.

9. The disk drive as recited in claim 1, further including a defect map, the data regions being identified based on information from the defect map.

10. A fixed-block architecture embedded servo disk drive comprising:

a data recording disk having a plurality of tracks, each track being divided into a number of data regions and servo regions, the servo regions containing servo region count information, at least one of the data regions being split by a servo region, and wherein none of the tracks have, either within or outside the data regions and servo regions, identification (ID) regions containing information that uniquely identifies the data regions in the tracks;

a read head adjustable to different radial positions and capable of reading information in the servo regions, including a servo region that splits a data region;

a write head different from the read head for writing user data in the data regions, including a split data region; and

a disk data controller for initiating read and write operations, a write operation of user data in a split data region being preceded by reading of servo region count information from servo regions, including a servo region that splits a data region, but not preceded by reading of information from an ID region.

11. The disk drive as recited in claim 10, each of the tracks further including a start-of-track indicating mark, the split data region where data is to be written being located by detecting the start-of-track indicating mark and counting servo regions.

12. The disk drive as recited in claim 10, wherein the servo regions include error handling fields.

13. A fixed-block architecture embedded servo disk drive comprising:

a data recording disk having a plurality of tracks, each track being divided into a number of data regions, at least one of the data regions containing a defect where data cannot be written, and servo regions containing servo region count information, and wherein none of the tracks have, either within or outside the data regions and servo regions, identification (ID) regions containing information that uniquely identifies the data regions in the tracks;

a recording head which reads information in the servo regions and which, writes and reads data in the data regions;

a defect map which contains information relating to the locations of defects on the disk; and

a disk data controller coupled to the recording head for locating the data regions without defects where data is to be written by use of the servo region count information in the circumferentially preceding servo regions read by the recording head in combination with information read from the defect map but without use of ID regions.

14. The disk drive as recited in claim 13, wherein the defect map information converts logical sector numbers to physical sector numbers.

15. The disk drive as recited in claim 13, wherein the data regions without defects are located by data sector numbers derived from the servo region count information and the defect map.

16. The disk drive as recited in claim 15, each of the tracks further including a start-of-track indicating mark and the servo region count information including start-of-servo-sector marks, the data regions without defects being located by detecting the start-of-track indicating mark and counting start-of-servo-sector marks.

17. The disk drive as recited in claim 13, wherein at least one of the data regions is split by a servo region.

18. The disk drive as recited in claim 13, wherein the servo regions include error handling fields.

19. A fixed-block architecture embedded servo disk drive comprising:

a data recording disk having a plurality of tracks, each track having a start-of-track indicating mark and being divided into data regions and servo regions containing position fields and servo region count information, none of the tracks having, either within or outside the data regions and servo regions, identification (ID) regions containing information that uniquely identifies the data regions in the tracks;

a magnetoresistive read head which reads position fields and servo region count information in the servo regions and user data in the data regions;

a write head not radially aligned with the read head and which writes user data in the data regions; and

data control electronics which identify the data regions where data is to be written based on detection of the start-of-track indicating mark and reading of servo region count information in the circumferentially preceding servo regions by the read head; whereby user data is written in the data regions by the write head without radially jogging the write head following reading of the preceding servo regions by the read head but without reading of information from ID regions.

20. The disk drive as recited in claim 19, wherein the servo regions have track number information recorded therein and the data control electronics are responsive to the track number information.

21. The disk drive as recited in claim 10, wherein the read head is a magnetoresistive read head.

22. The disk drive as recited in claim 19, wherein the start-of-track indicating mark is an index mark.

23. The disk drive according to claim 19, wherein the start-of-track indicating mark is located in one of the servo regions.

24. The disk drive as recited in claim 19, wherein the servo region count information is a servo sector number.

25. The disk drive as recited in claim 19, wherein the servo region count information is a start-of-servo-sector mark.

26. The disk drive as recited in claim 19, wherein at least one of the data regions is split by a servo region.

* * * * *

EXHIBIT 4

US005500848A

United States Patent [19]

Best et al.

[11] **Patent Number: 5,500,848**

[45] **Date of Patent: Mar. 19, 1996**

[54] **SECTOR SERVO DATA RECORDING DISK HAVING DATA REGIONS WITHOUT IDENTIFICATION (ID) FIELDS**

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[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

[21] Appl. No.: **82,826**

[22] Filed: **Jun. 23, 1993**

Related U.S. Application Data

[63] Continuation of Ser. No. 727,680, Jul. 10, 1991, abandoned.

[51] **Int. Cl.**[6] **G11B 5/76**; G11B 5/09

[52] **U.S. Cl.** **369/275.3**; 369/59; 360/48

[58] **Field of Search** 360/47, 48, 77.05, 360/77.08, 78.04, 78.14, 135, 77.02, 49, 54, 61, 50, 27, 53; 369/32, 59, 275.3, 13, 47, 48, 49, 54, 58

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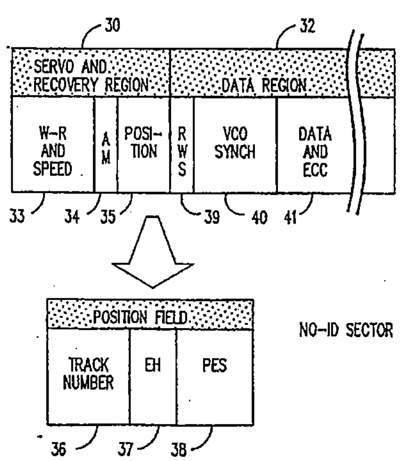
[57] **ABSTRACT**

A data recording disk file with a fixed block architecture sector format that eliminates the ID region. The servo region contains sector identification information in the form of a start-of-track indicating mark recorded in a selected sector of each track and a start-of-sector indicating mark recorded in each sector. A full track number identifier is encoded in the position field within the servo region of each sector. A look-up table is built at format time to map bad sectors out of the disk file. The table contains entries for each cluster of contiguous bad sectors, and is searched at runtime to provide conversion of logical sector location identifiers to physical sector location identifiers.

15 Claims, 4 Drawing Sheets



NO-ID SECTOR SERVO SECTOR FORMAT

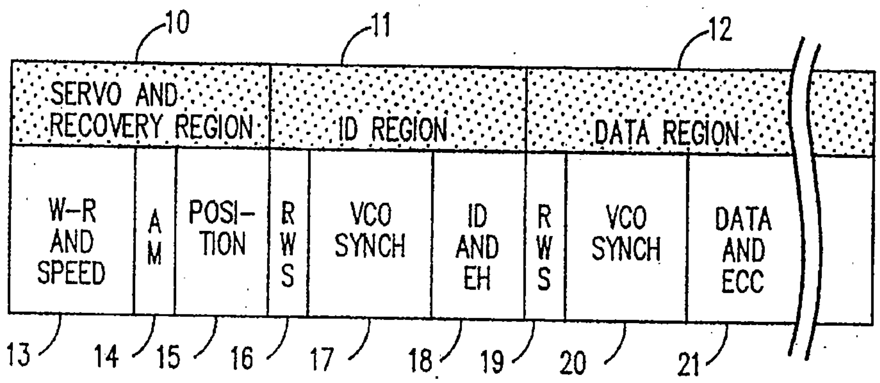


FIG. 1A: PRIOR ART SECTOR SERVO SECTOR FORMAT

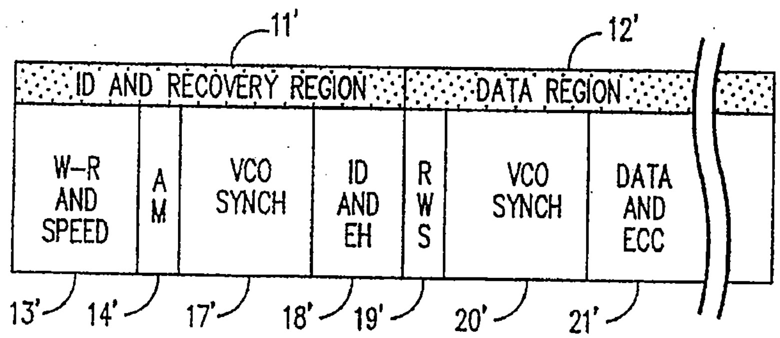


FIG. 1B: PRIOR ART DEDICATED SERVO SECTOR FORMAT

Bad Sector List							
Physical Sector	3	5	6	9	10	11	13
Logical to Physical Mapping							
Logical Sector	1	2	3	4	5	6	7
Physical Sector	1	2	4	7	8	12	14
Look–up Table							
Logical Sector	3	4	6	7			
Offset	1	3	6	7			

FIG. 3: EXAMPLE OF LOOK–UP TABLE CREATION

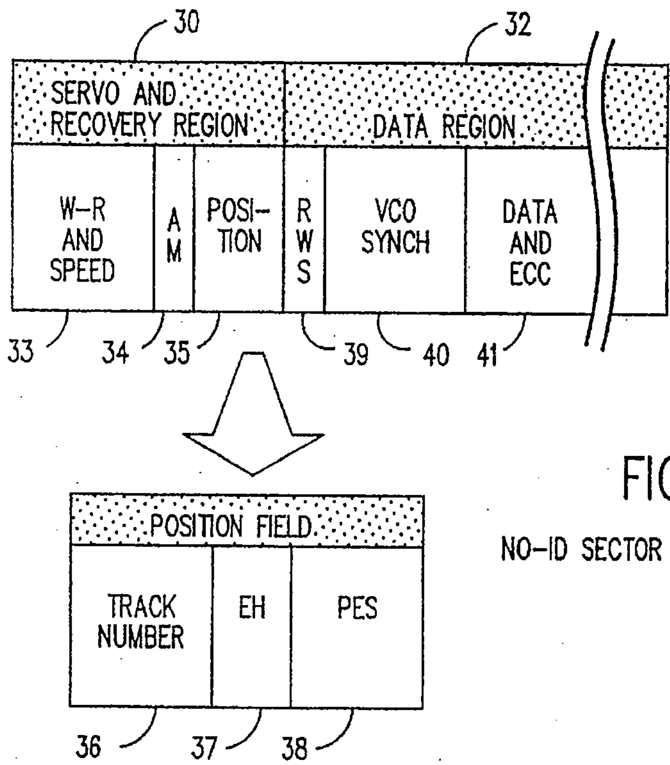


FIG. 2A:

NO-ID SECTOR SERVO SECTOR FORMAT

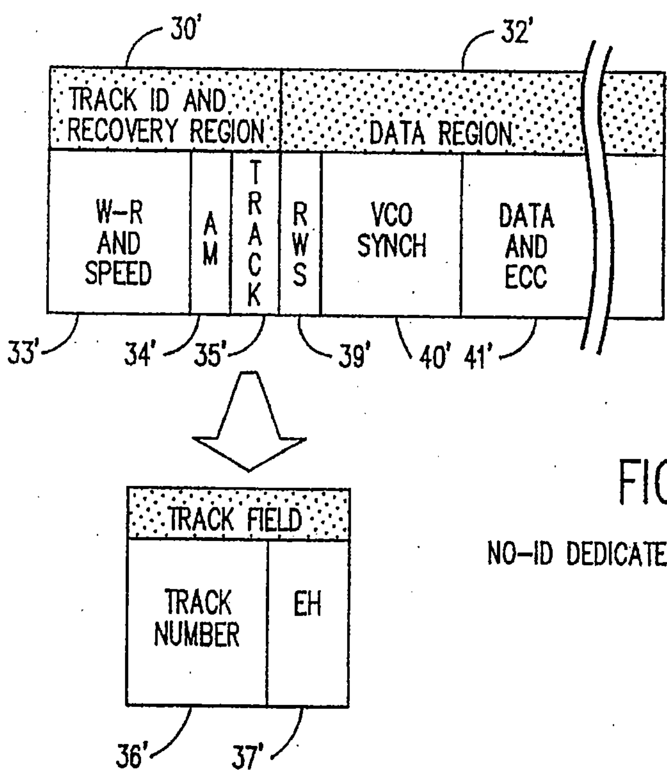


FIG. 2B:

NO-ID DEDICATED SERVO SECTOR FORMAT

```
static int tl[MAXBAD];                      /*lookup table: logical #*/
static int to[MAXBAD];                      /*lookup table: offset*/
static int nt = 0;                          /*number table entries*/

void build(b,nbad)                          /*build bad sector table*/
int b[MAXBAD];                              /*physical bad sectors*/
int nbad;                                   /*number of bad sectors found*/
{
  int bad;

  bad = 0;                                  /*bad sector counter*/
  nt = 0;                                   /*table index counter*/

  tl[nt] = b[bad];                          /*first entry*/
  to[nt] = 1;                               /*offset starts at 1*/
  bad++;                                    /*next bad sector*/
  while (b[bad] == b[bad-1]+1) {            /*while adjacent sectors*/
    to[nt]++;                               /*increment offset*/
    bad++;                                  /*next sector*/
 }

 while (bad < nbad) {
  nt++;                                     /*next table entry*/
  tl[nt] = b[bad] - to[nt-1];               /*will be next entry*/
  to[nt] = to[nt-1] + 1;                    /*starting offset*/
  bad++;                                    /*next bad sector*/
  if (bad == nbad) break;                   /*end of the list*/
  while (b[bad] == b[bad-1]+1) {            /*while adjacent sectors*/
    to[nt]++;                               /*increment offset*/
    bad++;                                  /*next sector*/
    if (bad == nbad) break;                 /*end of the list*/
  }
 }
 nt++;                                      /*nt is now # elements*/
 if ((nt & 1) == 0) {                       /*table should be odd*/
  tl[nt] = 32767;                           /*max allowed value*/
  nt++;
 }
} /* build */
```

FIG. 4: Look-up Table Generation Algorithm in C.

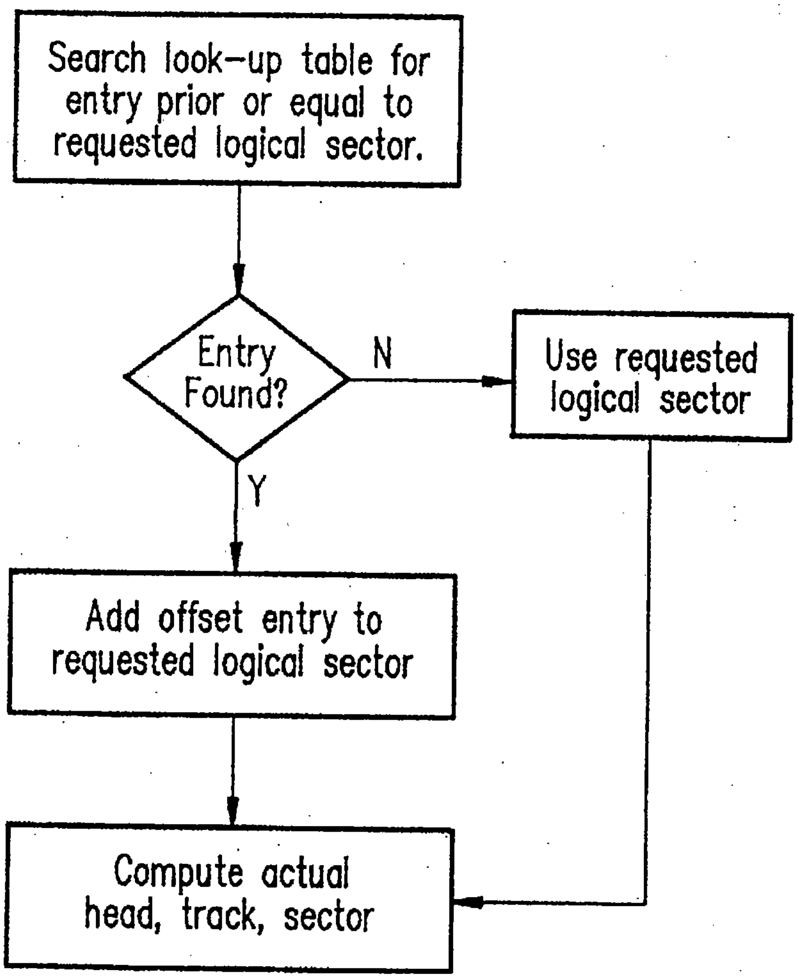


FIG. 5: Logical-to-Physical Sector Conversion Algorithm

SECTOR SERVO DATA RECORDING DISK HAVING DATA REGIONS WITHOUT IDENTIFICATION (ID) FIELDS

This is a continuation of application Ser. No. 07/727,680, filed Jul. 10, 1991, now abandoned.

This invention relates in general to data recording disk drives, and in particular to sector formats on multiple-track data storage media used in fixed block architecture disk drives.

BACKGROUND OF THE INVENTION

All disk drives require some means of determining the radial position of the READ-WRITE heads over the disks so that the heads can be accurately positioned over any desired track. Typically this is accomplished by placing servo information on one or more of the disk surfaces for reading by magnetic or optical heads. Some disk drives, known as dedicated servo drives, contain servo information only on a dedicated surface of one disk in the disk stack. In contrast, some modern drives, known as sector servo drives, store the servo information interspersed with the data on each disk surface. This latter approach represents the direction in which the technology is progressing and is preferred because it can be implemented at low cost and without additional componentry beyond that required to store the data and further because it provides the servo information at the data surface being accessed, thereby eliminating many mechanical and thermal sources of track misregistration. Fixed block architecture (FBA) is a common configuration used to format both dedicated servo disk drives and sector servo disk drives. In an FBA formatted disk drive, each disk track is divided into a number of equal-sized sectors, and each sector is divided into regions containing servo information, identification information (ID), and data.

A typical FBA sector servo sector format according to the prior art is illustrated in FIG. 1A. The sector is divided into three regions: servo and recovery region **10**, ID region **11** and data region **12**. Generally, servo and recovery region **10** contains overhead associated with sectoring, as well as servo information for sector servo drives. Also, this region marks the beginning of the sector. Specifically, servo region **10** contains WRITE-to-READ recovery (W-R) and speed compensation field **13**, which is used to switch the data channel from WRITE to READ and accommodate spindle speed variations; address mark (AM) field **14**; and servo position field **15** containing a position-error-signal (PES). Data region **12** contains the user data, as well as overhead fields. READ-to-WRITE recovery (R-W) and speed field **19** performs a function like that of W-R and speed field **13**. Voltage controlled oscillator sync (VCO) field **20** is used to synchronize the read clock with the read data. Data field **21** contains the user data and associated error checking and correction (ECC) information. ID region **11** is used by the disk data controller (DDC) to identify the physical sector number. It contains R-W and speed field **16**, VCO synch field **17** and identification/error handling (ID/EH) field **18**, which contains the identification information including the logical sector number.

A typical FBA dedicated servo sector format according to the prior art is illustrated in FIG. 1B. The data disk sector shown is divided into two regions: ID and recovery region **11'** and data region **12'**. ID and recovery region **11'** contains substantially the same information as servo and recovery region **10** and ID region **11** of FIG. 1A, with the exception that servo position field **15** and R-W and speed field **16** are

removed. In a dedicated servo scheme, servo position field **15** is not needed because the position information is contained on a separate surface; R-W and speed field **16** is not needed because address mark field **14'** can be written whenever the succeeding VCO synch field **17'** and ID/EH field **18'** are written. Data region **12'** contains substantially the same information as data region **12** of FIG. 1A.

ID regions **11** and ID and recovery region **11'** of the prior art FBA sector formats perform two important functions. First, they uniquely identify the logical sector number of the sector in which they are located. Second, they indicate whether the sector is good or bad (that is, whether the sector can be successfully written to and read from). Unfortunately, in both the dedicated servo and sector servo scheme, the ID region requires a great deal of disk space to perform its functions. Since the disk uses the information in the ID region to perform a logical-to-physical sector conversion in order to locate the physical position on the disk corresponding to the requested logical sector, the ID region must be large enough to avoid misidentifying sectors. Furthermore, since a phase synchronous clock is typically used to read the ID/EH field, the VCO field is required; this field is typically much larger than the ID/EH field. Finally, in the sector servo scheme, due to the region transition an R-W and speed field is required to switch the data channel from READ to WRITE and accommodate spindle speed variations.

In sum, due to overhead and accuracy requirements, the ID region of the prior art FBA sector accounts for a substantial portion of the overall sector length (typically about 4%), a portion that could otherwise be used for data storage. However, the importance of its two functions has hampered efforts to eliminate it from the FBA sector.

One approach that has been used to eliminate the ID region is to encode the ID information into the data field. This eliminates the overhead associated with synching (fields **16** and **17**), and allows the ECC to provide error checking for the ID information. However, it does not eliminate or reduce the actual ID information as contained in ID/EH field **18**. Also, it adds a minimum of one sector time to the latency during WRITE, since the disk drive controller cannot determine the good/bad sector relationship until it has read at least one sector. Further, this scheme is not well suited to compact and low-cost disk drives, where the error correction time is typically quite long, since it means a revolution may be lost in the case of a sector where any bit is bad in the entire field containing the combined ID and data. Thus, while the approach of combining the ID and data regions reduces the disk space required for ID information, this approach introduces performance penalties that restrict its usefulness.

OBJECTS OF THE INVENTION

It is therefore an object of the present invention to provide a data recording disk drive having a sector format that eliminates the need for an ID region.

It is another object of the present invention to provide a data recording disk drive having a sector format that uniquely identifies each track and each sector of a multiple track data storage medium.

It is another object of the present invention to provide a data recording disk drive having a sector format that includes information encoded in the servo region of a sector to uniquely identify the sector.

It is another object of the present invention to provide a data recording disk drive having a table for cataloging and mapping around bad sectors caused by media defects.

These and other objects will become more apparent when read in light of the following specification and drawings.

SUMMARY OF THE INVENTION

In accordance with the invention, a data recording disk drive is provided with an FBA sector architecture that eliminates the ID region while preserving its function. For disk drives implementing a sector servo scheme, the position field in the servo region of each sector is expanded to include a full track number identifier. For disk drives implementing a dedicated servo scheme, a track field is created in the servo region of each sector to include a full track number identifier. In either scheme, this enables the DDC to verify the full physical track number. The function performed by the ID/EH field is moved to the servo region in the form of a start-of-track indicating mark recorded in a selected sector of each track and a start-of-sector indicating mark recorded in each sector. The disk drive uniquely identifies a requested sector by detecting the start-of-track indicating mark and then counting start-of-sector marks to the appropriate sector.

Bad sectors are mapped out of the disk drive by means of a look-up table. At disk format time, each sector is written to and read from to determine whether it is operable or defective. Clusters of defective sectors are marked bad by recording in the look-up table the sector location identifier of the first bad sector in the cluster and the quantity of consecutive bad sectors in the cluster. During operation, the disk drive performs logical-to-physical sector conversion by searching the look-up table for an entry having a value less than or equal to the requested logical sector location identifier. If none is found, the physical sector location identifier is equal to the logical sector location identifier. If an entry is found, an offset representing the quantity of consecutive bad sectors associated with the entry is added to the logical sector location identifier to produce the physical sector location identifier. Then the physical sector location identifier is convened into an actual head, track and sector location, which is accessed by counting start-of-sector marks after a start-of-track mark on the appropriate track.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a schematic diagram illustrating a fixed block architecture sector servo sector fore, at according to the prior art.

FIG. 1B is a schematic diagram illustrating a fixed block architecture dedicated servo sector format according to the prior art.

FIG. 2A is a schematic diagram illustrating a fixed block architecture sector servo sector format according to the present invention.

FIG. 2B is a schematic diagram illustrating a fixed block architecture dedicated servo sector format according to the present invention.

FIG. 3 is a table illustrating a bad sector list, a logical-to-physical mapping, and a look-up table according to the present invention.

FIG. 4 is a C language procedure illustrating an algorithm for creating a look-up table according to the present invention.

FIG. 5 is a flowchart illustrating an algorithm for performing logical-to-physical sector conversion according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

IA. NO-ID FBA SECTOR SERVO SECTOR FORMAT

FIG. 2A illustrates in schematic diagram form an FBA sector servo sector according to the present invention. Servo and recovery region **30** includes W-R and speed field **33**, AM field **34** and position field **35**. Position field **35** itself includes track number subfield **36**, EH subfield **37** and PES subfield **38**. Data region **32** includes R-W and speed field **39**, VCO synch field **40** and data field **41**.

In operation, fields **33**, **34**, **39**, **40** and **41** provide substantially the same functions as fields **13**, **14**, **19**, **20** and **21** shown in prior an FIG. **1**A and described previously. Fields **16**, **17** and **18** from prior art FIG. **1**A are eliminated.

Position field **35** is expanded over position field **15** of the prior art, as shown in the lower portion of FIG. **2**A. According to the preferred embodiment of the present invention, the full track number corresponding to the track on which the sector is located is recorded in track number subfield **36**. EH subfield **37** is provided as an adjunct to the full track number to ensure that the track number has been read correctly. Finally, the actual position-error-signal is encoded in PES subfield **38**. This subfield contains substantially the same information as position field **15** of prior art FIG. 1A.

It is to be noted that both the full track number and the EH information may be recorded according to any of a variety of techniques well know to those skilled in the art of data recording disk sector formats. For instance, a gray code may be used to record the full track number because it allows the full track number to be accurately read when the disk head is off-track. The EH information may implement any of a variety of schemes well known to those skilled in the an, including error checking and correction (ECC) codes and cyclic redundancy check (CRC) codes. According to the preferred embodiment of the present invention, EH subfield **37** is implemented using CRC, an error-check-only code. CRC is chosen because it is easy to compute and because it requires a small number of bits (roughly **16**). Since CRC bits will not form a gray code, EH subfield **27** is implemented in a code that is accurately readable only when the head is on track. This implementation has no adverse impact on the present invention, since an absolutely accurate reading of the track number subfield is required only when the head is already on-track.

The no-id sector format of the present invention provides several space saving advantages over the prior art. The track number need not be redundantly encoded in an ID region but instead is communicated to the DDC by the servo system at runtime. Track number subfield **36** and EH subfield **37** are substantially shorter than ID region **11** shown in prior art FIG. 1A, since the FBA format of the present invention is able to use CRC rather than other forms of ECC and since the maximum track number is one or two orders of magnitude smaller than the maximum sector number encoded in prior art ID/EH field **18**. Since fewer bits are required to represent the track number, this quantity may be recorded at lower density, so that track number subfield **36** and EH subfield **37** can be read without a phase synchronous clock; therefore VCO synch field **17** is not required. Finally, since no separate ID region is set up, R-W and speed field **16** is eliminated.

As discussed above, the preferred embodiment of the present invention contemplates the use of a full track number in track number subfield **36** in order to provide absolute identification of the track number for READ and WRITE operations. However, it is to be understood that the track number may be encoded according to a variety of alternative preferred embodiment of the present invention. The bad sector list indicates that physical sectors **3**, **5**, **6**, **9**, **10**, **11** and **13** were found to be bad at fore, at time. The logical-to-physical mapping shows the desired mapping to be achieved by the look-up table. Logical sector **1** will be found at physical sector **1**; logical sector **2** will map to physical sector **2**; logical sector **3** will map to physical sector **4** since physical sector **3** is defective, etc.

The look-up table shows the result of compressing the bad sector list in accordance with the present invention. Starting at logical sector **3**, there is a cluster of 1 bad sector; thus, sectors **3** and beyond must be offset by **1** to map into the correct physical sector. Starting at logical sector **4**, there is a cluster of 2 bad sectors; thus, sectors **4** and beyond must be offset by a total of **3** to map into the correct physical sector. Starting at logical sector **6**, there is a cluster of 3 bad sectors; thus, sectors **6** and beyond must be offset by a total of **6** to map into the correct physical sector. Finally, starting at logical sector **7**, there is a cluster of 1 bad sector; thus, sectors **7** and beyond must be offset by a total of **7** to map into the correct physical sector.

It is to be noted that the look-up table may be stored either on the boot track of the disk or in some non-volatile semiconductor memory in the data recording disk drive, such as EEPROM, FRAM, or PROM. The first column of the table must be wide enough to hold the largest physical sector number (24 bits is sufficient in most cases). The second column must be wide enough and the table long enough to hold the maximum number of bad sector clusters likely to be encountered (16 bits is sufficient in most cases).

FIG. **4** illustrates in algorithmic form a procedure for creating a look-up table according to the preferred embodiment of the present invention. The look-up table generation algorithm (shown in C programming language) processes the bad sector list as follows. First, the list of bad sectors is convened into the compact table representation. Then the first "while" loop computes the offset for the first block by determining its size (i.e. the number of contiguous bad sectors). Next, the second "while" loop performs the same operation for all the remaining blocks, determining each offset by adding the number of sectors in the block to the total number of bad sectors prior to the block. Finally, the look-up table is adjusted to contain an odd number of entries, for ease of access by a binary search look-up routine. Of course, many other search types are possible, the use of which would obviate this final step. Also, it is worthy of note that the look-up table generation algorithm may be executed against the entire bad sector list, or, where storage or processing constraints arise, may be executed in a piecewise fashion, so that each block of bad sectors is processed as it is located.

FIG. **5** illustrates in flowchart form an algorithm for performing logical-to-physical sector conversion according to the preferred embodiment of the present invention. A READ or WRITE request, including a logical sector location identifier, is generated within the disk drive. A look-up table containing bad sector information and indices as described above is accessed and searched for the largest logical sector entry less than or equal to the requested logical sector. In the event no entry is found, the physical sector location identifier is equal to the logical sector location identifier, and the requested logical sector is accessed by computing head, track and sector number directly from the logical sector location identifier according to any of a variety of techniques well known to those skilled in the art.

If an entry is found in the look-up table, the corresponding offset is extracted from the look-up table and added to the

logical sector location identifier of the requested logical sector. This sum, representing the physical sector location identifier, is used to compute the head, track and sector number corresponding to the requested logical sector.

In some implementations (e.g. SCSI), it may be desirable to allow for the relocation of bad sectors without resorting to a complete device format operation. This feature is implemented in conjunction with the present invention by allocating a set of sectors as spares prior to an initial format operation. The spares are treated as though they are bad sectors for purposes of constructing the logical-to-physical mapping table. The spare sectors are then distinguished from bad sectors, for instance by means of a flag in the mapping table or a separate list. Relocation of a bad sector is accomplished by logically substituting one of the spare sectors in its place, shifting all the intervening sectors by one logical sector location, updating the spare sector list to reflect the use of the spare sector, and re-constructing the logical-to-physical mapping table to reflect all the above changes.

A look-up table constructed according to the preferred embodiment of the present invention as described above has the advantageous effect of placing most of the computational overhead into building the table during the format operation, leaving a simple computation to support logical-to-physical mappings during seek operations. It is to be noted that the preferred embodiment look-up table approach is maximally effective when the total number of bad sectors in the data recording disk drive is small, since this keeps the overall table size small and thus keeps the worst-case binary search of the table short. For example, a disk drive having 240K sectors and 0.1% bad sectors would require a table having less then 1000 entries. The look-up table, in cooperation with the above-described algorithm, provides a scheme that efficiently catalogues bad sectors and enables rapid calculation of the correct physical sector corresponding to a requested logical sector.

Furthermore, the No-ID scheme of the present invention is particularly well suited for use with disk drives having different heads for reading and writing, such as magneto-resistive read heads, where the heads must be moved to slightly different radial positions for reading and writing (a practice known as micro-jog). With prior art fixed block architectures, writing a data field requires prior reading of the ID field. However, it is not possible to complete a micro-jog between the two fields, so a revolution is lost in performing the micro-jog. The No-ID format of the present invention eliminates this problem since it has no ID field to be read.

While the invention has been particularly described and illustrated with reference to a preferred embodiment, it will be understood by those skilled in the art that changes in the description or illustrations may be made with respect to form or detail without departing from the spirit and scope of the invention.

Having thus described the invention, what is claimed is:

1. A data recording disk having a pattern of radially spaced tracks and a plurality of circumferentially spaced angular sectors having prerecorded servo positioning information for identifying track and sector locations, each of the plurality of sectors including only a data region for recording user data and, preceding the data region in the circumferential direction, a servo-and-recovery region which provides the prerecorded servo positioning information to uniquely identify the sector and track, wherein the servo-and-recovery region includes a write-to-read-recovery and speed-compensation field, an error handling field, a position-

error-signal field, a start-of-sector indicating mark, and a track number field, but no data region identification (ID) field, wherein the data region includes, in sequence, a read-to-write-recovery and speed-compensation field and a synchronization field, and wherein one of the plurality of sectors also includes a start-of-track indicating mark.

2. The data recording disk as recited in claim 1, wherein the track number field includes a full track number prerecorded therein.

3. The data recording disk as recited in claim 1, wherein the start-of-track indicating mark is encoded in the track number field.

4. The data recording disk as recited in claim 1, wherein the start-of-sector indicating mark is an address mark located in the servo-and-recovery region, and wherein the address mark precedes the track number field in the circumferential direction.

5. The data recording disk as recited in claim 1, wherein the track number field includes a full sector number prerecorded therein.

6. The data recording disk as recited in claim 1 wherein some of the tracks also have servo-and-recovery regions located within some of the data regions.

7. A data recording disk having a plurality of tracks, each of the plurality of tracks having a start-of-track indicating mark and being divided into a number of data regions for recording user data and a number of servo-and-recovery regions, the servo-and-recovery regions containing a position-error-signal field, a servo-and-recovery region count mark, and a track number field, at least one of the data regions being split by a servo-and-recovery region, and wherein none of the plurality of tracks have, either within or outside the data regions and servo-and-recovery regions, identification (ID) regions containing information that uniquely identifies the data regions in the tracks.

8. The data recording disk as recited in claim 7 wherein the track number field includes a full track number prerecorded therein.

9. The data recording disk as recited in claim 7 wherein the start-of-track indicating mark is located within one of the servo-and-recovery regions.

10. The data recording disk as recited in claim 9 wherein the start-of-track indicating mark is encoded in the track number field.

11. The data recording disk as recited in claim 7 wherein the servo-and-recovery region count mark is a start-of-servo-and-recovery region mark.

12. The data recording disk as recited in claim 11 wherein the start-of-servo-and-recovery region mark is an address mark that precedes the track number field in the track.

13. The data recording disk as recited in claim 11 wherein the start-of-servo-and-recovery region mark is a servo-and-recovery region number.

14. The data recording disk as recited in claim 7 wherein the servo-and-recovery regions include a write-to-read recovery and speed-compensation field.

15. The data recording disk as recited in claim 7 wherein the data regions include, in sequence, a read-to-write recovery and speed-compensation field and a synchronization field.

* * * * *