Description

This invention pertains to rotating memory and more par ticularly to circuitry for processing serial data in a magnetic disk drive system.

Two aspects of data storage devices are under constant pressure for enhancement. One is the continuing effort to increase storage density and the other is the continuing development work directed to the reduction of response time by higher speed components or improved techniques.

Storage density is increased by increasing bit densities and by narrower, more closely spaced data tracks. These changes result in a reduction of the size of the bit domains which requires that the reading and writing capabilities be upgraded to higher levels of performance to maintain the same standard of reliability previously attained.

Among the characteristics that are designed to optimize drive performance are the write current supplied to the transducer during the write operating mode and during the reading mode, the delta-V, which is the voltage change per unit time threshold which is used to discriminate between data and noise signals on the channel. It has been common practice to set both of these values to obtain optimum performance. However, with both of these parameters, the value that obtain best performance varies from transducer to transducer and also with the radial position of transducer location which is a function of the speed of the head relative to the media surface. Another problem that arises is the phenomena that components that test as being within the product specification can fail to function properly in combination with other components, while component that appear to fail with respect to specification standards, may function properly in combination with other components.

Prior art document EP-A-27547 discloses a high density data readout system with data signal detection circuits wherein transients and noise signals are eliminated from the readback output signal. The circuits comprise a data signal detector which senses changes in voltage of the signal waveform relative to peak signal amplitude. Threshold detectors sense those signal peak amplitudes which exceed a preset magnitude. A differentiator is provided to locate signal peak position by sensing changes in slope of the signal waveform.

Prior art document EP-A-87907 discloses a calibration system for a data storage device applying at first and successively a plurality of record drive currents in order to optimize recording, and subsequently applying a plurality of adjustments of the reading device in order to optimized reading.

The present invention relates to a disk drive including means for optimizing read/write performance and to a method of determining optimum read/write performance in such a drive.

In the magnetic disk drive and method of the present invention, provision is made to vary the write current and the Delta-V (the minimum voltage change per unit time which tests data to discriminate between data and noise). This is done to improve the general performance of the drive and to adapt these factors on a transducer head by transducer head basis. This procedure also accommodates the system to the peculiarities of the various components.

The magnetic disk drive of the present invention is of the type disclosed in EP-A-87907, using at least one magnetic transducer head associated with the medium surface, the write currents of the transducer head and the reading circuits being adjustable by digital signals. It is characterized by a module connected to the transducer head associated with disk surfaces and comprising:

- first circuit means for generating a plurality of reference currents,
- second circuit means for selecting and adding an optimum combination of said plurality of reference currents in response to the value of a first digital signal, to generate a write current, said write current being provided to the coil of the transducer head to write data on a disk surface, the selection of said plurality of values of write current being in response to the radial positions of each of said magnetic transducer heads independently of the other transducer heads,

said module further comprising:

- circuitry wherein a serial data read signal is verified for a true peak by determining that the read signal has a minimum change delta-V during a given time,
- third circuit means for generating a plurality of reference currents,
- fourth means for selecting and adding an optimum combination of said plurality of reference currents in response to the value of a second digital signal received by said third circuit means, in order to generate a delta-V value to verifying a read signal from a data surface track with each of said heads at a given radial position, which optimum delta-V value can vary from head to head, and the selection of said plurality of delta-V values being in response to the radial positions of each of said heads.

The method of determining optimum transducer head read-write performance in the device of the present invention is characterized in that it comprises the steps of:

writing a predetermined pattern of information on a selected track;
reading the data on said selected track using an initial value of write current and recording the number of errors;
incrementing said write current within said plurality of selectable values, reading data on said selected track and recording the number of errors;
if the number of errors is fewer than the number recorded after the next previous reading, repeating the prior step of incrementing the write current and
reading the selected track or if the present write current value is the final incremental value, set ting the write current at the present value and if the number of errors exceeds the next previous recorded error count, setting the write current at the next prior write current value;
reading said selected track and recording the number of errors occuring with the current delta-V;
decrement the current delta-V and reread said select ed track, recording the number of errors;
if errors are less, repeat last step and if errors are more, increment delta-V, reread said selected track and record the number of errors;
if errors are less than the previous sum, repeat step of incrementing delta-V and rereading;
when retest produces an increased error sum, set delta-V at immediately preceding value or at the final value if fewer errors and current delta-V value is the final incremental value.

Another factor in the overall performance of a disk file is the data recovery procedure that enables the tolerance of an increased number of soft errors as the bit domains and read signal amplitudes diminish and it is necessary to maintain the same standard of hard error occurrence. The variable delta-V enables another data recovery tool to be added to the recovery sequence. After the correction of errors in the data stream that are transparent to the system and impose no delay, it is the most common procedure to re-read the data and thereafter again re-read with several increments of head shift in each direction. Thereafter, re-reads can be conducted using various incremented values of delta-V prior to the various more complex error correction codes. This affords another vehicle for increasing storage system capabilities.

Fig. 1 is a vertical section of a typical magnetic disk storage device illustrating the principal mechanical elements.

Fig. 2 is a schematic block diagram of the electronic modules associated with the disk drive data channel and the read and write operating modes.

Fig. 3 is a diagram of the AGC module circuitry used to generate the variable write current.

Fig. 4 is a diagram of the detector module circuitry used to generate the variable values of delta-V.

Fig. 5 is a flow chart showing the procedure for optimizing the variable write current and the variable delta-V values.

Fig. 1 illustrates a typical magnetic disk drive wherein the actuator assembly 10 accesses the lower two disks 11 of a four disk spindle drive assembly. The hub 12 has four disks mounted thereon which are separated by spacers 13. The disk stack is compressively retained on hub 12 by a resilient element 15, collar 16 and the shrink ring 17 that is secured against the outer surface of the hub 12 by a shrink fit after assembly when heated and expanded. The hub/disk assembly is mounted on spindle shaft 18 such that the disks 11, hub 12, spindle shaft 18 and the rotor of the spindle drive motor 19 rotate in unison with the support of bearings 20.

The linear actuator carriage 21 is driven by a voice coil wound on the bobbin 23 to effect radial inward and outward motion. The voice coil reciprocates in the working air gap 24 in which a magnetic field is established by the radially polarized permanent magnets 25 and the pole pieces 26. Actuator carriage 21 is guided along the radial path by three pairs of rollers 28 (one pair of which is shown) that engage a rod or way 29 at each lateral side of the actuator carriage. Two pairs of longitudinally spaced rollers are at one side and one pair at the other lateral side is disposed longitudinally intermediate the other two pairs. One roller of the single pair is spring biased to take up any play or slack in the mechanical system between the carriage/roller assembly and the ways or rails 29.

The carriage assembly includes the body 31 which carries rollers 28; the voice coil and transducer suspension assemblies wherein arm 33 has attached thereto a resilient suspension 34 that carries a transducer head 35. Each of the transducer coils is attached to the arm electronics module 36 on the flexible conductor 37 at the solder terminations 38. The arm electronics module 36 is connected to the remainder of the disk drive circuitry by conductors on the flat cable portion 39. There is also an internal air circulation within the head disk assembly which is induced by the impeller action of the hub 12 and the rotating disks 11. Air flows radially outward from the hub interior through apertures 41 in the spacers 13. Fig. 2 is a simplified block diagram illustrating the disk drive circuit modules associated with the data channel and the read/write signals transmitted to and received from the transducer heads. The arm electronics (AE) module is usually carried on the actuator as shown in Fig. 1. The AE module provides four

basic functions; read mode operation, write mode operation, select control line operation and safety and diagnostic circuitry operation. In read mode, the AE module 36 provides the initial high gain amplification of the head signal voltage. In write mode, the AE module causes reversals of the write current in one of the four heads it services thus allowing the alternating magnetization of the disk surface that constitute the encoded data bits. Driver stages steer the write current into alternate sides of the center tapped ferrite transducer head. In addition to the read and write modes of operation, the AE module can also be deselected. This mode is provided primarily for data integrity or safety. If the module were inadvertently in the write mode, deselecting the module would remove the condition. The AE module is also used to assure reliability which is achieved by monitoring and reporting conditions that have the potential of destroying recorded data. Besides monitoring the status of select and write circuitry within the module, the safety function also monitors the integrity of the recording head and control line attached to it.

As with the AE module 36, the AGC module 44 provides read, write and safety functions. When the channel is in the read mode, AGC module 44 receives the amplified head signal from AE module 36. This signal is then amplified, held to a constant amplitude and sent through a filter 45 to the detector module 46. Two basic write operations are provided by AGC module 44, the write trigger and the write current source. Write data from encoder circuitry is received, converted into a differential divide by two signal and then driven down the flex cable to the write pre-driver stage in AE module 36. The other write function is the current source which can be programmed by three bits (write current select bits 1, 2 and 3) to generate eight discrete values. This capability affords a means to compensate for other recording component tolerances. Since AGC module 44 contains write mode circuitry, safety circuitry has been incorporated to assure data integrity should these circuits malfunction by monitoring the internal AGC module write circuitry, insuring proper operation of the write current select line and checking fault conditions detected by monitoring the differential read signal lines.

The detector module 46 contains only read mode functions with the sole purpose being to transform the amplified linear head signal into a corresponding series of digital pulses. All waveform peaks are detected and a series of peak filtering circuits are employed to find the resultant valid data peaks. Two key criteria are applied to all the peaks identified by the differentiation, delta-V and "V threshold". The circuitry responsible for these two functions, along with some combinational logic, provide the discrimination between data and extraneous peaks necessary to pass a clean string of data pulses to VFO module 47. Provided within the detector module is the capability to externally select the values used for the detection algorithm. Eight levels of delta-V amplitude can be programmed using control lines, delta-V bits 1, 2 and 3.

Like detector module 46, VFO module 47 contains only read mode function. The function is to assign bit locations to the incoming data pulses and provide a read clock that is synchronous with the file spindle. The VFO is constantly comparing a string of pulses to its oscillator output. In the read mode the comparison pulse string is the read data. Adjustments are made to the oscillator frequency that are proportional to the the measured phase error of each compared pulse. The adjustment magnitude per sampled error or response time is determined by which of the two modes it is in. Prior to receiving actual data, the VFO receives a series of constant frequency pulses that make up the sync field. This field is written at the same time as the data and is used to prepare or set up the VFO to accept the actual data. When the sync field appears at the input of the VFO, the module is placed in the fast sync mode. During the time it is in this mode, the VFO reacts faster to maximize the oscillator adjustment per sampled phase error and therefore minimize the time it takes to lock the VFO to the data. For the remaining time the VFO is in the read mode. During the last part of the sync field and all through the data field, VFO response is slowed to provide optimum frequency compensation.

The adjustable write current source, shown in Fig. 3, provides the capability to select any of eight different values of write current, such that the optimal value of write current is attained for a particular head/disk combination, at a particular radial location. Moreover, the selected current is within 5% of the specified value. This tolerance value is achieved without the use of costly active laser trimming. The current source further provides an accurate write current value by making use of a precision reference that is generated on the electronics card. The reference voltage is applied to the negative inputs of two operational amplifiers 51, 52 of the adjustable current source circuit as shown in Fig. 3.

Operational amplifier 52 forms a current source with transistor Q9 and resistor R21. The reference voltage, which is maintained across R21 by the operational amplifier 52-transistor Q9 loop, sets the current in transistor Q9. This current is environmentally stable and is only a function of the 2.5% precision reference voltage and the 1% resistor tolerance. The current in transistor Q9 is then mirrored by transistors Q10 through Q14. This current, known as the base value of current, is five times the current in transistor Q9.

Operational amplifier 51 and transistor Q1 form another current source that is determined by resistor R20. This current, known as the step current, is mirrored by the transistors Q2 through Q8 to produce three binary weighted, environmentally stable currents. These three currents are switched by three differential switches formed using transistors Q15 through Q23, which are enabled by three receivers, M3, M4 and M5. Eight current levels are achievable through the possible combinations of the three binary weighted currents. The output of the three differential switches, along with the base value of current, are driven into the output mirror formed of transistors Q24 through QN. The output mirror multiplies the sum of the binary weighted current and the base level current by a large number to obtain the desired write current value.

Fig. 4 shows a detailed block diagram of the circuit used for the adjustable delta-V parameter. The delta-V detector circuit is depicted as a block 55 that senses the voltage Vdel across the resistor Rdel. A 2 volt, 2.5% reference voltage is used to set up the delta-V voltage.

The delta-V voltage is broken up into two components, a base value and an increment value. The base delta-V voltage represents the minimum desired value of delta-V. The incremental delta-V represents an adder to the base delta-V voltage which can be dynamically altered via a three bit digital control bus. Fig. 4 shows the base voltage generated using resistors R11 and R12 to divide down the 2 volt reference. The voltage is brought to a module pin 56 so that it can be monitored or modified. Amplifier 57 buffers this base voltage and feeds it to a transconductance amplifier made up of amplifier 58, transistors Q5 and Q6 and resistors R14 and R15. The resulting current is dropped across resistor Rdel in the delta-V detector to produce the base delta-V voltage. The emitter areas of transistors Q5 and Q6 are identical and the device emitter resistors are identical, so transistors Q5 and Q6 carry identical collector currents. Since the ratio of resistor R14 to resistor Rdel is four to one, the voltage generated across Rdel is one fourth the voltage applied to the input of amplifier 58. This offset current is controlled by laser trimming a module substrate resistor Rsub1 while monitoring the voltage across resistor Rdel.

Incremental voltage is generated using resistors R1 and R2 to divide down the 2 volt reference. Amplifier 59 buffers this increment voltage and feeds it to a transconductance amplifier made up of amplifier 60; transistors Q0, Q4C, Q2C and Q1C and resistors R4, R5, R5/4 and R5/2. Because the relative emitter areas of transistors Q0, Q4C, Q2C and Q1C are 1, 4, 2 and 1 respectively and the inverse at the emitter resistances are in the same ratio; the collector currents of these devices scale in the same ratio as emitter area. A differential transducer pair above each of the transconductance amplifier current source transistors Q4C, Q2C and Q1C allows each of these currents to be turned on or off by a logic signal passed through a TTL to ECL converter. Since the currents are binary scaled 4, 2, 1 the combined current magnitude scales with the three bit binary number on the digital bus. The combined current in the collectors of transistors Q4A, Q2A and Q1A are mirrored by transistors Q3A, Q3B, Q3C, Q3D and resistors R6 and R7 and mirrored again by transistors Q7A, Q7B and Q7C and resistors R8 and R9 to be dropped across resistor Rdel. Since the ratio of resistor R4 to resistor Rdel is twenty to one, the voltage generated across Rdel for a binary one digital control input is one twentieth the voltage applied by the resistor divider of resistor R1 and R2. Up to seven increments in delta-V increment voltage can be obtained with an all ones binary input. The offset error of this circuit is nulled out by an offset current applied to the input of amplifier 60. This offset current is controlled by laser trimming a module substrate resistor Rsub2 while monitoring voltage across Rdel.

The availability of variable write current values and variable values for delta-V that can be set and reset on a head by head and track by track basis enables previously unavailable techniques for test and adjustment during manufacture to improve performance. This ability can be used to optimize all head-media combinations or, as is described hereafter, as a qualification test to bring poorer performing component combinations to an acceptable level and thereby increase manufacturing throughput by increasing the percentage of devices that meet required specifications of performance. The qualification test more accurately detects error performance of single components or of single files. More accurate test data improves yield by allowing tighter component performance specifications, lowers cost by discarding fewer so called good components measured bad and improves the quality by detecting more of the bad components measured good. The test will detect poor error performance whether it results from poor signal to noise, adjacent track interference (squeeze) or other factors.

The following is a specific test and optimization sequence. To accommodate variations due to the distance of the head from the center of rotation which is reflected in a varying tangential speed and a variable fly height of the head, the data tracks are divided into three bands of contiguous tracks; an inner band of shortest radius, a middle band and an outer band. The inner band is most critical and consequently the tests and optimization techniques are conducted on tracks in the inner band with respect to both the write current and the delta-V. When the optimum value of write current or delta-V is established at the inner band test track or tracks, corresponding settings are made for the middle band and the outer band tracks.

The values in the following tables are the 0 through 7 settings of the three bit signals which respectively select the write current or delta-V.

WRITE CURRENT SELECTIONS
FOR MIDDLE AND OUTER BANDS

OPTIMUM VALUE	CORRESPONDING SETTINGS FOR AT	
INNER BAND	MIDDLE BAND	OUTER BAND
6	7	7
5	6	7
4	5	6
3	4	5
2	3	4
1	2	3
0	1	2

TABLE I

DELTA-V SELECTIONS
FOR MIDDLE AND OUTER BANDS

OPTIMUM VALUE	CORRESPONDING SETTINGS FOR AT	
INNER BAND	MIDDLE BAND	OUTER BAND
5	6	7
4	5	7
3	4	6
2	3	5
1	2	4
0	1	3

TABLE II

Each of five tracks within the inner band which are separated by at least two intermediate tracks are written with test information. Old information, new information and squeeze information are respectively three patterns of information that are written and repeated to the full length of the data field on the track in the following manner:

Pattern	Position
1. Old information	on track +2 micron head shift
2. Old information	on track -2 micron head shift
3. New information	on track
4. Squeeze information	on track + one track -1 micron head shift
5. Squeeze information	on track - one track +1 micron head shift

The write current test sequence follows with the step sequence repeated for each of the five tracks written with test information:

1. Write the information patterns as set out above. Use current write current.
2. Read the new information pattern 10 times, recording the number of failures for each sector. Use present delta-V.
3. Remove errors associated with the four worst sectors. Tally remaining errors.
4. Repeat steps 1, 2 and 3 twice for a total of three times.
5. Sum all errors tallied.

The following delta-V test sequence is performed and repeated for each of the tracks written with test information:

1. Read the new information pattern 30 times, recording the number of failures for each sector. Use present delta-V.
2. Remove the errors associated with the four worst sectors on each track. Tally remaining errors.

In either of the above test sequences, if the total error count is zero, then increment the error count to 1. This will prevent possible division by zero errors in the control algorithm.

Fig. 5 illustrates the control technique and sequence for optimizing the values of write current and delta-V. Th sequence will always optimize write current, provided the head fails the initial cut. Delta-V is optimized only if the write current optimization does not improve the head beyond the required specification.

The test is initiated using initial settings of write current and delta-V. If the error sum during the first write current test sequence exceeds a specified high value, the head is immediately failed and if the error sum is below a second predetermined sum, the head is immediately passed as satisfactory without further test. If neither of these conditions occurs, the write current is incremented and the head retested until the number of errors do not show a reduction from the previous test sequence. The write current is then decremented and the test sequence rerun until the error count fails to decrease. The current for the head is then set to the last value and if the last error count is less than the second predetermined sum, the head is passed and the test sequence terminated.

If the head does not meet the specification at the end of the write current optimization test sequence, the delta-V is decremented, the delta-V test sequence run and the steps repeated until the number of errors tallied is not less than the prior sequence. The delta-V is then incremented, the test sequence run and the steps repeated until the error sum fails to decrease with respect to the next previous test sequence. The number of errors at the optimized value of delta-V is compared to a third predetermined number indicative of a head-media combination that meets specification and if the error count exceeds such number the head is failed and if less than such number the head is passed as meeting the required specification.

The ability to vary a significant read mode parameter is also used as an effective tool in the data correction and recovery procedure. The processing of serial data read from the storage media includes an initial error identification and correction procedure that is capable of identifying error conditions and making modest corrections without interrupting the data flow and is therefore transparent to the using system. The more complex error conditions require that the data recovery procedure be invoked. This is a many step procedure that is pursued until the error is corrected and the procedure thereupon terminated or continued through the entire routine of procedures to identify a hard, unrecoverable error. Although current devices are highly reliable and it is seldom necessary to utilize the data recovery procedures, satisfactory performance is dependent upon the capability of the device to recover from and correct the occasional

errors without the errors becoming "hard", unrecoverable failures to read the data. It is also important that the device be capable of recovering data through its own capabilities without the ultimate factory intervention to recover vital user data.

Accurate test capability of a single transducer head near component design limits is important. Good and bad components may be sorted more accurately. Test specifications may be set closer to design limitations. This means less excess test specification margin is necessary with the more accurate test. The prior poorer test to actual performance correlation meant additional test margin was necessary. Now with tighter correlation, the margin may be decreased and the resultant quality of the population of produced product will not be affected. At the same time yield or capacity of the product can improve, lowering cost or increasing competitiveness of the device or both.

The actual test is similar to tests performed on precision test stands during file development. First, two bands of old information are written by offsetting the head position and writing a data pattern in each radial direction from the nominal position. Then the data pattern (normally another random pattern) is written in the nominal on-track position. Then the head is accessed to the next track and offset back toward the data track and a third random pattern is written. This is termed a squeeze track. Another squeeze pattern is also written on the opposite side. The error rate of the data track is then measured from the on track position. The read is then repeated on the same track for better statistics, and the writing and reading is repeated on three other tracks representing each of the four types of servo tracks for a sector servo implementation or adjacent tracks for a dedicated servo application so that a representative average of error performance is achieved. For a typical drive this procedure takes only a short time, since it is not necessary to measure the actual error rate of very good heads, but only marginal heads. Allowed raw error rates may be significantly higher since the ECC and automatic recovery significantly improves the apparent error rate. For narrow heads, the squeeze track would be some distance away from the data track, and will cause few detrimental effects in normal file operation. The head is therefore tested with the same type of interference as seen in normal file operation. For wide heads, the squeeze track will partially protrude into the edge of the data track, partially erasing data and writing additional interference much as in normal file operation. Writing the squeeze track closer to the data track simulates a much more rare track misregistration than occurs in normal file operation. This allows testing of the failure mechanism in a short amount of test time. The wide heads are tested with stressful squeezes from adjacent tracks with normal signal to noise conditions. This proves to be a reasonable test for heads, since the heads that are normal or good in signal to noise performance can withstand more squeeze interference. A poor quality, poor efficiency head within the width specification may fail while a head which may be too wide, but of good efficiency could be passed. Thus the test measures the actual performance of a file in contrast to imposing a somewhat arbitrary maximum track width.

Most magnetic transducer head tests have a loose correlation to file performance. Compromises in specifications are made which cloud whether the components are acceptable or not. Many unmeasurable component parameters can affect the error rate while not correspondingly affecting the ability of the head to pass a magnetic amplitude test. The use of an error rate test allows testing of head or disk components with the data transferring channel used in the product. Thus, although small factors may not be identified as influencing the performance in a magnetic transducer head test, their effect is directly included in the error rate measurement. Therefore a more accurate prediction of file performance is achieved than is possible with an amplitude measurement system.

The actual file error rate differs somewhat from tested head error rates due to several factors. One factor is that the magnetic error rate test is performed using a standard disk. In the file, the disk used will be different and may perform differently. Another difference is that the noise level in a file may differ slightly from one to the next, causing some differences in equivalent head performances. In an actual device environment, the file may have a throughput specification which dictates the average file error rate. The average file error rate depends on the variation of error rate between components on each of the surfaces and across each of the surfaces of the total file. For near worst case components, the variation due to the performance ramp with radius does not differ much from the estimates done using single cylinder test data. This is because the inner radii in many files dominate the error rate. Overall projections based on the error rate at the inner radius can be fairly accurate. No head test is absolutely accurate in projecting file performance, but the magnetic error rate test is more accurate and less arbitrary than previous tests.

Claims

1. A data storage device wherein data is stored in parallel tracks on a magnetic medium using at least one magnetic transducer head (35) associated with the medium surface, the write currents of the transducer

errors without the errors becoming "hard", unrecoverable failures to read the data. It is also important that the device be capable of recovering data through its own capabilities without the ultimate factory intervention to recover vital user data.

Accurate test capability of a single transducer head near component design limits is important. Good and bad components may be sorted more accurately. Test specifications may be set closer to design limitations. This means less excess test specification margin is necessary with the more accurate test. The prior poorer test to actual performance correlation meant additional test margin was necessary. Now with tighter correlation, the margin may be decreased and the resultant quality of the population of produced product will not be affected. At the same time yield or capacity of the product can improve, lowering cost or increasing competitiveness of the device or both.

The actual test is similar to tests performed on precision test stands during file development. First, two bands of old information are written by offsetting the head position and writing a data pattern in each radial direction from the nominal position. Then the data pattern (normally another random pattern) is written in the nominal on-track position. Then the head is accessed to the next track and offset back toward the data track and a third random pattern is written. This is termed a squeeze track. Another squeeze pattern is also written on the opposite side. The error rate of the data track is then measured from the on track position. The read is then repeated on the same track for better statistics, and the writing and reading is repeated on three other tracks representing each of the four types of servo tracks for a sector servo implementation or adjacent tracks for a dedicated servo application so that a representative average of error performance is achieved. For a typical drive this procedure takes only a short time, since it is not necessary to measure the actual error rate of very good heads, but only marginal heads. Allowed raw error rates may be significantly higher since the ECC and automatic recovery significantly improves the apparent error rate. For narrow heads, the squeeze track would be some distance away from the data track, and will cause few detrimental effects in normal file operation. The head is therefore tested with the same type of interference as seen in normal file operation. For wide heads, the squeeze track will partially protrude into the edge of the data track, partially erasing data and writing additional interference much as in normal file operation. Writing the squeeze track closer to the data track simulates a much more rare track misregistration than occurs in normal file operation. This allows testing of the failure mechanism in a short amount of test time. The wide heads are tested with stressful squeezes from adjacent tracks with normal signal to noise conditions. This proves to be a reasonable test for heads, since the heads that are normal or good in signal to noise performance can withstand more squeeze interference. A poor quality, poor efficiency head within the width specification may fail while a head which may be too wide, but of good efficiency could be passed. Thus the test measures the actual performance of a file in contrast to imposing a somewhat arbitrary maximum track width.

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Claims

1. A data storage device wherein data is stored in parallel tracks on a magnetic medium using at least one magnetic transducer head (35) associated with the medium surface, the write currents of the transducer

head (35) and the reading circuits being adjustable by digital signals, said data storage device being characterized by a module (36) connected to the transducer head associated with disk surfaces and comprising:

- first circuit means (52, Q9, R21; 51, Q1, R20) for generating a plurality of reference currents,
- second circuit means (Q15-23) for selecting and adding an optimum combination of said plurality of reference currents in response to the value of a first digital signal, to generate a write current, said write current being provided to the coil of the transducer head (35) to write data on a disk surface, the selection of said plurality of values of write current being in response to the radial positions of each of said magnetic transducer heads independently of the other transducer heads, whereby the write current may be varied radially with respect to each of said magnetic transducer heads (35) independently of the other transducer heads (35)

said module further comprising:

- circuitry (46,47) wherein a serial data read signal is verified for a true peak by determining that the read signal has a minimum change delta-V during a given time,
- third circuit means (Q6, Q4C, Q2C, Q1C) for generating a plurality of reference currents,
- fourth means (R5, Q4A-B, Q2A-CB, Q1A-B, TTL to ECL), for selecting and adding an optimum combination of said plurality of reference currents in response to the value of a second digital signal received by said third circuit means, in order to generate a delta-V value to verifying a read signal from a data surface track with each of said heads at a given radial position, which optimum delta-V value can vary from head to head, and the selection of said plurality of delta-V values being in response to the radial positions of each of said heads.

2. The rotating magnetic disk (11) data storage device of claim 1 wherein each of said plurality of write current values includes a base value of current plus an incremental value that varies in accordance with the first digital signal received by said second circuit means (Q15-23).

3. The rotating magnetic disk (11) data storage device of claim 2 wherein one of said incremental values is zero.

4. The rotating magnetic disk (11) data storage device of claim 2 wherein said parallel tracks are divided into a plurality of contiguous bands of tracks and each said band uses a write current value that can vary from band to band.

5. The rotating magnetic disk (11) data storage device of claim 4 wherein the write current value is optimized for one band of tracks on each disk (11) sur face and selected for the other bands of tracks on the disk (11) surface based on the optimized value for said one band and a predetermined set of values selected from said plurality of write current values for other bands of tracks on the same disk (11) surface.

6. The rotating magnetic disk (11) data storage device of claim 5 wherein the optimum one of said write current values is selected for the innermost band of tracks on a disk (11) surface and the write current value for other bands of tracks of greater radius is selected in accordance with a predetermined sequence of values based on said optimum write current value.

7. A method of determining optimum transducer head read-write performance in the device (11) of any one of claims 1 to 6, said method being characterized in that it comprises the steps of:

writing a predetermined pattern of information on a selected track;

reading the data on said selected track using an initial value of write current and recording the number of errors;

incrementing said write current within said plurality of selectable values, reading data on said selected track and recording the number of errors;

if the number of errors is fewer than the number recorded after the next previous reading, repeating the prior step of incrementing the write current and

reading the selected track or if the present write current value is the final incremental value, setting the write current at the present value and if the number of errors exceeds the next previous recorded error count, setting the write current at the next prior write current value;

reading said selected track and recording the number of errors occuring with the current delta-V;

decrement the current delta-V and reread said selected track, recording the number of errors;

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if errors are less, repeat last step and if errors are more, increment delta-v, reread said selected track and record the number of errors;
if errors are less than the previous sum, repeat step of incrementing delta-V and rereading;
when retest produces an increased error sum, set delta-V at immediately preceding value or at the final value if fewer errors and current delta-V value is the final incremental value.

8. The method of claim 7 wherein said step of writing a predetermined pattern of information on a selected track is performed using an initial value of write current and comprises the steps of:
writing two bands of information by offsetting the transducer head (35) position by a first predetermined distance in each radial direction away from its nominal on-selected track position and writing a first pattern of information in each offset trans ducer head (35) positions;
writing said predetermined pattern of information with the transducer head (35) in its nominal on-selected track position;
writing a second pattern of information on each track adjoining said selected track with the transducer head (35) offset by a second predetermined distance toward said selected track, said second predetermined distance being smaller than said first prede termined distance.

9. The method of claim 8 wherein:
if the number of errors recorded after the first reading of said selected track exceeds a first pre-established number, the transducer head (35) is failed and the test is terminated;
if the number of errors recorded at the final write current value setting is not less than a second pre-established number, the test is continued using successive decremented and incremented values of delta-V.

10. The method of claim 9 wherein if the number of errors recorded while using the final incremented value of delta-V is less than a third pre-established number, the head is passed as within specification and if the number of errors exceeds said third pre-established number, the head is failed.

Patentansprüche

1. Gerät zur Datenspeicherung, worin Daten in parallelen Spuren auf einem magnetischen Medium gespeichert werden, mindestens ein magnetischer Übertragungskopf (35) verwendet wird, der in Verbindung mit der Oberfläche des Mediums steht und wobei die Schreibströme des Übertragungskopfes (35) sowie die Leseschaltungen durch digitale Signale einstellbar sind, dadurch gekennzeichnet, daß dieses Gerät zur Datenspeicherung ein Modul (36) enthält, das mit dem Übertragungskopf, der in Verbindung mit der Plattenoberfläche steht, verbunden ist und
   - erste Schaltungsmittel (52, Q9, R21; 51, Q1, R20) zur Erzeugung einer Vielzahl Referenzströme und
   - zweite Schaltungsmittel (Q15 bis Q23) für die Auswahl und das Aufsummieren einer optimalen Kombination dieser Referenzströme in Abhängigkeit von dem Wert eines ersten digitalen Signals enthält, um daraus einen Schreibstrom zu erzeugen, wobei dieser Schreibstrom für die Spule des Übertragungskopfes (35) bereitgestellt wird, um Daten auf eine Plattenoberfläche zu schreiben, die Auswahl aus der Vielzahl der Schreibstromwerte erfolgt in Abhängigkeit von der radialen Position jedes der Übertragungsköpfe unabhängig von den jeweils anderen Übertragungsköpfen, wobei der Schreibstrom jedes Übertragungskopfes (35) unabhängig von den anderen Übertragungsköpfen (35) in Abhängigkeit von der radialen Position verändern werden kann,
   und daß dieses Modul desweiteren umfaßt:
   - Schaltungsanordnungen (46, 47) in denen ein serielles Datenlesesignal auf gültige Spitzenwerte überprüft wird, indem festgestellt wird, daß das Lesesignal eine minimale Änderung Delta-V während einer gegebenen Zeit besitzt,
   - dritte Schaltungsmittel (Q6, Q4C, Q2C, Q1C) zur Erzeugung einer Vielzahl Referenzströme,
   - vierte Mittel (R5, Q4A-B, Q2A-CB, Q1A-B, TTL-ECL-Anpaßstufe) für die Auswahl und das Aufsummieren einer optimalen Kombination dieser Referenzströme in Abhängigkeit von dem Wert eines zweiten digitalen Signals, das durch die dritten Schaltungsmittel empfangen wird, um daraus einen Delta-V-Wert zu erzeugen, mit dem ein Lesesignal von einer Datenspur auf der Plattenoberfläche überprüft wird, das von einem der Übertragungsköpfe aus einer vorgegeben radialen Position kommt, wobei der optimale Delta-V-Wert von Kopf zu Kopf variieren kann und die Auswahl aus der Vielzahl der Delta-V-Werte in Abhängigkeit von der radialen Position jedes

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der Köpfe erfolgt.

2. Gerät zur Datenspeicherung mit rotierender Magnetplatte (11) nach Anspruch 1, dadurch gekennzeichnet, daß jeder Wert aus der Vielzahl der Schreibstromwerte einen Stromgrundwert plus einen Inkrementalwert umfaßt, der entsprechend des ersten digitalen Signals verändert wird, das durch die zweiten Schaltungsmittel (Q15 bis 23) empfangen wird.

3. Gerät zur Datenspeicherung mit rotierender Magnetplatte (11) nach Anspruch 2, dadurch gekennzeichnet, daß einer der Inkrementalwerte Null ist.

4. Gerät zur Datenspeicherung mit rotierender Magnetplatte (11) nach Anspruch 2, dadurch gekennzeichnet, daß die parallelen Spuren in eine Vielzahl benachbarter Spurbänder unterteil werden und für jedes dieser Bänder ein Schreibstromwert verwendet wird, der von Band zu Band variieren kann.

5. Gerät zur Datenspeicherung mit rotierender Magnetplatte (11) nach Anspruch 4, dadurch gekennzeichnet, daß der Schreibstromwert für ein Spurband auf jeder Plattenoberfläche (11) optimiert und für die anderen Spurbänder der Plattenoberfläche ausgewählt wird, wobei dies auf Grundlage des optimierten Wertes für dieses eine Band und aus einem vorgegeben Satz von Werten erfolgt, die aus der Vielzahl der Schreibstromwerte für die anderen Spurbänder derselben Plattenoberfläche (11) ausgewählt wurden.

6. Gerät zur Datenspeicherung mit rotierender Magnetplatte (11) nach Anspruch 5, dadurch gekennzeichnet, daß das Optimum der Schreibstromwerte für das innerste Spurband auf einer Plattenoberfläche (11) ausgewählt wird und daß der Schreibstromwert für die anderen Spurbänder mit größerem Radius entsprechend einer vorgegebenen Folge von Werten ausgewählt wird, die auf diesem optimalen Schreibstromwert basiert.

7. Verfahren zur Bestimmung der optimalen Lese-Schreib-Leistungsfähikeit des Übertragungskopfes in einem Gerät (11) nach einem der Ansprüche 1 bis 6, dadurch gekennzeichnet, daß das Verfahren die folgenden Schritte umfaßt:
Schreiben eines vorgegeben Informationsmusters auf eine ausgewählte Spur,
Lesen der Daten von dieser ausgewählten Spur, wobei ein Anfangswert für den Schreibstrom verwendet und die Anzahl der Fehler aufgezeichnet wird,
Inkrementieren des Schreibstroms innerhalb der Vielzahl der wählbaren Werte, Lesen der Daten auf der ausgewählten Spur und Aufzeichnen der Anzahl der Fehler,
wenn die Anzahl der Fehler kleiner ist als die Anzahl, die nach dem vorletzten Lesen aufgezeichnet worden war, Wiederholen des letzten Schrittes des Inkrementierens des Schreibstroms und
Lesen der ausgewählten Spur oder wenn der gegenwärtige Schreibstromwert der letzte Inkrementalwert ist, Setzen des Schreibstroms auf den gegenwärtigen Wert und wenn die Anzahl der Fehler die nach dem vorletzten Lesen aufgezeichnete Fehlerzahl übersteigt, Setzen des Schreibstromwertes auf den vorletzten Schreibstromwert,
Lesen der ausgewählten Spur und Aufzeichnen der Anzahl der Fehler, die bei dem momentanen Delta-V-Wert auftreten,
Dekrementieren des momentanen Delta-V-Wertes und erneutes Lesen der ausgewählten Spur mit Aufzeichnung der Anzahl der Fehler,
wenn die Fehler weniger geworden sind, Wiederholen des letzten Schrittes und wenn die Fehler mehr geworden sind, Inkrementieren von Delta-V, erneutes Lesen der ausgewählten Spur und Aufzeichnen der Anzahl der Fehler,
wenn die Fehlerzahl jetzt kleiner als die vorhergehende Summe geworden ist, Wiederholen des Schrittes des Inkrementierens von Delta-V und erneutes Lesen,
wenn der erneute Test eine größere Fehlersumme erzeugt, Setzen von Delta-V auf den unmittelbar vorhergehenden Wert oder auf den letzten Wert, wenn weniger Fehler aufgetreten sind und der momentane Delta-V-Wert der letzte Inkrementalwert ist.

8. Verfahren nach Anspruch 7, dadurch gekennzeichnet, daß der Schritt des Schreibens eines vorgegebenen Informationsmusters auf eine ausgewählte Spur unter Verwendung eines Anfangswertes für den Schreibstrom ausgeführt wird und folgende Schritte umfaßt:
Schreiben von zwei Informationsbändern durch Verschieben der Position des Übertragungskopfes (35)

um eine erste vorgegebene Distanz weg von der Nominalposition der ausgewählten Spur in jede radiale Richtung und Schreiben eines ersten Informationsmusters in jede verschobene Übertragungskopf-(35) Position,
Schreiben dieses vorgegeben Informationsmusters mit dem Übertragungskopf (35) auf die Nominalposition der ausgewählten Spur,
Schreiben eines zweiten Informationsmusters auf jede Spur, die an die ausgewählte Spur angrenzt mit einer Übertragungskopf-(35) Verschiebung um eine zweite vorgegebene Distanz in Richtung der ausgewählten Spur, wobei diese zweite vorgegebene Distanz kleiner ist als die erste vorgegebene Distanz.

9. Verfahren nach Anspruch 8, dadurch gekennzeichnet, daß,
wenn die Anzahl der aufgezeichneten Fehler nach dem ersten Lesen der ausgewählten Spur eine erste vorgegebene Anzahl übersteigt, der Übertragungskopf (35) als fehlerhaft gekennzeichnet und der Test beendet wird,
und daß,
wenn die Anzahl der aufgezeichneten Fehler mit dem letzten Setzen des Schreibstromwertes nicht kleiner ist als eine zweite vorgegeben Anzahl, der Test unter Verwendung sukzessive dekrementierter und inkrementierter Werte von Delta-V fortgesetzt wird.

10. Verfahren nach Anspruch 9, dadurch gekennzeichnet, daß, wenn die Anzahl der Fehler, die bei Verwendung des letztmalig inkrementierten Wertes für Delta-V aufgezeichnet worden ist, kleiner ist als eine dritte vorgegebene Anzahl, der Kopf den Test innerhalb der notwendigen Spezifikation bestanden hat und daß, wenn die Anzahl der Fehler diese dritte vorgegebene Anzahl übersteigt, der Kopf den Test nicht bestanden hat.

Revendications

1. Un dispositif d'emmagasinage de données dans lequel des données sont emmagasinées dans des pistes parallèles sur un support magnétique, utilisant au moins une tête de transducteur magnétique (35) associée à la surface du support, les courants d'écriture de la tête de transducteur (35) et les circuits de lecture étant réglables par des signaux numériques, ledit dispositif d'emmagasinage de données étant caractérisé par un module (36) connecté à la tête de transducteur associée aux surfaces de disques et comprenant:
   - des premiers moyens à circuits (52, Q9, R21; 51, Q1, R20) pour générer une pluralité de courants de référence,
   - des seconds moyens à circuits (Q15-23) pour sélectionner et ajouter une combinaison optimale de ladite pluralité de courants de référence en réponse à la valeur d'un premier signal numérique, afin de générer un courant d'écriture, ledit courant d'écriture étant appliqué à la bobine de la tête de transducteur (35) pour écrire des données sur la surface d'un disque, la sélection de ladite pluralité de valeurs du courant d'écriture étant faite en réponse aux positions radiales de chacune des dites têtes de transducteur magnétique indépendamment des autres têtes de transducteur, ce qui permet de faire varier radialement le courant d'écriture par rapport à chacune desdites têtes de transducteur magnétique (35) indépendamment des autres têtes de transducteur (35),
   ledit module comprenant en outre:
   - des circuits (46, 47) dans lesquels un signal de lecture de données en série est vérifié afin d'y détecter un sommet vrai en déterminant que le signal de lecture présente un changement delta-V minimal pendant un temps donné,
   - des troisièmes moyens à circuits (Q6, Q4C, Q2C, Q1C) pour générer une pluralité de courants de référence,
   - des quatrièmes moyens (R5, Q4A-B, Q2A-CB, Q1A-B, TTL à ECL), pour sélectionner et ajouter une combinaison optimale de ladite pluralité de courants de référence en réponse à la valeur d'un second signal numérique reçu par lesdits troisièmes moyens à circuits, afin de générer une valeur delta-V pour vérifier un signal de lecture issu d'une piste en surface de données, chacune desdites têtes étant dans une position radiale donnée, laquelle valeur delta-V optimale peut varier d'une tête à l'autre, et la sélection de ladite pluralité de valeurs delta-V se faisant en réponse aux positions radiales de chacune desdites têtes.

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2. Le dispositif d'emmagasinage de données à disques magnétiques rotatifs (11) de la revendication 1 dans lequel chacune de ladite pluralité de valeurs de courant d'écriture comprend une valeur de courant de base plus une valeur incrémentielle qui varie selon le premier signal numérique reçu par lesdits seconds moyens à circuits (Q15-23).

3. Le dispositif d'emmagasinage de données à disques magnétiques rotatifs (11) de la revendication 2 dans lequel l'une desdites valeurs incrémentielles est de zéro.

4. Le dispositif d'emmagasinage de données à disques magnétiques rotatifs (11) de la revendication 2 dans lequel lesdites pistes parallèles sont divisées en une pluralité de bandes de pistes contiguës et chacune desdites bandes utilise une valeur de courant d'écriture qui peut varier d'une bande à l'autre.

5. Le dispositif d'emmagasinage de données à disques magnétiques rotatifs (11) de la revendication 4 dans lequel la valeur du courant d'écriture est optimisée pour une bande des pistes sur la surface de chaque disque (11) et sélectionnée pour les autres bandes des pistes sur la surface du disque (11) en se basant sur la valeur optimisée pour ladite première bande et un ensemble prédéterminé de valeurs est sélectionné parmi ladite pluralité de valeurs du courant d'écriture pour d'autres bandes de pistes sur la même surface de disque (11).

6. Le dispositif d'emmagasinage de données à disques magnétiques rotatifs (11) de la revendication 5 dans lequel la valeur optimale desdites valeurs du courant d'écriture est sélectionnée pour la bande la plus à l'intérieur des pistes sur la surface d'un disque (11) et la valeur du courant d'écriture pour les autres bandes des pistes de plus grand rayon est sélectionnée selon une séquence prédéterminée de valeurs en se basant sur ladite valeur de courant d'écriture optimale.

7. Une méthode de détermination des performances optimales de lecture/écriture d'une tête de transducteur dans le dispositif (11) de l'une quelconque des revendications 1 à 6, ladite méthode étant caractérisée en ce qu'elle comprend les étapes suivantes:
   - l'écriture d'une configuration prédéterminée d'informations sur une piste sélectionnée,
   - la lecture des données sur ladite piste sélectionnée en utilisant une valeur initiale de courant d'écriture et en enregistrant le nombre d'erreurs,
   - l'incrémentation dudit courant d'écriture dans les limites de ladite pluralité de valeurs pouvant être sélectionnées, la lecture des données sur ladite piste sélectionnée et l'enregistrement du nombre d'erreurs,
   - si le nombre d'erreurs est inférieur au nombre enregistré après la lecture immédiatement précédente, la répétition de l'étape précédente d'incrémentation du courant d'écriture et
   - la lecture de la piste sélectionnée ou si la valeur présente du courant d'écriture est égale à la valeur incrémentielle finale, le réglage du courant d'écriture à la valeur présente et si le nombre d'erreurs excède le compte d'erreurs enregistré immédiatement précédent, le réglage du courant d'écriture à la valeur du courant d'écriture immédiatement précédent,
   - la lecture de ladite piste sélectionnée et l'enregistrement du nombre d'erreurs survenant avec le courant delta-V,
   - la décrémentation du courant delta-V et la relecture de ladite piste sélectionnée, l'enregistrement du nombre d'erreurs,
   - si le nombre d'erreurs est moindre, répéter la dernière étape et si le nombre d'erreurs est supérieur, incrémenter delta-V, relire ladite piste sélectionnée et enregistrer le nombre d'erreurs,
   - si le nombre d'erreurs est inférieur à la somme précédente, répéter l'étape d'incrémentation de delta-V et relecture,
   - lorsque la répétition du test résulte en une somme d'erreurs supérieure, régler delta-V à la valeur immédiatement précédente ou à la valeur finale si le nombre d'erreurs est moindre et la valeur du courant delta-V est la valeur incrémentielle finale.

8. La méthode de la revendication 7 dans laquelle ladite étape d'écriture d'une configuration prédéterminée d'informations sur une piste sélectionnée, est exécutée en utilisant une valeur initiale du courant d'écriture et comprend les étapes suivantes:
   - l'écriture de deux bandes d'informations en décalant la position de la tête de transducteur (35) sur une première distance prédéterminée dans chaque direction radiale en s'écartant de sa position nominale sur la piste sélectionnée et l'écriture d'une première configuration d'informa-

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tions dans chacune des positions décalées de la tête de transducteur (35),

- l'écriture de ladite configuration prédéterminée d'informations avec la tête de transducteur (35) dans sa position nominale sur la piste sélectionnée,
- l'écriture d'une seconde configuration d'informations sur chaque piste contiguë à ladite piste sélectionnée avec la tête de transducteur (35) décalée sur une seconde distance prédéterminée vers ladite piste sélectionnée, ladite seconde distance prédéterminée étant inférieure à ladite première distance prédéterminée.

9. La méthode de la revendication 8 dans laquelle:

- si le nombre d'erreurs enregistré après la première lecture de ladite piste sélectionnée, excède un premier nombre pré-établi, la tête de transducteur (35) est défectueuse et le test est terminé,
- si le nombre d'erreurs enregistré au réglage final de la valeur du courant d'écriture n'est pas inférieur à un second nombre pré-établi, le test est poursuivi en utilisant des valeurs successives décrémentées et incrémentées de delta-V.

10. La méthode de la revendication 9 dans laquelle, si le nombre d'erreurs enregistré en utilisant la valeur finale incrémentée de delta-V, est inférieur à un troisième nombre pré-établi, la tête est acceptée comme répondant aux normes et si le nombre d'erreurs excède ledit troisième nombre pré-établi, la tête est défectueuse.