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**Wang et al.**

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(45) **Date of Patent: Jun. 7, 2005**

(54) **PERFORMANCE OF A ROTARY ACTUATOR IN A DISK DRIVE**

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(22) Filed: **Jun. 27, 2003**

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(52) **U.S. Cl.** ................................ **360/78.07**; 360/78.06; 360/77.02; 318/561; 318/632

(58) **Field of Search** ........................... 360/78.06, 78.07, 360/78.12, 78.04, 75, 77.02; 318/560, 561, 632, 636

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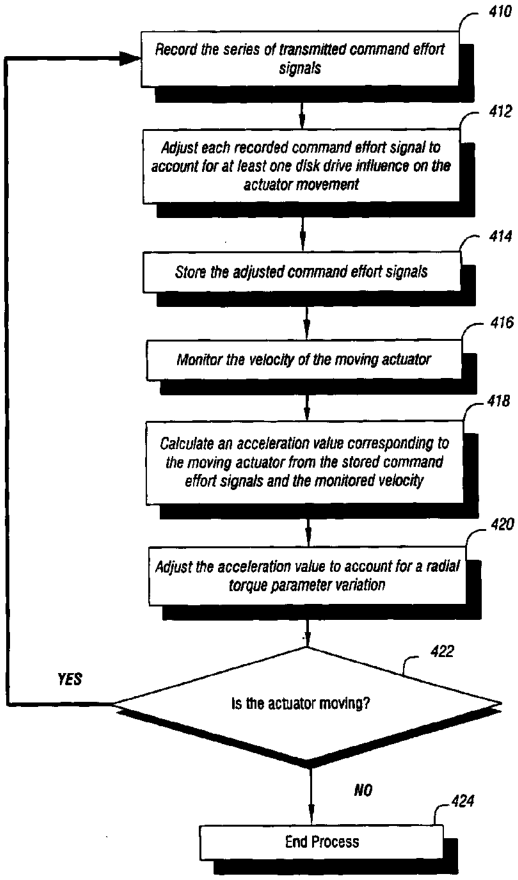
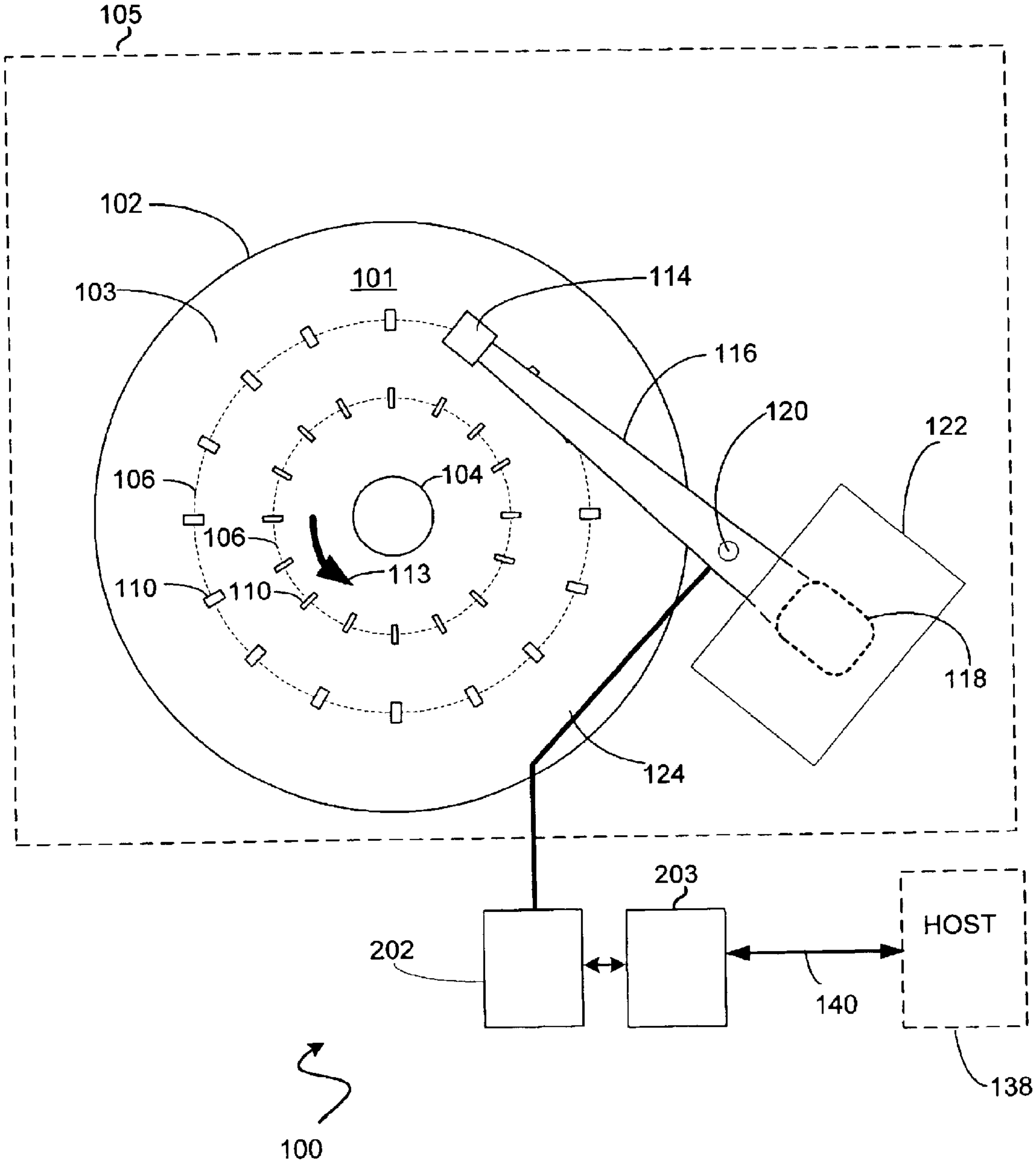
(74) *Attorney, Agent, or Firm*—Ramin Mobarhan, Esq.

## (57) ABSTRACT

A method for improving the performance of a rotary actuator in a disk drive, the rotary actuator comprises a voice coil motor (VCM) characterized by a torque parameter, the disk drive comprises a servo control system having a motor driver circuit for receiving a series of command effort signals (CEFs) transmitted based on a first seek profile, and for providing an operating current to VCM based on the CEFs for causing a movement of the actuator from a first radial location to a target radial location. The method includes recording the transmitted CEFs, and while actuator is moving: adjusting each recorded CEF to account for a disk drive influence on actuator movement; storing adjusted CEFs; monitoring velocity of moving actuator; calculating an acceleration value corresponding to moving actuator from the stored CEFs and monitored velocity; and adjusting the acceleration value to account for a radial torque parameter variation.

**28 Claims, 13 Drawing Sheets**




105
102
101
103
114
116
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122
106
104
106
113
110
110
118
124
203
202
HOST
140
138
100

FIG. 1

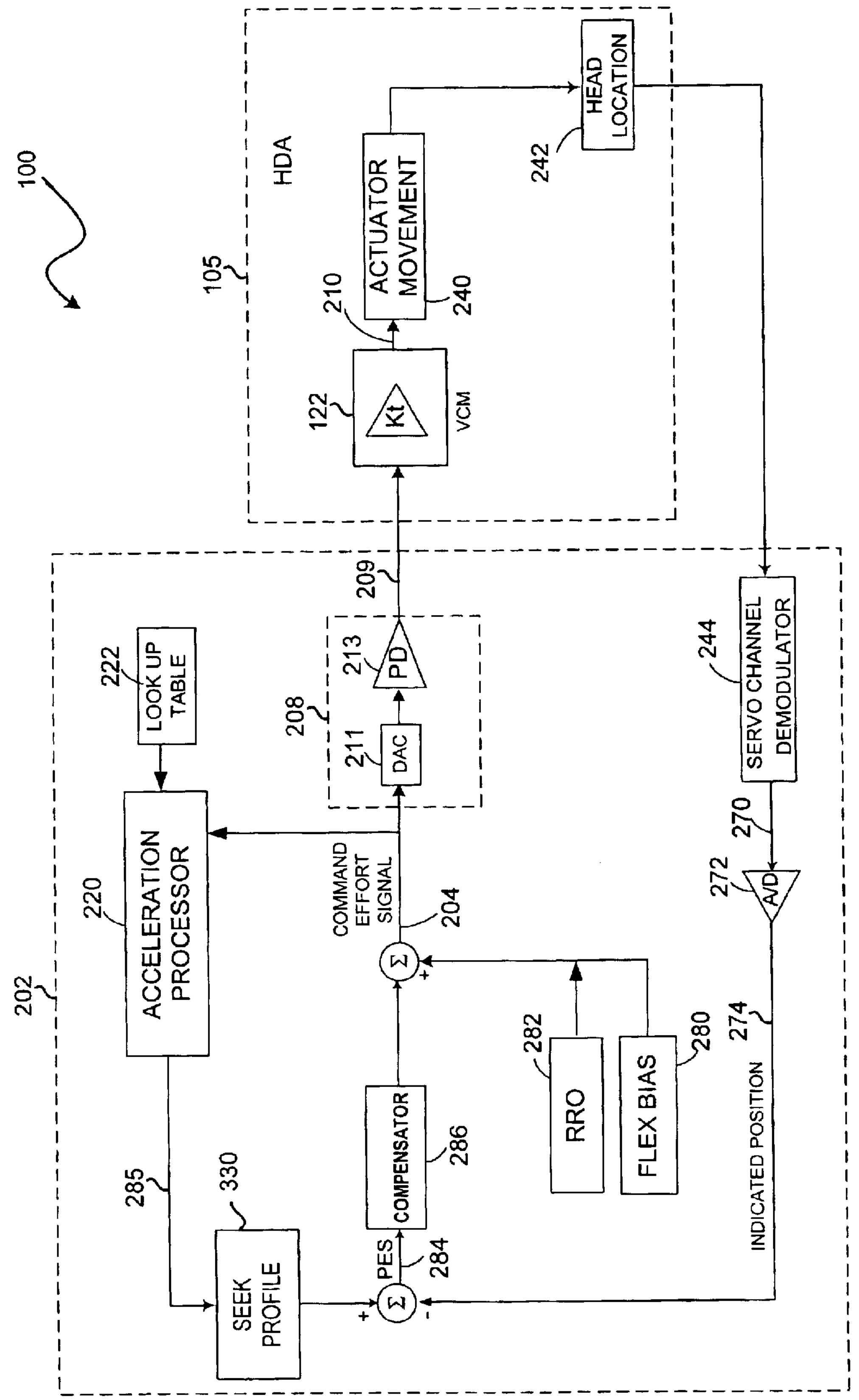
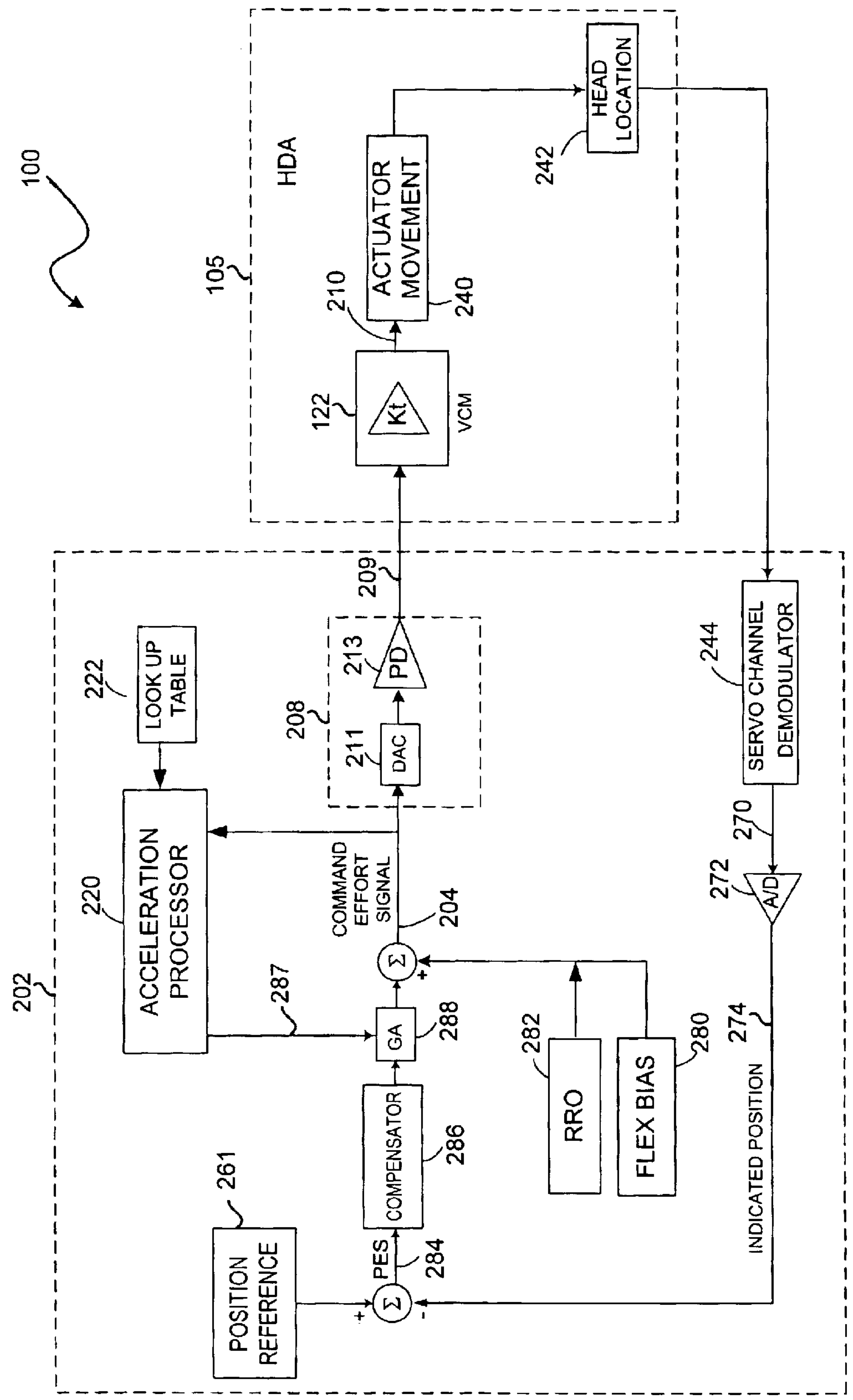

100
105
HDA
122
Kt
VCM
210
ACTUATOR MOVEMENT
240
HEAD LOCATION
242
202
ACCELERATION PROCESSOR
220
LOOK UP TABLE
222
208
211
DAC
213
PD
209
COMMAND EFFORT SIGNAL
204
Σ
+
+
SERVO CHANNEL DEMODULATOR
244
270
272
A/D
274
INDICATED POSITION
285
330
SEEK PROFILE
Σ
+
-
PES
284
COMPENSATOR
286
RRO
282
FLEX BIAS
280

FIG. 2A


100
105
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122
Kt
VCM
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240
HEAD LOCATION
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202
ACCELERATION PROCESSOR
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LOOK UP TABLE
222
208
DAC
211
PD
213
209
COMMAND EFFORT SIGNAL
204
287
GA
288
Σ
+
POSITION REFERENCE
261
PES
284
+
-
COMPENSATOR
286
RRO
282
FLEX BIAS
280
SERVO CHANNEL DEMODULATOR
244
270
A/D
272
274
INDICATED POSITION

FIG. 2B

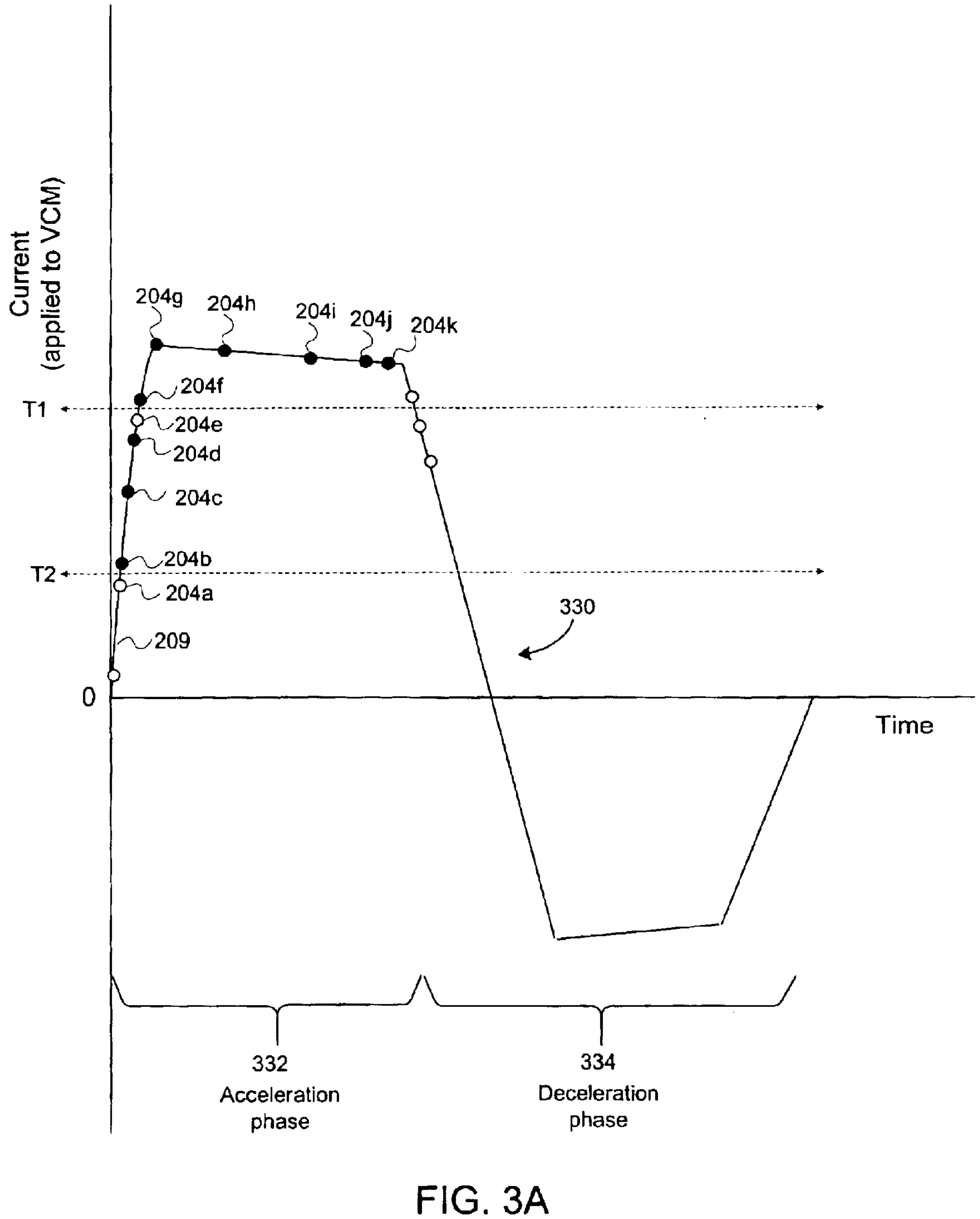
Current
(applied to VCM)
204g
204h
204i
204j
204k
204f
T1
204e
204d
204c
204b
T2
204a
209
330
0
Time
332
Acceleration phase
334
Deceleration phase

FIG. 3A

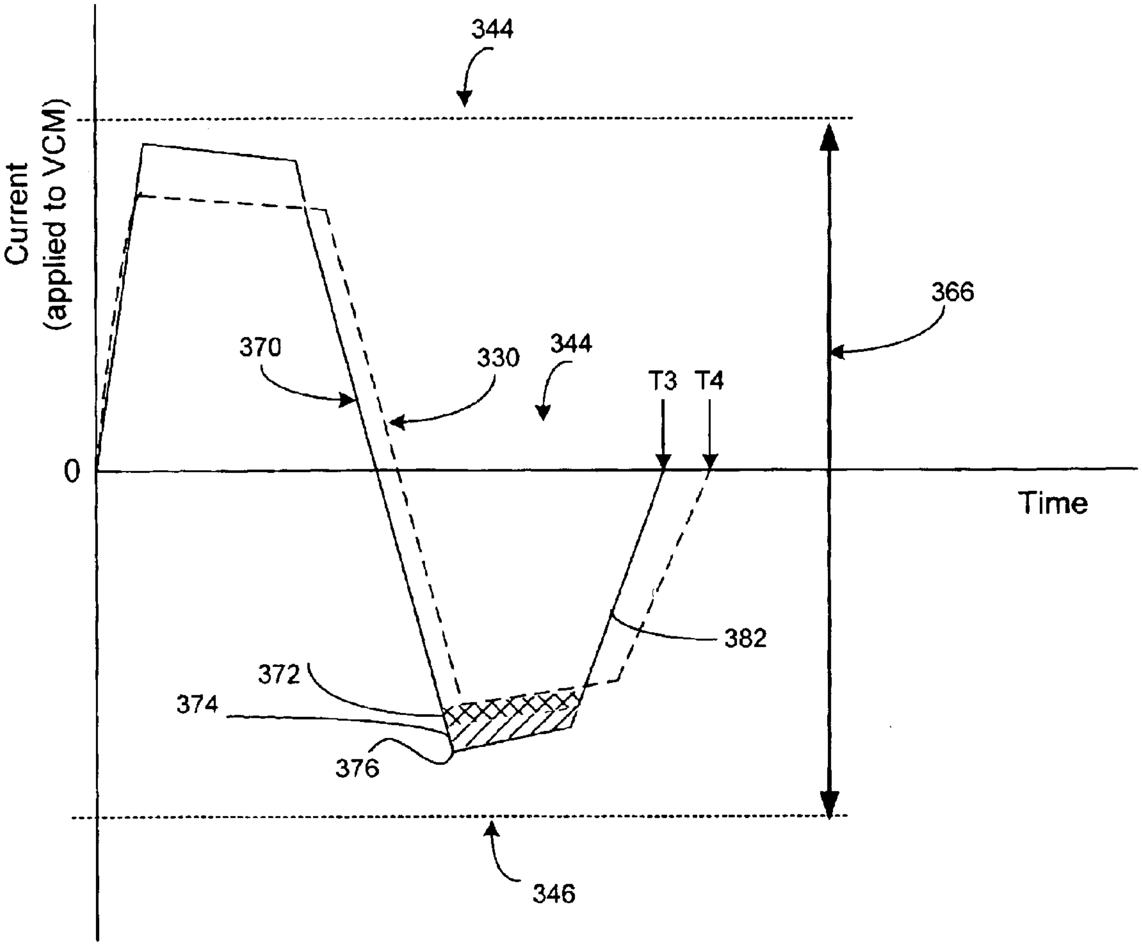
344
Current
(applied to VCM)
366
370
330
344
T3
T4
0
Time
382
372
374
376
346

FIG. 3B

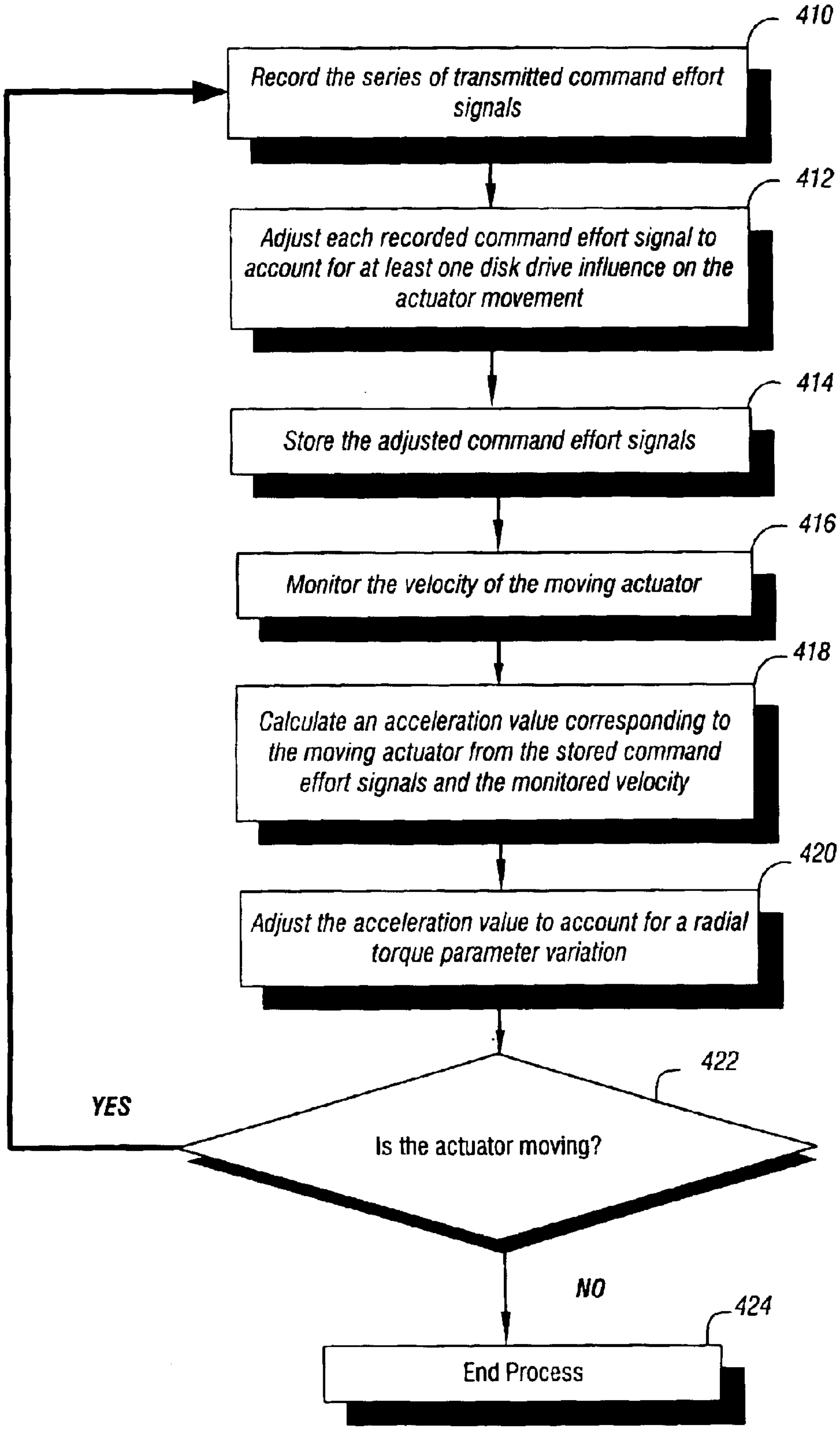
410
Record the series of transmitted command effort signals
412
Adjust each recorded command effort signal to account for at least one disk drive influence on the actuator movement
414
Store the adjusted command effort signals
416
Monitor the velocity of the moving actuator
418
Calculate an acceleration value corresponding to the moving actuator from the stored command effort signals and the monitored velocity
420
Adjust the acceleration value to account for a radial torque parameter variation
422
Is the actuator moving?
YES
NO
424
End Process

FIG. 4

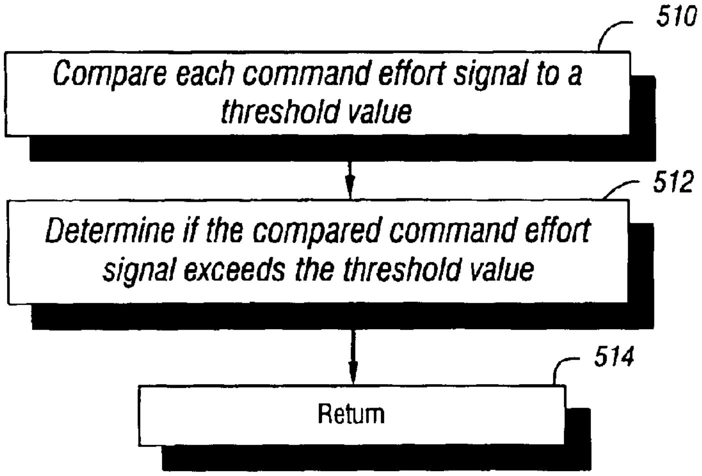

FIG. 5

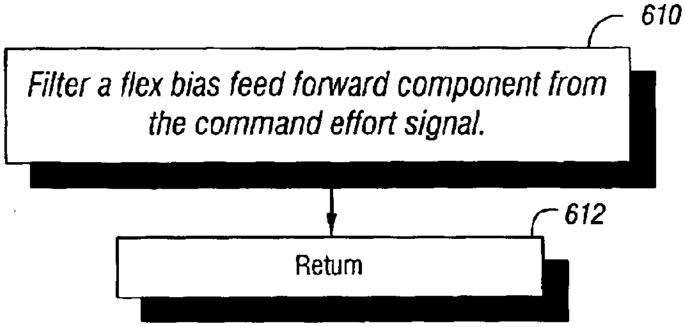

FIG. 6A

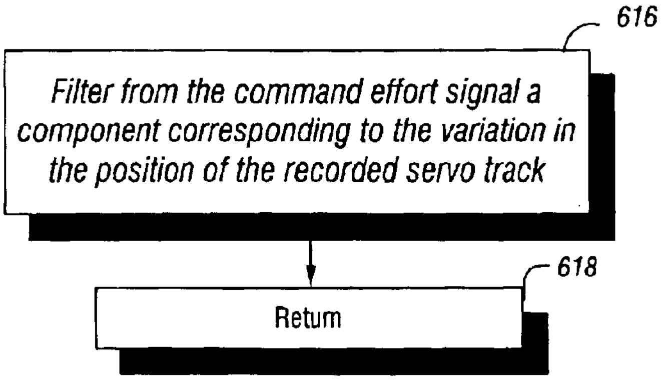

FIG. 6B

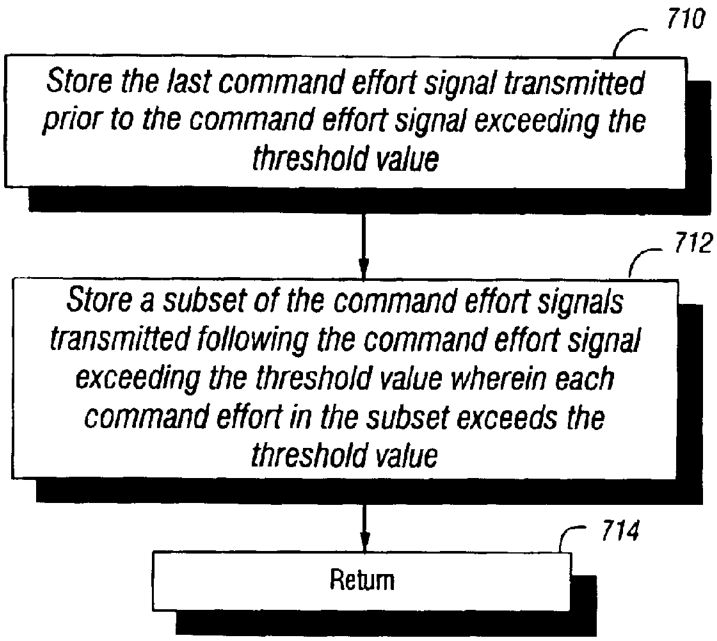
710
Store the last command effort signal transmitted prior to the command effort signal exceeding the threshold value
712
Store a subset of the command effort signals transmitted following the command effort signal exceeding the threshold value wherein each command effort in the subset exceeds the threshold value
714
Return

FIG. 7

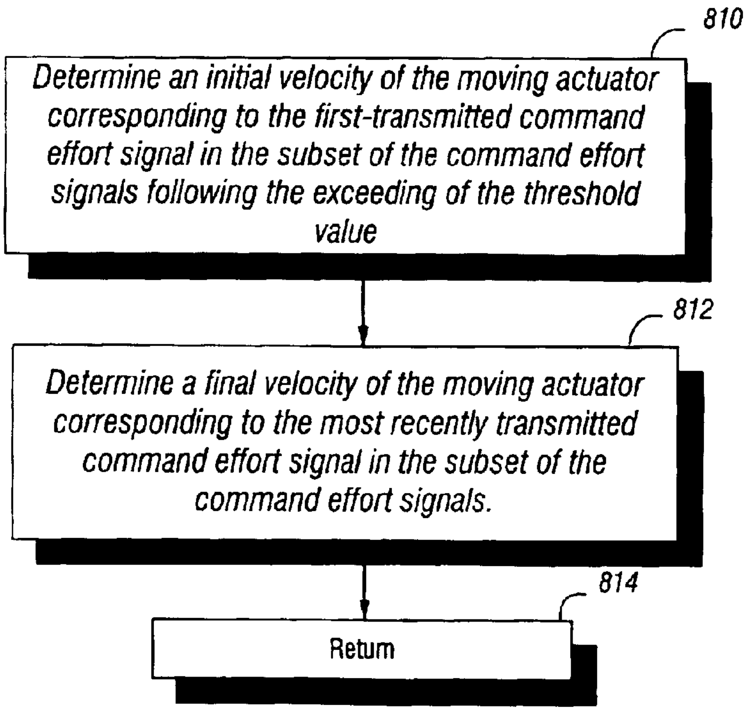
810
Determine an initial velocity of the moving actuator corresponding to the first-transmitted command effort signal in the subset of the command effort signals following the exceeding of the threshold value
812
Determine a final velocity of the moving actuator corresponding to the most recently transmitted command effort signal in the subset of the command effort signals.
814
Return

FIG. 8

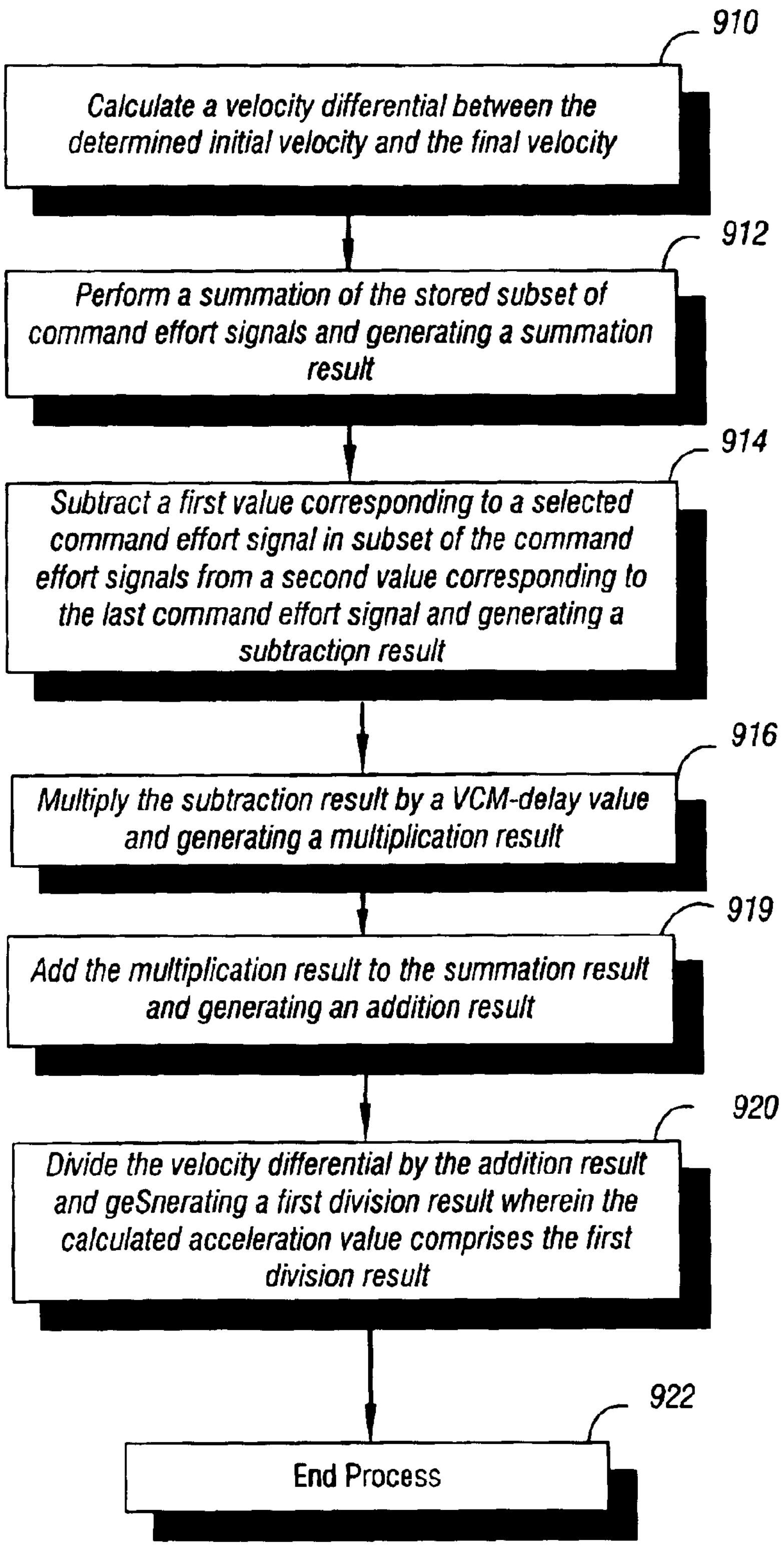
910
Calculate a velocity differential between the determined initial velocity and the final velocity
912
Perform a summation of the stored subset of command effort signals and generating a summation result
914
Subtract a first value corresponding to a selected command effort signal in subset of the command effort signals from a second value corresponding to the last command effort signal and generating a subtraction result
916
Multiply the subtraction result by a VCM-delay value and generating a multiplication result
919
Add the multiplication result to the summation result and generating an addition result
920
Divide the velocity differential by the addition result and geSnerating a first division result wherein the calculated acceleration value comprises the first division result
922
End Process

FIG. 9

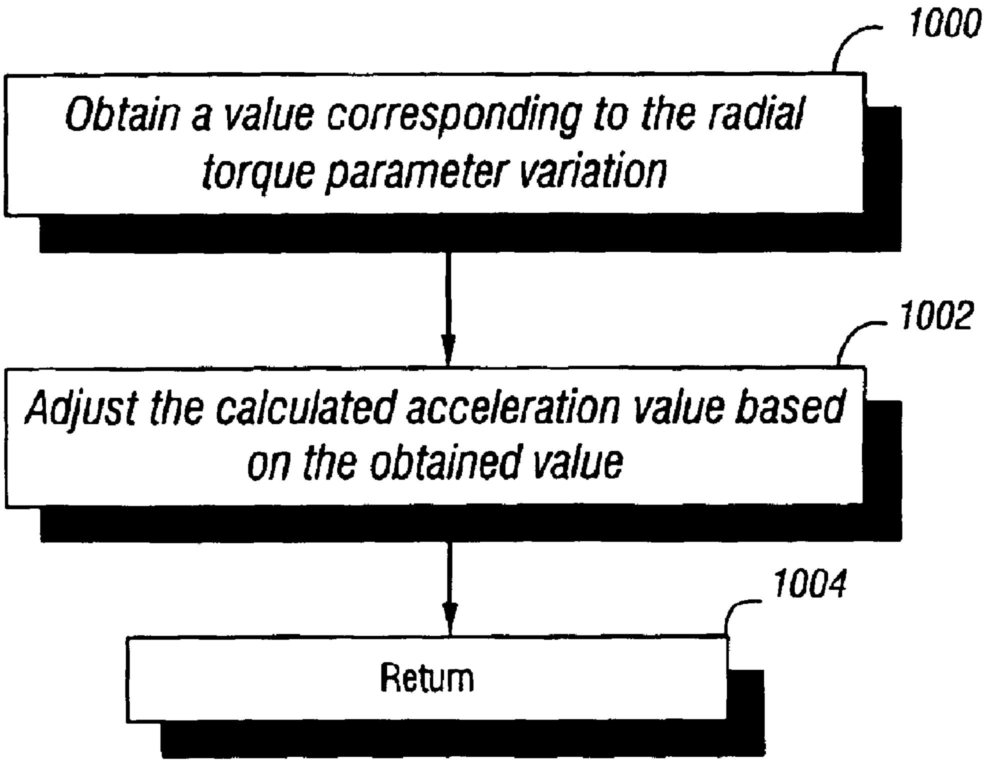
1000
Obtain a value corresponding to the radial torque parameter variation
1002
Adjust the calculated acceleration value based on the obtained value
1004
Return

FIG. 10

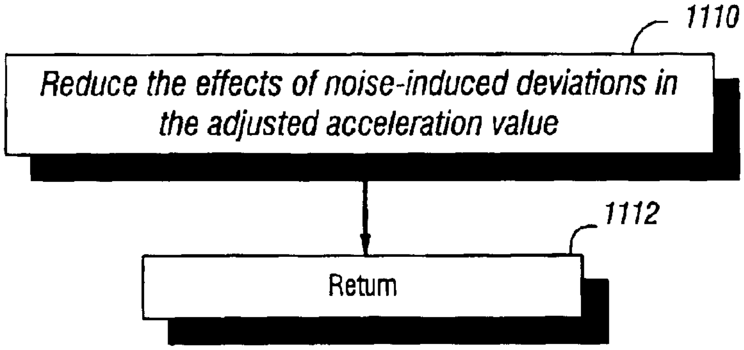

FIG. 11A

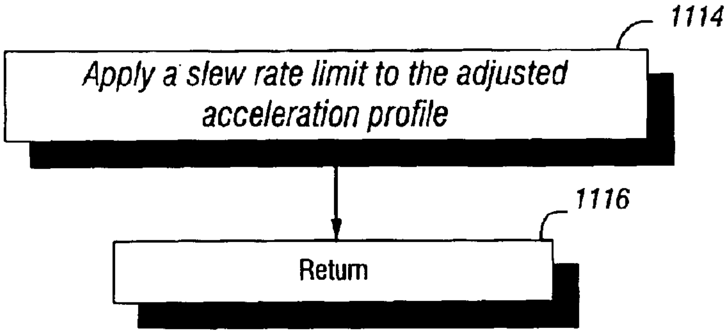

FIG. 11B

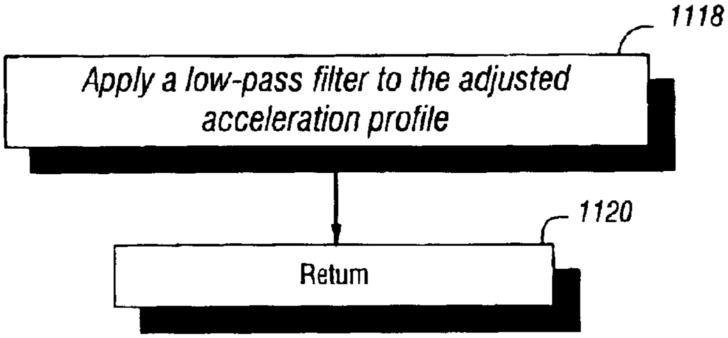

FIG. 11C

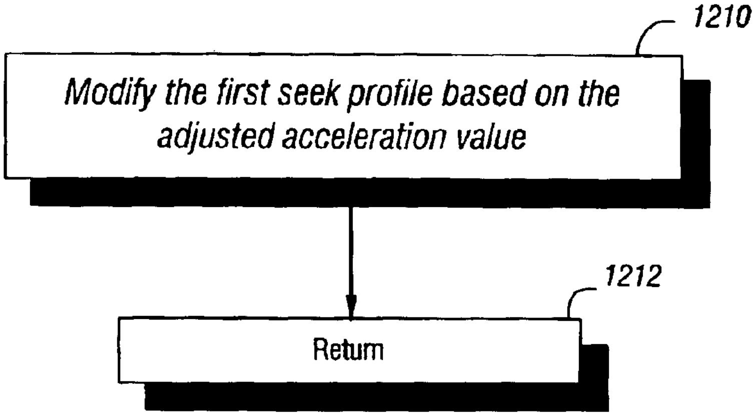

FIG. 12A

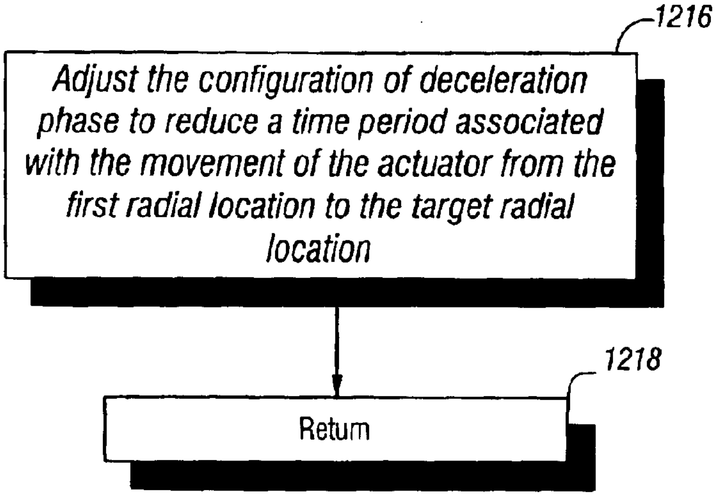

FIG. 12B

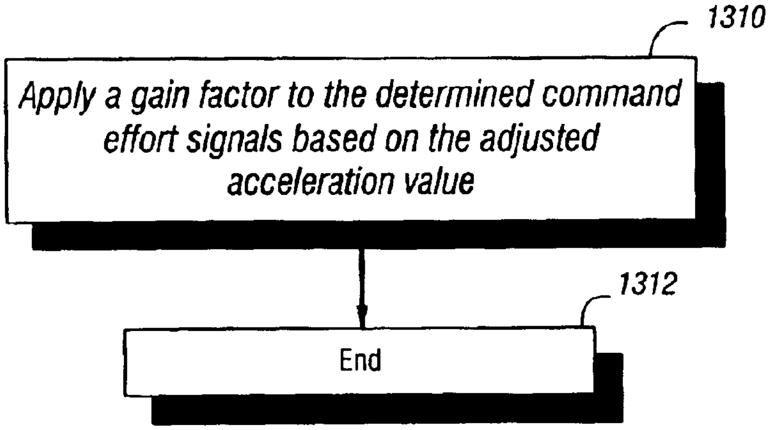

FIG. 13A

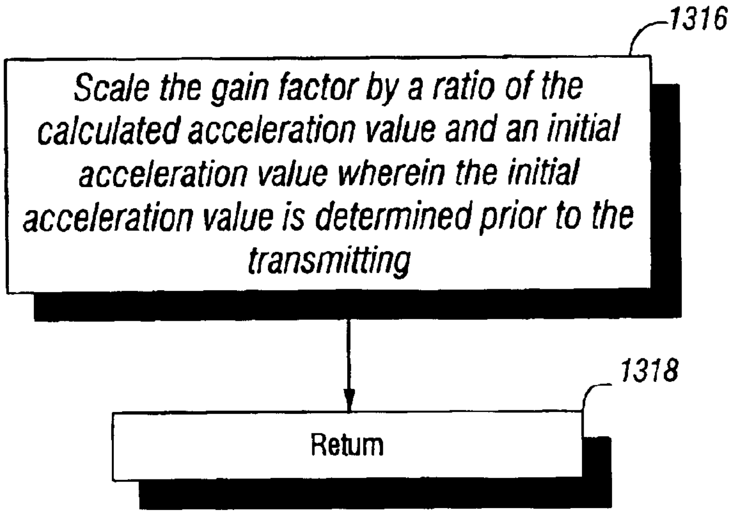

FIG. 13B

# PERFORMANCE OF A ROTARY ACTUATOR IN A DISK DRIVE

## FIELD OF THE INVENTION

This invention relates to disk drives and, in particular, relates to a disk drive having an actuator controller that adjusts seek current profile on the fly so as to improve seek performance.

## BACKGROUND OF THE INVENTION

Hard disk drive storage devices enable computer systems to quickly store data in a non-volatile manner and to retrieve the stored data when needed. The ongoing industry trend is toward computer systems with increased performance, which mandates disk drives with increased data access speeds.

A hard disk drive typically comprises pivotally mounted disks having a magnetic recording layer disposed thereon and a magnetic head elements for affecting and sensing the magnetization states of the recording layer. The recording layer comprises concentric circular tracks with data written to or read from each track by positioning a transducer head over the disk at a corresponding radius while the disk is rotated at a fixed angular speed. The time required to reposition the head is known as the "seek time" of the drive, with a shorter seek time generally translating into shorter data access time.

To position the head over a desired track, a head stack assembly (HSA) is used that includes a pivotally mounted actuator arm that supports the head, a voice coil motor (VCM) for exerting a torque onto the actuator arm, and a servo-controller for controlling the VCM and the movement of the actuator arm by directing a control current to flow through the coil which generates a torque that moves the actuator arm. The direction of the torque is dictated by the direction of control current flow, thus enabling the servo-controller to reposition the head by directing the control current through the VCM to angularly accelerate the actuator arm in a first direction and then reversing the control current to angularly decelerate the actuator arm, typically followed by some additional time for the head to settle on the proper target track. Once the head is on the desired track, a track following current is provided to the VCM in order to maintain tracking.

The current supplied to the VCM during a seek operation typically follows a predetermined profile that includes acceleration and deceleration phases. Currently, these profiles are conservatively configured and implemented so that the values used for maximum acceleration and deceleration values leave ample margins between the values and maximum current that is available for use. One reason for such conservative margins is that the maximum current available for use by the VCM varies with the operating conditions (e.g. temperature, supply voltage), and drive parameters (e.g. FET resistance, VCM winding resistance) of the disk drive, both of which affect how much current can be delivered to the VCM. Additionally, during a seek operation, the servo-controller generally has little or no visibility as to the variations in the VCM motor torque parameter (Kt) which also affects the overall seek process. Thus, if during a seek the head is first accelerated to above a maximum allowed acceleration value dictated by the varying operating conditions, drive parameters and the VCM motor torque parameter of the disk drive, then the deceleration phase may not able to stop the head at the target track. In such a situation, the head overshoots the intended target, and a substantial amount of extra time is then required to bring the head back and settle at the target track. Because of such a negative consequence, the acceleration profiles are generally configured conservatively so that the deceleration phase may have ample reserve of current to prevent overshoot during the seek operation. One disadvantage of utilizing conservative current profiles, however, is that some seek time is sacrificed.

The linear gain variations in the VCM motor torque parameter also affect track-follow operations of the actuator. These variations of the VCM motor torque parameter may cause the servo bandwidth to drift away from the pre-set optimum values, resulting in degradation of the performance of drives by increasing the risk of off-track head position, and could even cause the servo system to become unstable as a whole.

Accordingly, what is needed is a servo system that can improve the performance of the actuator by accounting for the variations in the VCM motor torque parameter.

## SUMMARY OF THE INVENTION

This invention can be regarded as a method of improving the performance of a rotary actuator in a disk drive, the rotary actuator comprises a voice coil motor (VCM) characterized by a torque parameter, the disk drive comprises a servo control system having a motor driver circuit for receiving a series of command effort signals transmitted based on a first seek profile, and for providing an operating current to the VCM based on the command effort signals for causing a movement of the actuator from a first radial location to a target radial location.

The method includes recording the series of transmitted command effort signals, and while the actuator is moving: adjusting each recorded command effort signal to account for at least one disk drive influence on the actuator movement; storing the adjusted command effort signals; monitoring the velocity of the moving actuator; calculating an acceleration value corresponding to the moving actuator from the stored command effort signals and the monitored velocity; and adjusting the acceleration value to account for a radial torque parameter variation.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates an exemplary hard disk drive in which the present invention may be practiced.

FIGS. **2**A–B illustrate diagrams of exemplary servo systems of the disk drive FIG. **1**.

FIGS. **3**A–B illustrates exemplary seek current profiles with an acceleration phase followed by a deceleration phase.

FIG. **4** is a flow chart illustrating a process used in an embodiment of the invention.

FIGS. **5**–**10** are flow charts farther illustrating the process used in the embodiment of the invention shown in FIG. **4**.

FIGS. **11**A–**13**B are flow charts illustrating other processes used in the embodiment of the invention shown in FIG. **4**.

## DETAILED DESCRIPTION OF THE INVENTION

With reference to FIG. **1**, an exemplary hard disk drive **100** in which the present invention may be practiced is shown. As shown, the hard disk drive **100** includes a head disk assembly (HDA) **105** having one or more disks **102** with a magnetic media **101** formed on each surface **103** of a disk **102**. The disks **102** are suitably organized into concentric magnetic domains which include servo tracks **106** defined by servo wedges **110** that are equally spaced from an axis of a spindle **104** about which the disk **102** rotates. The servo wedges **110** on a given track **106** are spaced circumferentially in a periodic manner and provide positional information used by a voice coil motor servo system (not shown) during reading and writing operations, and seeking and settling operations.

The HDA **105** further comprises a transducer head **114** mounted on a rotary actuator **116** that rotates about a pivot **120** via controlled torques applied by a voice coil motor (VCM) **122**. A signal bus **124**, such as a flex cable, interconnects the HDA **105** to a control system **202** which can control the movement of the actuator **116** in a manner well known in the art. In addition, the control system **202** sends to and receives signals from the head **114** during read and write operations performed on the disk **102**. As also shown in FIG. **1** the control system **202** is interconnected to the interface control system **203** which is in turn interconnected to a host computer **138** by a bus **140** for transferring of data between the hard disk drive **100** and the host **138**.

While the disk drive **100** is in operation, the disk **102** rotates in an exemplary direction **113** about the axis of the spindle **104** at a substantially fixed angular speed such that the surface **103** of the disk **102** moves relative to the head **114**. The head's radial position on the disk **102** is changeable by the rotation of the actuator **116** for positioning of the head **114** over a desired servo track **106**. The head's radial and circumferential position on the disk **102** is determined by reading the information contained in the servo wedges **110** in a manner well known in the art. Once the head **114** is positioned on the desired servo track **106** within desirable limits, data can be written to or read from portions of servo tracks **6** located between the servo wedges **110**.

FIG. **1** further illustrates a coil **118** located at the end of the actuator **116** opposite from the head **114**. As is well known in the art, when a current is passed through the coil **118**, the coil forms an electromagnet that interacts with an existing magnetic field from a source such as a permanent magnet. The coil **118** and the permanent magnet are configured such that passing of the current in the coil **118** in one direction causes the actuator **116** to rotate in a first direction. When the current is passed through the coil **118** in the opposite direction, the actuator **116** rotates in a second direction that is substantially opposite from the first direction. In this manner, the bead **114** can be moved from one servo track to another servo track in what is referred to as a seek operation. The motion of the head **114** is induced by the current flowing through the VCM **122**, wherein the VCM **122** generates a torque that is generally proportional to the magnitude of the current.

FIG. 2A illustrates a diagram of an exemplary servo system **200** in a disk drive **100** in which the method of the present invention for improving the performance of a rotary actuator **116** in a disk drive **100** during a seek operation may be practiced. As shown in FIG. **2**A, the rotary actuator **116** (shown in FIG. **1**) comprises a voice coil motor (VCM) **122** characterized by a torque output parameter **210**. The disk drive **100** further comprises a servo control system **202** having a motor driver circuit **208** for receiving a series of command effort signals **204**. Suitably, the motor driver circuit **208** comprises a digital to analog converter (DAC) **211** and a power driver (PD) **213**, such as a power driver circuit. The motor driver circuit **208** provides an operating current **209** to the VCM **122** based on the command effort signals **204** for causing an actuator movement **240**, which in turn causes a change in head location **242** from a first radial location to a target radial location on the surface **103** of a disk **102**. Suitably, the head location **242** is concurrently monitored by a servo channel demodulator **244** which outputs an analog signal **270** corresponding to the head location **242** that is typically converted to a digital signal **274** by an analog to digital converter (ADC) **272**. The digital signal **274** corresponds to an indicated track position and off-track percentage value. The digital signal **274** is then combined with a signal corresponding to a seek profile **330** to generate a position error signal **284** that is then generated and fed into the compensator **286** which determines the command effort signals **204**. During the seek operations, the compensator **286** functions as a velocity control compensator. The series of command effort signals **204** are then transmitted based on the seek profile **330** as described below and in greater detail in conjunction with FIG. **3**A.

FIG. **3**A illustrates a seek profile **330** representing the time dependence of the current **209** applied to the VCM **122** during a typical seek operation. As shown, a typical seek operation comprises application of a current **209** that accelerates the head **114** during an acceleration phase **332**, followed by application of a reverse current **209** that decelerates the head **114** during a deceleration phase **334**. As shown in FIG. **3**A, the current **209** is applied based on the transmitted command effort signals **204**, symbolically represented by the circles **204***a*–**204***k* in FIG. **3**A. Suitably, the servo control system **202** is configured to suppress disk drive related resonance interferences in the transmitted command effort signals **204**, such as by use of a notch-filter. It should be noted that the number and frequency of the circles **204***a*–**204***k* as shown in FIG. **3**A are meant to be exemplary only and the present invention is not limited to the forgoing number of transmitted command effort signals **204**.

The magnitude of the current **209** as shown in FIG. **3**A depends on factors such as supply voltages, environmental factors (such as temperature), driver variations (such as on-resistance), and actuator variations (such as coil resistance). Thus in certain operating conditions, the available VCM current **209** cannot meet the demanded current by the command effort signal **204**. One such condition arises when the command effort signal **204** demands a current that exceeds a saturation level for a given operating condition affected by factors such as those described above. The amount of current which is delivered to the VCM **122** under such condition is called the saturation current. Suitably, the peak acceleration current applied to the VCM **122** corresponds to a saturation current.

FIG. **4** is a flow chart illustrating a process used in an embodiment of the invention. As shown, the process begins in block **410** where the series of transmitted command effort signals **204** are recorded by the acceleration processor **220**, as described below and in greater detail in conjunction with FIG. **5**. Next, in block **412**, each recorded command effort signal is adjusted to account for at least one disk drive influence on the actuator movement, as described below and in greater detail in conjunction with FIGS. **6**A–B. Next, in block **414**, the adjusted command effort signals are stored, as described below and in greater detail in conjunction with FIG. **7**.

The flow in FIG. **4** then proceeds to block **416**, in which the velocity of the moving actuator **116** is monitored, as described below and in greater detail in conjunction with FIG. **8**. Next, in block **418**, an acceleration value corresponding to the moving actuator **116** is calculated from the stored command effort signals and the monitored velocity, as described below and in greater detail in conjunction with FIG. **9**. Next, in block **420**, the acceleration value is adjusted to account for a radial torque parameter variation as described below and in greater detail in conjunction with FIG. **12**. The flow then proceeds to decision block **416**, in which it is determined whether the actuator **116** remains in motion. If it is determined that the actuator **116** is in motion, then the flow is returned to block **410** for further recordings of the transmitted command effort signals **204**. If in decision block **416** it is determined that the actuator **116** is not in motion, then the flow proceeds to block **424** in which the overall process ends.

FIG. **5** in conjunction with FIG. **3**A, illustrates in greater detail the recording process in block **410** of FIG. **4**. As shown, the process begins in block **510** where each recorded command effort signal is compared to a threshold value, such as T1. For seek operations, the threshold value T1 corresponds to an approximate saturation current of the motor driver circuit **208**. Next, in block **512**, it is determined if the compared command effort signal **204** exceeds the threshold value. In FIG. **3**A, for example, it will be determined by comparison that the command effort signals **204** transmitted between command effort signals **204***f* and **204***k* exceed the threshold value T1. Next, the process flow then proceeds to block **514** for returning to block **410** of FIG. **4**. The overall process flow then proceed to block **412** of FIG. **4** as described above.

FIGS. **6**A–B in conjunction with FIG. **3**A, illustrate in greater detail the adjusting process for the recorded command effort signals, introduced in block **412** of FIG. **4**. In FIG. **6**A, the disk drive influence is caused by a flex bias **280** (shown in FIG. **2**A) of a cable **124** connecting the rotary actuator **116** to the servo control system **202**. Generally, the flex cable **124** is a spring which coils and uncoils with radial motion of the actuator **116**, thus exerting a static flex bias force on the actuator **116**, which varies with the radial position of the actuator **116**. As shown in FIG. **6**A, the process begins in block **610** wherein the flex bias feed forward component is filtered out by the acceleration processor **220** from the command effort signals **204**. Next, the process flow then proceeds to block **612** for returning to block **412** of FIG. **4**. The overall process flow then proceed to block **414** of FIG. **4** as described above.

In FIG. **6**B, the disk drive influence is caused by a variation in the position of a recorded servo track **106**, such due to a runout **282** (shown in FIG. **2**A) which may result in perceived movement of the rotary actuator **116**. As shown in FIG. **6**B, the process begins in block **616** wherein the component in the command effort signal **204** corresponding to the variation in the position of the recorded servo track is filtered out by the acceleration processor **220**. Next, the process flow then proceeds to block **618** for returning to block **412** of FIG. **4**. The overall process flow then proceed to block **414** of FIG. **4** as described above.

FIG. **7** in conjunction with FIG. **3**A, illustrates in greater detail the storing process in block **414** of FIG. **4**. As shown, the process begins in block **710** where the last command effort signal **204** transmitted prior to the command effort signal exceeding the threshold value is stored by the acceleration processor **220**. In FIG. **3**A, for example, command effort signal **204***e* is the last command effort signal **204** transmitted prior to the command effort signal exceeding the threshold value T1. Next, in block **712**, a subset of the command effort signals **204** transmitted following the command effort signal exceeding the threshold value is stored, wherein each command effort in the subset exceeds the threshold value. The subset of command effort signals comprises a predetermined number of command effort signals, suitably six command effort signals for seek operations. In FIG. **3**A, an exemplary subset of the command effort signals **204** transmitted following the command effort signal **204***e* (which exceeded the threshold value T1) comprises the six command effort signals **204***f*, **204***g*, **204***h*, **204***i*, **204***j* and **204**K, wherein as shown, each of the six command effort signals in the subset exceeds the threshold value T1. Next, the process flow then proceeds to block **714** for returning to block **414** of FIG. **4**. The overall process flow then proceed to block **416** of FIG. **4** as described above.

FIG. **8** in conjunction with FIG. **3**A, illustrates in greater detail the monitoring process in block **416** of FIG. **4**. As shown, the process begins in block **810** where an initial velocity of the moving actuator **116** corresponding to the first-transmitted command effort signal **204** in the subset of the command effort signals following the exceeding of the threshold value is determined by the acceleration processor **220**. In FIG. **3**A, the first-transmitted command effort signal **204** in the subset of the command effort signals following the exceeding of the threshold value T1 is that of command effort signal **204***f*. The velocity of the moving actuator **116** corresponding to command effort signal **204***f* is then determined. Next, in block **812**, a final velocity of the moving actuator **116** corresponding to the most recently transmitted command effort signal **204** in the subset of the command effort signals is also determined. In FIG. **3**A, the most recently transmitted command effort signal **204** in the subset of the command effort signals is that of command effort signal **204***k*. The velocity of the moving actuator **116** corresponding to command effort signal **204***k* is then determined. Next, the process flow then proceeds to block **814** for returning to block **416** of FIG. **4**. The overall process flow then proceed to block **418** of FIG. **4** as described above.

FIG. **9** in conjunction with FIG. **3**A, illustrates in greater detail the calculating process in block **418** of FIG. **4**. As shown, the process begins in block **910** where a velocity differential between the determined initial velocity and the final velocity is calculated by the acceleration processor **220**. In FIG. **3**A, the differential is calculated between the velocity of the moving actuator **116** corresponding to command effort signal **204***k* and the velocity of the moving actuator **116** corresponding to command effort signal **204***f*. Next, in block **912**, a summation of the stored subset of command effort signals is performed and a summation result is generated. Suitably, the summation is performed from the first transmitted command effort signal in the subset till the next to the last transmitted command effort signal. Thus, in the exemplary subset of command effort signals **204***f*, **204***g*, **204***h*, **204***i*, **204***j* and **204***k* shown in FIG. **3**A, a summation is performed on the five command effort signals **204***f*, **204***g*, **204***h*, **204***i* and **204***j*.

Next, in block **914**, a first value corresponding to a selected command effort signal in subset of the command effort signals is subtracted from a second value corresponding to the last command effort signal transmitted prior to the command effort signal exceeding the threshold value and a subtraction result is generated. Suitably, the selected command effort signal is the next to the last transmitted commanded effort signal in the subset. In FIG. **3**A, a value corresponding to command effort signal **204***j* is subtracted from a value corresponding to the previously stored command effort signal **204***e*. Next, in block **916**, a the subtraction result of block **9** is multiplied by **14** a VCM-delay value and a multiplication result is generated. Suitably, the VCM-delay value is a normalized VCM-delay value of 0.5. Next, in block **918**, the multiplication result of block **916** is added to the summation result of block **912** and an addition result is generated. Next, in block **920**, the velocity differential of block **910** is divided by the addition result of block **918** and a first division result is generated, wherein the calculated acceleration value comprises the first division result.

For ease of illustration, the process of FIG. **9** may be represented by the following exemplary Equation 1:

$$\text{Max}AA = \frac{V(K) - V(k_0)}{\sum_{i=k_o}^{k-1} U(i) + 0.5[U(k_0 - 1) - U(k - 1)]} \qquad \text{Equation 1}$$

wherein in the numerator: V(K)–V(ko) represents calculating a velocity differential between the determined initial velocity (i.e. V(ko)) and the final velocity (i.e. V(K)); wherein in the dominator: 0.5 [U(ko–1)–U(k–1)] represents subtracting the first value corresponding to a selected command effort signal in subset of the command effort signals (i.e. U(k–1)), from the last command effort signal transmitted prior to the command effort signal exceeding the threshold value (i.e. U(ko–1)), with the subtraction result multiplied by a normalized VCM-delay value of 0.5; wherein ΣU(i) represents the summation performed on the subset from the first transmitted command effort signal in the subset (i.e. U(ko)) till the next to the last transmitted commanded effort signal (i.e. U(k–1)) in the subset; and wherein MaxAA represents the calculated acceleration value. It should be noted that the sequence of mathematical operations as shown in FIG. **9** and illustrated in the provided Equation 1 is meant to be exemplary only and any rearrangement of the foregoing sequence of the mathematical operations which results in the calculation of an acceleration value is contemplated to be within the scope of the present invention.

As shown in FIG. **3**A the movement of the actuator **116** comprises an acceleration phase **332** followed by a deceleration phase **334**. Suitably, the calculating process of FIG. **9** occurs during the acceleration phase **332**. Returning to FIG. **9**, the process flow then proceeds to block **922** for returning to block **418** of FIG. **4**. The overall process flow then proceed to block **420** of FIG. **4** as described above.

FIG. **10** in conjunction with FIG. **3**A, illustrates in greater detail the adjusting calculated acceleration value process, as introduced in block **420** of FIG. **4**. As shown, the process begins in block **1000** where a value corresponding to the radial torque parameter variations of the VCM **122** is obtained by the acceleration processor **220**, suitably from a look up table **222** (shown in FIG. **2**A). The radial torque parameter variations of the VCM **122** comprises the variations in the motor torque parameter (Kt) based on the radial position of the actual on the disk surface **103**. Next, in block **1002**, the calculated acceleration value is adjusted based on the obtained value, such as by multiplying the acceleration value by the obtained value, to reflect the deviations in the motor torque parameter from a nominal motor torque parameter. The process flow then proceeds to block **1004** for returning to block **420** of FIG. **4**. The overall process flow then proceed to block **422** of FIG. **4** as described above.

FIG. **11**A in conjunction with FIG. **3**A, illustrates another process used in the embodiment of the invention shown in FIG. **4**. As shown, the process begins in block **1110** where the effects of noise-induced deviations in the adjusted acceleration value are reduced, as shown in greater detail in conjunction with FIGS. **11**B and **11**C. As shown in block **1114** of FIG. **11**B, the effects of noise-induced deviations in the adjusted acceleration value are reduced by applying a slew rate limit to the adjusted acceleration profile. The process flow then proceeds to block **1116** for returning to block **1110** of FIG. **11**A. As shown in block **1118** of FIG. **11**C the effects of noise-induced deviations in the adjusted acceleration value may also be reduced by applying a low-pass filter to the adjusted acceleration profile. The process flow then proceeds to block **1120** for returning to block **1110** of FIG. **11**A.

FIG. **12**A, in conjunction with FIG. **3**B, illustrates the application of the adjusted acceleration value to the seek profile **330**. As shown, the process begins in block **1210** where the seek profile **330** is modified to a seek profile **370** based on the adjusted acceleration value received from the acceleration processor **220** via signal **285** as shown in FIG. **2**A. Suitably, the seek profile **330** is initially determined based on an initial acceleration value determined prior to start of the recording process in block **410** of FIG. **4**, and thereafter modified to a seek profile **370** according to the adjusted calculated acceleration values during the movement of the actuator **116**. The process flow then proceeds to block **1212** for returning to block **420** of FIG. **4**.

FIG. **12**B in conjunction with FIG. **3**B, further illustrates the process used in block **1210** of FIG. **12**A. As shown, the process begins in block **1216**, where the configuration of deceleration phase **334** is adjusted to reduce a time period associated with the movement of the actuator **116** from the first radial location to the target radial location. One advantage of the foregoing feature of the present invention over the prior art is that by calibrating the current applied to VCM **122** on the fly and adaptively adjusting the seek profile **370** during each seek, maximum acceleration of the head **114** can be achieved while reducing the risk of head overshoot. In addition, since the relationship between the change in the current applied to the VCM **122** and the resulting change in torque output of the VCM **122** is reflective of the environmental temperature changes in the VCM **122**, the foregoing process of the present invention provides a cost-effective solution to monitor the temperature variations in a disk drive without the need for incorporation of physical sensors therein.

As shown in FIG. **3**B, an exemplary seek current profile **370** is generated by the foregoing processes of the present invention and compared to the traditional seek current profile **330** of FIG. **3**A for which a conservatively predetermined maximum acceleration current that is considerably less than the actual saturation level was used by the compensator **286** (shown in FIG. **2**A). The modified seek current profile **370**, however, achieves a shorter duration acceleration by maximizing the acceleration value used, so as to provide a faster seek operation than that of the traditional seek current profile **330**. As shown in FIG. **3**B, the available range of current **366** comprises a range of current magnitudes between an acceleration saturation current level **344** and deceleration saturation current level **346**. The current profile **370** reaches a maximum deceleration magnitude **376** aided by back-emf boost **372** and efficient use of available current **374**. Thus, deceleration phase **382** of the seek operation is able to advantageously complete the seek operation at time T3 that is less than T4, the time required to complete the same seek operation using the traditional current profile **380**. Returning to FIG. **12**B, the process flow then proceeds to block **1218** for returning to block **1210** of FIG. **11**A.

In another aspect of the present invention, as shown in conjunction with FIG. **2**B a second acceleration value may be calculated for use in subsequent track-follow operations for regulating the track-follow bandwidth. The second acceleration value can be used to provide the servo control system

**202** with inferred visibility as to the variations in the motor torque parameter (Kt) of VCM **122**.

FIG. **2**B illustrates a diagram of an exemplary servo system **200** in a disk drive **100** in which the method of the present invention for improving the performance of a rotary actuator **116** in a disk drive **100** during a track-follow operation may be practiced. As shown in FIG. **2**B, the rotary actuator **116** (shown in FIG. **1**) comprises a voice coil motor (VCM) **122** characterized by a torque output parameter **210**. The disk drive **100** further comprises a servo control system **202** having a motor driver circuit **208** for receiving a series of command effort signals **204**. Suitably, the motor driver circuit **208** comprises a digital to analog converter (DAC) **211** and a power driver (PD) **213**, such as a power driver circuit. The motor driver circuit **208** provides an operating current **209** to the VCM **122** based on the command effort signals **204** for causing an actuator movement **240**, which in turn causes adjustments to he head location **242** to maintain the head **114** over a desired servo track **106**. Suitably, the head location **242** is concurrently monitored by a servo channel demodulator **244** which outputs an analog signal **270** corresponding to the head location **242** that is typically converted to a digital signal **274** by an analog to digital converter (ADC) **272**. The digital signal **274** corresponds to an indicated track position and off-track percentage value. The digital signal **274** is then combined with a signal corresponding to a position reference **261** to generate a position error signal **284** that is then generated and fed into the compensator **286** which determines the command effort signals **204**. During the track-follow operations, the compensator **286** functions as a position control compensator. The series of command effort signals **204** are then transmitted based on a gain adjustment **288** as described below and in greater detail in conjunction with FIGS. **13**A–B.

As described below, the foregoing processes of the present invention shown in FIGS. **4**–**11**C may be substantially applied to calculating the second acceleration value, with the following differences:

In FIG. **5**, for track-follow operations, the threshold value now corresponds to a current that is less than a saturation current of the motor driver circuit **208**, as shown by the threshold value T2 in FIG. **3**A wherein T2 is less than T1. In FIG. **7**, the same process for seek operations is applied but now based on the threshold value T2. Thus, in block **710** the last command effort signal **204** transmitted prior to the command effort signal exceeding the threshold value T2 is stored by the acceleration processor **220**. In FIG. **3**A, for example, command effort signal **204***a* is the last command effort signal **204** transmitted prior to the command effort signal exceeding the threshold value T2. Next, in block **712**, a subset of the command effort signals **204** transmitted following the command effort signal exceeding the threshold value is stored, wherein each command effort in the subset exceeds the threshold value T2. Suitably, each command effort signal in the subset is of a value corresponding to a current that is less than the saturation current. The subset of command effort signals comprises a predetermined number of command effort signals, suitably three command effort signals for the track-follow operations. In FIG. **3**A, an exemplary subset of the command effort signals **204** transmitted following the command effort signal **204***a* (which exceeded the threshold value) comprises three command effort signals **204***b*, **204***c*, and **204***d*, wherein as shown, each of the three command effort signals in the subset exceeds the threshold value T2. Next, the process flow then proceeds to block **714** for returning to block **414** of FIG. **4**. The overall process flow then proceed to block **416** of FIG. **4** as described above.

In FIG. **8**, for the track-follow operations, the process begins in block **810** where an initial velocity of the moving actuator **116** corresponding to the first-transmitted command effort signal **204** in the subset of the command effort signals following the exceeding of the threshold value T2 is determined by the acceleration processor **220**. In FIG. **3**A, the first-transmitted command effort signal **204** in the subset of the command effort signals following the exceeding of the threshold value T2 is that of command effort signal **204***b*. The velocity of the moving actuator **116** corresponding to command effort signal **204***b* is then determined. Next, in block **812**, a final velocity of the moving actuator **116** corresponding to the most recently transmitted command effort signal **204** in the subset of the command effort signals is also determined. In FIG. **3**A, the most recently transmitted command effort signal **204** in the subset of the command effort signals is that of command effort signal **204***d*. The velocity of the moving actuator **116** corresponding to command effort signal **204***d* is then determined. Next, the process flow then proceeds to block **814** for returning to block **416** of FIG. **4**. The overall process flow then proceed to block **418** of FIG. **4** as described above.

In FIG. **9**, for the track-follow operations, the calculation of a second acceleration value is then performed as described above in conjunction with the seek operations but using the different track following values obtained based on the threshold value T2. The second acceleration value is then adjusted in the manner described in conjunction with the the track follow operations of FIGS. **10** and **11**A–C.

FIG. **13**A, in conjunction with FIG. **2**B, illustrates another process used in the embodiment of the invention shown in FIG. **4** for track-follow operations. As shown in FIG. **2**B, the servo control system **202** comprises a compensator **286** for determining command effort signals during track-follow operations and a gain adjust (GA) module **288** for receiving the command effort signals and a gain factor signal **287** from the accleration processor **220**. The process in FIG. **13**A begins in block **1310** where the gain factor is applied to the determined command effort signals based on the adjusted second acceleration value obtained for the track follow-operations by the the accleration processor **220**. The flow then proceeds to block **1312** where the process ends.

FIG. **13**B in conjunction with FIG. **2**A, further illustrates the process used in block **1310** of FIG. **13**A. The process in FIG. **13**B begins in block **1316** where the gain factor is scaled by a ratio of the calculated acceleration value and an initial acceleration value wherein the initial acceleration value is determined prior to the recording. Suitably, the gain adjust (GA) module **288** is configured to perform the process of FIGS. **13**A–B.

One advantage of the foregoing feature of the present invention over the prior art is that by adaptively regulating the track-follow bandwidth to reduce the risk of off-track head position, the movement-related performance of the head **114** during track-follow operations can be improved.

It should be noted that the various features of the foregoing embodiment were discussed separately for clarity of description only and they can be incorporated in whole or in part into a single embodiment of the invention having all or some of these features.

What is claimed is:

**1**. A method for improving the performance of a rotary actuator in a disk drive, the rotary actuator comprises a voice coil motor (VCM) characterized by a torque parameter, the disk drive comprises a servo control system having a motor driver circuit for receiving a series of command effort signals transmitted based on a first seek profile, and for providing an operating current to the VCM based on the command effort signals for causing a movement of the actuator from a first radial location to a target radial location, the method comprising:

recording the series of transmitted command effort signals, and while the actuator is moving:

adjusting each recorded command effort signal to account for at least one disk drive influence on the actuator movement;

storing the adjusted command effort signals;

monitoring the velocity of the moving actuator;

calculating an acceleration value corresponding to the moving actuator from the stored command effort signals and the monitored velocity; and

adjusting the acceleration value to account for a radial torque parameter variation.

**2**. The method as defined in claim **1**, wherein the recording further comprises:

comparing each command effort signal to a threshold value; and

determining if the compared command effort signal exceeds the threshold value.

**3**. The method as defined in claim **2**, wherein the storing further comprises:

storing the last command effort signal transmitted prior to the command effort signal exceeding the threshold value; and

storing a subset of the command effort signals transmitted following the command effort signal exceeding the threshold value wherein each command effort in the subset exceeds the threshold value.

**4**. The method as defined in claim **3**, wherein the monitoring further comprises:

determining an initial velocity of the moving actuator corresponding to the first-transmitted command effort signal in the subset of the command effort signals following the exceeding of the threshold value; and

determining a final velocity of the moving actuator corresponding to the most recently transmitted command effort signal in the subset of the command effort signals.

**5**. The method as defined in claim **4**, wherein the calculating further comprises:

calculating a velocity differential between the determined initial velocity and the final velocity;

performing a summation of the stored subset of command effort signals and generating a summation result;

subtracting a first value corresponding to a selected command effort signal in subset of the command effort signals from a second value corresponding to the last command effort signal transmitted prior to the command effort signal exceeding the threshold value, and generating a subtraction result;

multiplying the subtraction result by a VCM-delay value and generating a multiplication result;

adding the multiplication result to the summation result and generating an addition result; and

dividing the velocity differential by the addition result and generating a first division result wherein the calculated acceleration value comprises the first division result.

**6**. The method as defined in claim **5**, wherein the VCM-delay value is a normalized VCM-delay value of 0.5.

**7**. The method as defined in claim **5**, further comprising:

modifying the first seek profile based on the adjusted acceleration value.

**8**. The method as defined in claim **7**, wherein the movement of the actuator comprises an acceleration phase followed by a deceleration phase.

**9**. The method as defined in claim **8**, wherein the calculating occurs during the acceleration phase.

**10**. The method as defined in claim **9**, wherein modifying the first seek profile comprises:

adjusting the configuration of deceleration phase to reduce a time period associated with the movement of the actuator from the first radial location to the target radial location.

**11**. The method as defined in claim **10**, wherein the threshold value corresponds to an approximate saturation current of the motor driver circuit.

**12**. The method as defined in claim **11**, wherein the subset of command effort signals comprises a predetermined number of command effort signals.

**13**. The method as defined in claim **12**, wherein the predetermined number of command effort signals is six.

**14**. The method as defined in claim **5**, wherein the servo control system comprises a compensator for determining command effort signals during track-follow operations.

**15**. The method as defined in claim **14**, further comprising:

applying a gain factor to the determined command effort signals based on the adjusted acceleration value.

**16**. The method as defined in claim **15**, further comprising:

scaling the gain factor by a ratio of the calculated acceleration value and an initial acceleration value wherein the initial acceleration value is determined prior to the recording.

**17**. The method as defined in claim **16**, wherein the threshold value corresponds to a current less than a saturation current of the motor driver circuit.

**18**. The method as defined in claim **17**, wherein the subset of command effort signals comprises a predetermined number of command effort signals.

**19**. The method as defined in claim **18**, wherein the predetermined number of command effort signals is three.

**20**. The method as defined in claim **1**, wherein the adjusting the acceleration value further comprises:

obtaining a value corresponding to the radial torque parameter variation; and

adjusting the calculated acceleration value based on the obtained value.

**21**. The method as defined in claim **20**, wherein the value corresponding to the radial torque parameter variation is obtained from a look up table.

**22**. The method as defined in claim **1**, wherein the motor driver circuit comprises a digital to analog converter (DAC).

**23**. The method as defined in claim **1**, wherein the first seek profile is determined based on an initial acceleration value determined prior to the recording.

**24**. The method as defined in claim **1**, further comprising:

reducing the effects of noise-induced deviations in the adjusted acceleration value.

**25**. The method as defined in claim **24**, wherein the reducing further comprises:

applying a slew rate limit to the adjusted acceleration profile.

**26**. The method as defined in claim **25**, wherein the reducing further comprises:

applying a low-pass filter to the adjusted acceleration profile.

**27**. The method as defined in claim **1**, wherein the disk drive influence is caused by a flex bias of a cable connecting the rotary actuator to the servo system and wherein the adjusting each command effort signal further comprises filtering a flex bias feed forward component from the command effort signal.

**28**. The method as defined in claim **1**, wherein the disk drive comprises a disk having a plurality of recorded servo tracks and wherein the disk drive influence is caused by a

variation in the position of a recorded servo track and wherein the adjusting each command effort signal further comprises filtering from the command effort signal a component corresponding to the variation in the position of the recorded servo track.

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