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A METHOD OF CONTROLLING THE SPEED OF AN ARM OF A DISK DRIVE

The present invention relates to a method of controlling the speed of an arm of a disk drive and, more particularly, to a method of controlling the speed of parking the arm on a ramp.

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A data storage disk drive consists of at least one disk on which data is stored, a read/write head mounted on an arm to read or write on the disk surface, and the necessary control circuits. The disk is rotated at a constant velocity by a spindle motor and the arm is moved over the disk surface to read from or write to different locations on the disk surface by a voice coil motor (VCM).

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When there are no read or write operations for a relatively long time or upon power down of the disk drive, the VCM arm is traditionally parked towards the inner diameter of the disk. This is necessary to avoid any damage to the surface of the storage medium by physical contact with the read/write head. The storage area of the disk is generally made smooth to maximize the data density. If the arm is parked on the smooth surface, the spindle motor will experience more friction when it starts to spin the disk. To avoid this friction, the surface of the disk over which the arm rests can be made with a particular texture. This method of parking has two main disadvantages: the effective area that can be used for storage is reduced; and the read/write head will wear more quickly.

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To avoid the problems mentioned above associated with parking the arm at the inner diameter of the disk, the arm can be parked away from the disk surface. The arm can be moved over a ramp at the outer edge of the disk. It is desirable to be able to actively control the speed of the arm to deliver the arm to the ramp as fast as possible without damaging the disk drive.

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In accordance with the present invention there is provided a method of controlling the speed of an arm of a disk drive, including the steps of:

- obtaining a feedback signal representative of the speed of said arm;
- comparing said feedback signal with a predetermined command signal representing a
- 5 command speed; and
- adjusting a drive signal for a motor to drive said arm at said command speed.

The present invention also provides a system for controlling the speed of an arm of a disk drive, including:

- 10 feedback means for generating a feedback signal representative of the speed of said arm; and
- drive means for comparing the feedback signal with a predetermined command signal representing a command speed and for adjusting a drive signal for a motor to drive said arm at said command speed.

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A preferred embodiment of the present invention is described in greater detail below, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a block diagram of a preferred embodiment of a VCM system; and

Figure 2 is a flow chart of a method of adaptively controlling the speed of an arm of

20 a VCM system.

In the embodiment of the VCM system shown in Figure 1, a voice coil motor M is driven by two complimentary drivers A and B. The PWM logic 8 controls these two drivers with PWM drive signals based on the feedback information on the motor current I_m and the back

25 electromotive force (BEMF) of the motor. The BEMF is sampled by a BEMF feedback circuit 6 across the motor, when the current is zero during the down-pulses of the PWM cycle of the PWM logic 8. The current through the motor I_m is detected by a current feedback circuit 4 by a sensor resistor (R_s) 2 connected in series with the motor. The PWM logic 8 is responsive to a current feedback signal generated by the current feedback circuit 4, representative of the

30 current I_m , to adjust the drive signals for the drivers A and B so as to drive the motor at a

motor current limit I_{limit} . The PWM logic 8 adjusts the value I_{limit} , as described below, based on a BEMF signal generated by the BEMF feedback circuit 6 that represents the BEMF and the speed of the motor.

- 5 The steps executed by the system are shown in Figure 2. When commanded to park or there is a power down at step 12, the arm is driven at a preprogrammed or command speed towards the ramp, and then driven up the ramp at the command speed to complete the parking. The command speed is chosen to be small enough to avoid the situation whereby the arm hits the ramp at a relatively high speed, bounces back and damages the disk.

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The speed of the motor is determined by a drive voltage, V_{drv} , provided by the drivers A and B across the motor M. The current through the motor has an upper limit determined by the value of I_{limit} , and, together with V_{drv} , defines the maximum power delivered to the motor for a given acceleration state of the arm. The speed of the arm is determined to have one of
15 three acceleration states at any given time: accelerate, decelerate and idle; and the acceleration state number is given by "i" (e.g. $state_i = accel$; $state_{i+1} = idle$).

Initially, at step 14, the current limit value I_{limit} is set to a predefined value I_0 , the number of the state is set to zero and the initial state is set to "idle". At step 16, the number of the state
20 variable "i" is incremented and the timer is reset. After tri-stating the output of the drivers and waiting until the timer has been on for a period of time T_1 at step 18 (for the recirculation of the current to die down), the BEMF of the motor is sensed by BEMF feedback 6 at the motor terminals. The next state is determined at step 20 based on a comparison of the measured BEMF and a command voltage signal V_{cmd} . The level V_{cmd} of the command voltage is
25 representative of the desired command speed at which the motor is to be driven. If the measured BEMF is greater than V_{cmd} , the state is determined in step 24 to be "decel". If the measured BEMF is less than V_{cmd} , the state is determined in step 22 to be "accel". If the measured BEMF is equal to V_{cmd} , the state is determined in step 26 to be "idle". Then, whether or not the motor is in motion is determined by checking for zero BEMF in step 28,
30 whereby if the BEMF is zero, it is determined that there is no motion. If there is no motion,

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a time counter "count" is incremented at step 32. If there is motion, the counter is reset at step 30. The counter is compared with a preset value N at step 34, and if there is a lack of motion, this indicates that the arm has been loaded on the ramp and that it has encountered a mechanical stopper and the loading is determined to be done at step 36. Otherwise, at step 38, 5 using the last two states, the current limit value I_{limit} is updated (according to the algorithm shown in Table 1 below).

Since the torque applied to the motor is proportional to the current (if the motor is moving), different current limit values will result in different torques per PWM cycle delivered by the 10 PWM logic 8. At step 40, if the current state is "idle", the process returns to step 20, where the BEMF is monitored to update the next state. When the present state is not "idle" (i.e. either "accelerate" or "decelerate"), the output drivers are driven at step 42 in an appropriate direction until the motor current I_m reaches the current limit value I_{limit} at step 44. Then the process returns to step 16 and the BEMF is sampled and compared with V_{cmd} at step 20 after 15 tri-stating the output drivers and waiting at step 18 until the timer has been on for a period of time T_1 .

After a certain number of cycles, the arm will be driven at a constant speed corresponding to the command BEMF voltage. When the arm is climbing the ramp, it experiences additional 20 friction which reduces the speed, and in-turn a lesser BEMF is produced. The feedback loop adjusts the current limit value to provide the required torque per PWM cycle to maintain the command speed.

An advantage of the adaptive current limit value is that until the command speed is achieved, 25 the current limit is modified to provide more torque to achieve the command speed in a shorter time. Once the commanded speed is achieved, the current limit value is minimised, and hence the torque applied in each PWM cycle is smaller, resulting in a smoothly controlled speed.

30 Table 1 shows the algorithm for changing the current limit value. The current limit value I_{limit}

determines the amount of torque provided to the motor in each PWM cycle, such that a higher I_{limit} value results in a faster change in the BEMF with respect to time. Whether the arm is accelerated or decelerated is determined by the direction of the motor current (i.e. from driver A to driver B or from driver B to driver A) which produces a corresponding direction of the BEMF. When two consecutive states are "idle", implying that the arm is at the command speed, the current limit value is decremented by one step, so as to reach the minimum current limit value, which will result in smoother speed control. When two consecutive states are "decel", implying that the arm is slowing down due to friction, the current limit value is incremented by one step, to provide more torque to overcome the friction. When two consecutive states are "accel", the current limit value is incremented by one step, to slow down the arm in a shorter time. For other cases the current limit value is not changed. When two consecutive states are both "accel" or "decel" this indicates that the target BEMF, i.e. the command speed, is further from the current value of the BEMF and accordingly more torque is required per PWM cycle to achieve the target in a shorter time.

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Table 1

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Decision No.	state _{i-1}	state _i	Change in I_{limit} for state _i
1	idle	idle	Decrement by one step
2	idle	accel	No change
3	idle	decel	No change
4	accel	accel	Increment by one step
5	accel	decel	No change
6	accel	idle	No change
7	decel	decel	Increment by one step
8	decel	accel	No change
9	decel	idle	No change

It will be appreciated by a person skilled in the art that enhancements and alterations may be made to the above-described method without departing from the spirit and scope of the present invention.

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CLAIMS:

1. A method of controlling the speed of an arm of a disk drive, including the steps of:
obtaining a feedback signal representative of the speed of said arm;
5 comparing said feedback signal with a predetermined command signal representing a
command speed; and
adjusting a drive signal for a motor to drive said arm at said command speed.
2. A method as claimed in claim 1, wherein said feedback signal is compared to said
10 command signal to determine an acceleration state of said arm.
3. A method as claimed in claim 2, wherein said step of adjusting includes increasing or
decreasing said drive signal.
- 15 4. A method as claimed in claim 3, wherein said acceleration state is used with a previous
acceleration state to determine whether to increase or decrease said drive signal.
5. A method as claimed in claim 4, wherein said drive signal is set to drive said motor
at a predetermined level, and when said acceleration state and said previous acceleration state
20 indicates no acceleration, said predetermined level is decreased.
6. A method as claimed in claim 5, wherein when said acceleration state and said
previous acceleration state indicates acceleration, said predetermined level is increased.
- 25 7. A method as claimed in claim 6, wherein when said acceleration state and said
previous acceleration state indicates deceleration, said predetermined level is increased.
8. A method as claimed in claim 5, further including the step of obtaining a current
feedback signal representative of a current supplied to said motor.

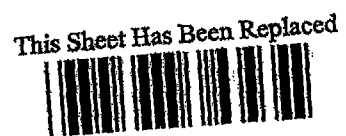
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9. A method as claimed in claim 8, further including the step of modifying said drive signal in response to said current feedback signal to drive said motor at said predetermined level.
- 5 10. A method as claimed in claim 9, wherein said feedback signal represents the back electromotive force (BEMF) of said motor.
11. A method as claimed in any preceding claim, wherein said drive signal is a pulse width modulation (PWM) signal and said BEMF is measured during low pulses of said PWM signal.
- 10 12. A method as claimed in claim 1 or 11 wherein said command speed corresponds to a speed at which said arm is commanded to move to a parking region.
13. A method as claimed in claim 1 or 12, wherein said arm includes a head of said disk
15 drive.
14. A method as claimed in claim 12, further including the step of determining said arm is parked when said BEMF is zero.
- 20 15. A method as claimed in claim 14, wherein said arm is parked in said parking region.
16. A method as claimed in claim 15, wherein said parking region includes a ramp.
17. A method as claimed in claim 16, wherein said ramp has a mechanical stopper for
25 stopping said motion of said arm.
18. A method as claimed in any one of claims 11 to 17, wherein said motor is a voice coil motor.
- 30 19. A system for controlling the speed of an arm of a disk drive, including:



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feedback means for generating a feedback signal representative of the speed of said arm; and

drive means for comparing the feedback signal with a predetermined command signal representing a command speed and for adjusting a drive signal for a motor to drive said arm
5 at said command speed.

20. A system as claimed in claim 19, wherein said feedback signal is compared to said command signal to determine an acceleration state of said arm.

10 21. A system as claimed in claim 20, wherein said adjusting includes increasing or decreasing said drive signal.

22. A system as claimed in claim 21, wherein said acceleration state is used with a previous acceleration state to determine whether to increase or decrease said drive signal.

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23. A system as claimed in claim 22, wherein said drive signal is set to drive said motor at a predetermined level, and when said acceleration state and said previous acceleration state indicates no acceleration, said predetermined level is decreased.

20 24. A system as claimed in claim 23, wherein when said acceleration state and said previous acceleration state indicates acceleration, said predetermined level is increased.

25. A system as claimed in claim 24, wherein when said acceleration state and said previous acceleration state indicates deceleration, said predetermined level is increased.

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26. A system as claimed in claim 23, including current feedback means for generating a current feedback signal representative of a current supplied to said motor.

27. A system as claimed in claim 26, wherein said drive means modifies said drive signal
30 in response to said current feedback signal to drive said motor at said predetermined level.



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28. A system as claimed in claim 27, wherein said feedback signal represents the back electromotive force (BEMF) of said motor.
29. A system as claimed in any preceding claim, wherein said drive signal is a pulse width modulation (PWM) signal and said BEMF is measured during low pulses of said PWM signal.
30. A system as claimed in claim 1 or 29 wherein said command speed corresponds to a speed at which said arm is commanded to move to a parking region.
31. A system as claimed in claim 1 or 30, wherein said arm includes a head of said disk drive.
32. A system as claimed in claim 30, wherein said drive means determines said arm is parked when said BEMF is zero.
33. A system as claimed in claim 32, wherein said arm is parked in said parking region.
34. A system as claimed in claim 33, wherein said parking region includes a ramp.
35. A system as claimed in claim 34, wherein said ramp has a mechanical stopper for stopping said motion of said arm.
36. A system as claimed in any one of claims 29 to 35, wherein said motor is a voice coil motor.

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**AMENDED CLAIMS**

[received by the International Bureau on 8 November 1999 (08.11.99);
original claims 2 and 20 cancelled; original claims 1, 4, 5, 19, 22 and 23 amended;
remaining claims unchanged (4 pages)]

1. (Amended) A method of controlling the speed of an arm of a disk drive, including the steps of:
 - 5 obtaining a feedback signal representative of the speed of said arm;
comparing said feedback signal with a predetermined command signal representing a
command speed to determine an acceleration state of said arm; and
adjusting a drive signal for a motor to drive said arm at said command speed, said
drive signal being adjusted, depending on said acceleration state, to drive said motor at a
10 predetermined level.
2. (Deleted)
3. A method as claimed in claim 2, wherein said step of adjusting includes increasing or
15 decreasing said drive signal.
4. (Amended) A method as claimed in claim 3, wherein said acceleration state is used
with a previous acceleration state to determine whether to increase or decrease said
predetermined level.
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5. (Amended) A method as claimed in claim 4, wherein when said acceleration state and
said previous acceleration state indicates no acceleration, said predetermined level is
decreased.
- 25 6. A method as claimed in claim 5, wherein when said acceleration state and said
previous acceleration state indicates acceleration, said predetermined level is increased.
7. A method as claimed in claim 6, wherein when said acceleration state and said
previous acceleration state indicates deceleration, said predetermined level is increased.

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AMENDED SHEET (ARTICLE 19)

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8. A method as claimed in claim 5, further including the step of obtaining a current feedback signal representative of a current supplied to said motor.
9. A method as claimed in claim 8, further including the step of modifying said drive
5 signal in response to said current feedback signal to drive said motor at said predetermined level.
10. A method as claimed in claim 9, wherein said feedback signal represents the back electromotive force (BEMF) of said motor.
- 10 11. A method as claimed in any preceding claim, wherein said drive signal is a pulse width modulation (PWM) signal and said BEMF is measured during low pulses of said PWM signal.
12. A method as claimed in claim 1 or 11 wherein said command speed corresponds to a
15 speed at which said arm is commanded to move to a parking region.
13. A method as claimed in claim 1 or 12, wherein said arm includes a head of said disk drive.
- 20 14. A method as claimed in claim 12, further including the step of determining said arm is parked when said BEMF is zero.
15. A method as claimed in claim 14, wherein said arm is parked in said parking region.
- 25 16. A method as claimed in claim 15, wherein said parking region includes a ramp.
17. A method as claimed in claim 16, wherein said ramp has a mechanical stopper for stopping said motion of said arm.
- 30 18. A method as claimed in any one of claims 11 to 17, wherein said motor is a voice coil motor.



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19. (Amended) A system for controlling the speed of an arm of a disk drive, including:
feedback means for generating a feedback signal representative of the speed of said
arm; and

drive means for comparing the feedback signal with a predetermined command signal
5 representing a command speed to determine an acceleration state of said arm and for adjusting
a drive signal for a motor to drive said arm at said command speed, said drive signal being
adjusted, depending on said acceleration state, to drive said motor at a predetermined level.

20. (Deleted)

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21. A system as claimed in claim 20, wherein said adjusting includes increasing or
decreasing said drive signal.

22. (Amended) A system as claimed in claim 21, wherein said acceleration state is used
15 with a previous acceleration state to determine whether to increase or decrease said
predetermined level.

23. (Amended) A system as claimed in claim 22, wherein when said acceleration state and
said previous acceleration state indicates no acceleration, said predetermined level is
20 decreased.

24. A system as claimed in claim 23, wherein when said acceleration state and said
previous acceleration state indicates acceleration, said predetermined level is increased.

25 25. A system as claimed in claim 24, wherein when said acceleration state and said
previous acceleration state indicates deceleration, said predetermined level is increased.

26. A system as claimed in claim 23, including current feedback means for generating a
current feedback signal representative of a current supplied to said motor.

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AMENDED SHEET (ARTICLE 19)

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27. A system as claimed in claim 26, wherein said drive means modifies said drive signal in response to said current feedback signal to drive said motor at said predetermined level.
28. A system as claimed in claim 27, wherein said feedback signal represents the back
5 electromotive force (BEMF) of said motor.
29. A system as claimed in any preceding claim, wherein said drive signal is a pulse width modulation (PWM) signal and said BEMF is measured during low pulses of said PWM signal.
- 10 30. A system as claimed in claim 1 or 29 wherein said command speed corresponds to a speed at which said arm is commanded to move to a parking region.
31. A system as claimed in claim 1 or 30, wherein said arm includes a head of said disk drive.
- 15 32. A system as claimed in claim 30, wherein said drive means determines said arm is parked when said BEMF is zero.
33. A system as claimed in claim 32, wherein said arm is parked in said parking region.
- 20 34. A system as claimed in claim 33, wherein said parking region includes a ramp.
35. A system as claimed in claim 34, wherein said ramp has a mechanical stopper for stopping said motion of said arm.
- 25 36. A system as claimed in any one of claims 29 to 35, wherein said motor is a voice coil motor.

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