

5 **DRIVE LEVEL ACTUATOR IMBALANCE TORQUE TEST**

Cross Reference to Related Applications

 This application claims the benefit of United States Pro-
10 visional Application Number 60/184,699, filed February 24, 2000.

Field of the Invention

 The present invention relates generally to disc drives, and
15 more particularly to determine the actuator imbalance torque as
well as to locate the position of the imbalance torque.

Background of the Invention

20 The track following servo systems in disc drives are required
to hold the read/write heads to very small off-track errors to
support the increasing track density of today's products. As errors
can be induced due to many effects including disc and bearing
runout, servo-track-writer induced irregularities, electronic noise,
25 spindle and actuator resonances, and external shock and vibration
excitations, modern disc drives must be designed and tested to
perform satisfactorily to increasingly stringent specifications of
shock and vibration. This is especially due to the needs of the
portable computing market. Thus, there exists a need to be able to
30 predict track following performance under external shock and
vibration excitation. The ability to measure the actuator imbalance
will be a good indication of the drive performance under shock and
vibration condition.

 In the existing setup to measure imbalance torque, the
35 actuator is held to be free to rotate about its cartridge centre which
is the pivot point and a load cell is located one inch from this point.
The distance from the pivot point to the load cell multiplied by the

5 force to move the actuator will give the imbalance torque. However,
there are problems in using this method. Firstly, there is a need to
remove the flex cable since it will contribute to the actuator an
additional imbalance during measurement. Secondly, the location of
the load cell may not be accurate enough to obtain a good
10 measurement. Thirdly, the measurement could only be carried out
at the component level.

Thus there remains a need for a more accurate and
sophisticated method to determine the imbalance torque. It will be
evident from the following description that the present invention
15 offers this and other advantages.

Summary of the Invention

The present invention relates to a more accurate method of
20 determining the imbalance torque of an actuator in a disc drive at
drive level and of locating the position of the imbalance torque
using voice coil motor bias current values so as to diagnose the
mechanical and servo performances of the disc drive.

According to one aspect of the invention, there is provided a
25 method to sense the change in the voice coil motor (VCM) current to
determine and to locate the position of the imbalance torque of an
actuator in a disc drive. There are several steps performing different
functions in the method. The first step of the method performs the
function of obtaining a difference in the VCM current of the disc
30 drive in the X orientation and in the Y orientation with the VCM
current of the disc drive when the disc drive is placed flat. The
second step performs the function of obtaining the square of each
difference in VCM current. The third step performs the function of
obtaining the imbalance current by adding the square of the VCM
35 current and subsequent square root of the addition. The value of
the imbalance torque is obtained by multiplying the imbalance
current with the torque constant of the voice coil magnet. The

5 fourth step performs the function of obtaining a division value of
the VCM current in the X orientation or in the Y orientation with
the VCM current of the disc drive when the disc drive is placed flat.
The fifth step performs the function of obtaining the angle between
the x-axis and the distance of the imbalance torque of the actuator
10 from the pivot centre and measuring the mass of the actuator. The
sixth step performs the function of obtaining the cosine or sine of
the angle and multiple either angle with the mass of the actuator.
The position of the imbalance torque of the actuator is located and
determined either from dividing the divided value in X orientation in
15 the fourth step with the cosine angle in the sixth step or dividing
the divided value in Y orientation in the fourth step with the sine
angle in the sixth step.

These and other features as well as advantages, which
characterize the present invention, will be apparent upon reading of
20 the following detailed description and review of the associated
drawings.

Brief Description of the Drawings

25 FIG. 1 is an exploded view of a typical disc drive.

FIG. 2 shows a simplified top view of a disc drive in an X
orientation, according to the present invention.

FIG. 3 shows a simplified top view of a disc drive in an Y
orientation, according to the present invention.

30 FIG. 4 shows a simplified top view of a disc drive placed flat
in a third orientation, according to the present invention.

FIG. 5 shows a simplified top view of an actuator for locating
the position of the imbalance torque of the actuator in the present
invention.

35 FIG. 6 shows a simplified top view of an actuator showing
four possible zones where the imbalance torque of the actuator may
be located.

5 FIG. 7 shows a flowchart of a disc drive configured in track following mode.

Detailed Description

10 FIG. 1 shows an exploded view of a typical disc drive 10. The disc drive 10, which has a housing base 11, also includes a plurality of discs 12 mounted to rotate on a spindle motor 13. An actuator 14, which mounts with a plurality of transducer heads 15, rotates under the control of a voice coil motor (VCM). The VCM
15 includes a voice coil 16 and magnets 17. When a VCM current is fed to the voice coil, electromagnetic forces are generated so that the actuator is rotated and the transducer heads 15 are moved to a desired track 18 along a path 19 on the discs 12. Position signals and data signals from the transducer heads 15 pass via a flex
20 circuit 20 and a connector 21 to and from electronic circuitry on a controller board (not visible). The controller board includes an interface, a serial port connector and a hub connector (the three parts are not visible from the figure).

 When the disc drive is in a track following mode, an amount
25 of current (F_{ivcm}) is required to allow the disc drive to remain on the track when the drive is placed flat. When the disc drive is in the X or Y orientation, the imbalance torque of the actuator will cause the actuator to draw current to stay on the correct track. The amount of current needed is dependent upon which part of the actuator is
30 heavier while on the track.

 A preferred embodiment of the present invention is now described as follows with reference to FIGs. 2 to 7. The disc drive 10, configured in the track following mode, is placed in a first orientation 46, designated as the X orientation as shown in FIG. 2.
35 This causes the actuator 14 to draw a first VCM current, X_{ivcm} , to keep the transducer heads in the same track. The first VCM current is obtained 48. The disc drive 10 is also placed in a second

5 orientation 50, designated as the Y orientation as shown in FIG. 3. The actuator 14 draws a second VCM current, Y_{ivcm} , and this value is obtained 52. The disc drive 10 is placed in a third orientation 54 and VCM current, F_{ivcm} , is obtained 56. The third orientation, as shown in FIG. 4, is one in which the disc drive is laid horizontally.

10 Due to the changes in VCM current, the following equations are applied to calculate the imbalance torque 58:

$$(1) \quad \text{Imbalance, } Imb = \sqrt{(Y_{ivcm} - F_{ivcm})^2 + (X_{ivcm} - F_{ivcm})^2} ;$$

15 (2) Imbalance torque, $T_{imb} = Imb \times K_t$;
where K_t is the torque constant of the voice coil magnet.

With the values of Y_{ivcm} and X_{ivcm} , the location of the imbalance torque of the actuator 14 can be located. As illustrated in FIG. 5, the imbalance torque, T_{imb} , determined above is assumed to be one cm from the pivot centre 22. To locate the actual position of the imbalance torque of the actuator 60, an angle 23, θ , between the x-axis and the distance 24, r , of the imbalance torque from the pivot centre is required, as illustrated in FIG. 5. The equation to
25 calculate θ is:

$$(3) \quad \theta = \tan^{-1} \frac{Y_{ivcm}}{X_{ivcm}} ;$$

30 where Y_{ivcm} 25 and X_{ivcm} 26 are obtained from the above method.

Since θ can be calculated from the above equation and mass, m , of the actuator can be measured, the distance of the imbalance torque from the pivot centre 24, r , can thus be located from the following equations:

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$$(4) \quad Y_{ivcm} = mg \times r \times \sin\theta$$

5 (5) $X_{ivcm} = mg \times r \times \cos\theta$

This method is implemented into a software program and tested on a disc drive as illustrated in Figure 7. The method may be preceded by steps of loading a program code to the disc drive 40.

10 The program code embodies instructions for executing a method of the present invention. The disc drive is connected to a computer system using serial communication 42. A command is sent to the disc drive, from the computer system, to seek a particular track 44.

From the values of Y_{ivcm} and X_{ivcm} obtained, the position of
15 imbalance torque of the actuator can be deduced based on the algorithm below and as shown in FIG. 6:

(a) If $Y_{ivcm} > F_{ivcm}$ AND $X_{ivcm} < F_{ivcm}$,
the location of the imbalance torque is at portion A 27.

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(b) If $Y_{ivcm} < F_{ivcm}$ AND $X_{ivcm} > F_{ivcm}$,
the location of the imbalance torque is at portion B 28.

(c) If $Y_{ivcm} > F_{ivcm}$ AND $X_{ivcm} > F_{ivcm}$,
25 the location of the imbalance torque is at portion C 29.

(d) If $Y_{ivcm} < F_{ivcm}$ AND $X_{ivcm} < F_{ivcm}$,
the location of the imbalance torque is at portion D 30.

30 The portions are defined with respect to a pair of X and Y-axes intersecting at the pivot point of the actuator. The portion A refers to the fourth quadrant, the portion B refers to the second quadrant, the portion C refers to the first quadrant and the portion D refers to the third quadrant in this frame of reference.

35 In another embodiment of the method to determine the imbalance torque, the disc drive is placed in a position with the use of an external fixture such that the actuator is in a first plane and

- 5 the VCM current, X_{ivcm} , is obtained. The disc drive is placed flat and the VCM current, F_{ivcm} , is obtained. The imbalance torque is calculated as follows:

$$\text{Imbalance torque, } T_{imb} = (X_{ivcm} - F_{ivcm}) \times K_t$$

- 10 where K_t is the torque constant

Another way of describing the present invention is as follows:

- A program storage device readable by a computer system tangibly embodying a program of instructions executable by the
15 computer system to perform a method for determining an imbalance torque of an actuator 14 in a disc drive 10, the actuator 14 being configured to be rotated about a pivot point 22 by a voice coil motor (VCM) 16,17, the VCM being operable by a VCM current, the imbalance torque being characterized by a center of imbalance
20 23,24, and a magnitude of imbalance, the method including steps of: obtaining a first VCM current (X_{ivcm}) when the disc drive is placed in a first plane characterized by a normal parallel to an X-axis; obtaining a third VCM current (F_{ivcm}) when the disc drive is placed in a horizontal plane characterized by a vertical normal. The
25 X-axis and the vertical axis are orthogonal to one another. The method includes a step of obtaining a first difference between the first VCM current and the third VCM current; and obtaining the magnitude of the imbalance torque from the first difference.

- According to one embodiment of the invention, the first
30 difference is multiplied by a torque constant to obtain the magnitude of imbalance.

- According to another embodiment of the invention, the method further involves obtaining a second VCM current (Y_{ivcm}) when the disc drive is placed in a second plane characterized by a
35 normal parallel to a Y-axis. The X-axis, the Y-axis and the vertical axis are orthogonal to one another. The method further includes obtaining a second difference between the second VCM current and

5 the third VCM current; adding together the square of the first
difference and the square of the second difference to give a first
intermediate value; and obtaining the square root of the first
intermediate value to give an imbalance value. The imbalance value
is multiplied by a torque constant to obtain the magnitude of
10 imbalance.

Preferably, the method further involves steps of: dividing the
second VCM current value by the first VCM current value to obtain
a second intermediate value; and applying a predetermined function
to the second intermediate value to obtain an angle, such that the
15 angle is representative of an angular displacement of the center of
imbalance from the X-axis. The method can further involve steps of
applying a cosine function to the angle obtained to give a third
intermediate value; multiplying the mass of the actuator with the
third intermediate value to obtain a fourth intermediate value; and
20 dividing the first VCM current with the third intermediate value to
determine a displacement of the imbalance torque center from the
pivot point. Alternatively, the method can further involve steps of
applying a sine function to the angle obtained to give a third
intermediate value; multiplying the mass of the actuator with the
25 third intermediate value to obtain a fourth intermediate value; and
dividing the second VCM current with the third intermediate value
to determine a displacement of the imbalance torque center from
the pivot point.

According to one aspect of the invention, the method provides
30 for estimating the position of the center of imbalance. The center of
imbalance is estimated to be in a first quadrant if Y_{ivcm} is greater
than F_{ivcm} and if X_{ivcm} is greater than F_{ivcm} . It is estimated to be in a
second quadrant if Y_{ivcm} is less than F_{ivcm} and if X_{ivcm} is greater than
 F_{ivcm} . If Y_{ivcm} is lesser than F_{ivcm} and X_{ivcm} is less than F_{ivcm} , the
35 center of imbalance is estimated to be in the third quadrant. If Y_{ivcm}
is greater than F_{ivcm} and if X_{ivcm} is less than F_{ivcm} , the center of
imbalance is estimated to be in the fourth quadrant. For reference,

- 5 the disc drive is placed in the horizontal plane with the pivot point coinciding with the intersection of the X-axis and the Y-axis. The first quadrant, the second quadrant, the third quadrant and the fourth quadrants are defined with reference to the X-axis and the Y-axis.
- 10 It is to be understood that even though numerous characteristics and advantages of various embodiments of the present invention have been set forth in the foregoing description, together with details of the structure and function of various embodiments of the invention, this disclosure is illustratively only,
- 15 and changes may be made in detail, especially in the matters of structure and arrangement of parts within the principles of the present invention to the full extent indicated by the broad general meaning of the terms in which the appended claims are expressed. For example, the particular elements may vary depending on the
- 20 particular application for the disc drive while maintaining substantially the same functionality without departing from the scope and spirit of the present invention. In addition, although the preferred embodiment described herein is directed to a disc drive, it will be appreciated by those skilled in the art that the teachings of
- 25 the present invention can be applied to other systems, without departing from the scope and spirit of the present invention.



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Claims

1. A method for determining an imbalance torque of an actuator in a disc drive, the actuator being configured to be rotated about a pivot point by a voice coil motor (VCM), the VCM being operable by a VCM current, the imbalance torque being characterized by a center of imbalance and a magnitude of imbalance, the method comprising steps of:
 - (a) obtaining a first VCM current (X_{ivcm}) when the disc drive is placed in a first plane, wherein the first plane is characterized by a normal parallel to an X-axis;
 - (b) obtaining a third VCM current (F_{ivcm}) when the disc drive is placed in a horizontal plane characterized by a vertical normal; wherein the X-axis and the vertical axis are orthogonal to one another;
 - (c) obtaining a first difference between the first VCM current and the third VCM current; and
 - (d) obtaining the magnitude of the imbalance torque from the first difference.
2. The method of claim 1 wherein the step (d) includes a step of multiplying the first difference with a torque constant to obtain the magnitude of imbalance.
3. The method of claim 1 further comprising:
 - (e) obtaining a second VCM current (Y_{ivcm}) when the disc drive is placed in a second plane, wherein the second plane is characterized by a normal parallel to a Y-axis, and wherein the X-axis, the Y-axis and the vertical axis are orthogonal to one another;
 - (f) obtaining a second difference between the second VCM current and the third VCM current;



- 5 (g) adding together the square of the first difference and the square of the second difference to give a first intermediate value;
- (h) obtaining the square root of the first intermediate value to give an imbalance value; and wherein the step (d) includes
- 10 a step (i) of multiplying the imbalance value with a torque constant to obtain the magnitude of imbalance.
4. The method of claim 3 further comprising steps of:
- (j) dividing the second VCM current value by the first VCM
- 15 current value to obtain a second intermediate value; and
- (k) applying a predetermined function to the second intermediate value to obtain an angle, such that the angle is representative of an angular displacement of the center of imbalance from the X-axis.
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5. The method of claim 4 further comprising steps of:
- (l) applying a cosine function to the angle obtained in step (k) to give a third intermediate value;
- (m) multiplying the mass of the actuator with the third
- 25 intermediate value to obtain a fourth intermediate value; and
- (n) dividing the first VCM current with the third intermediate value to determine a displacement of the imbalance torque center from the pivot point.
- 30 6. The method of claim 4 further comprising steps of:
- (l) applying a sine function to the angle obtained in step (k) to give a third intermediate value;
- (m) multiplying the mass of the actuator with the third intermediate value to obtain a fourth intermediate value; and
- 35 (n) dividing the second VCM current with the third intermediate value to determine a displacement of the imbalance torque center from the pivot point.



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7. A program storage device readable by a computer system tangibly embodying a program of instructions executable by the computer system to perform a method for determining an imbalance torque of an actuator in a disc drive, the actuator being configured to be rotated about a pivot point by a voice coil motor (VCM), the VCM being operable by a VCM current, the imbalance torque being characterized by a center of imbalance and a magnitude of imbalance, the method comprising steps of:
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- 15 (a) obtaining a first VCM current (X_{ivcm}) when the disc drive is placed in a first plane, wherein the first plane is characterized by a normal parallel to an X-axis;
- (b) obtaining a third VCM current (F_{ivcm}) when the disc drive is placed in a horizontal plane characterized by a vertical normal; wherein the X-axis and the vertical axis are orthogonal to one another;
- 20 (c) obtaining a first difference between the first VCM current and the third VCM current; and
- (d) obtaining the magnitude of the imbalance torque from the first difference.
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8. The method of claim 7 wherein the step (d) includes a step of multiplying the first difference with a torque constant to obtain the magnitude of imbalance.
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9. The method of claim 7 further comprising:
- (e) obtaining a second VCM current (Y_{ivcm}) when the disc drive is placed in a second plane, wherein the second plane is characterized by a normal parallel to a Y-axis, and wherein the X-axis, the Y-axis and the vertical axis are orthogonal to one another;
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- 5 (f) obtaining a second difference between the second VCM current and the third VCM current;
- (g) adding together the square of the first difference and the square of the second difference to give a first intermediate value;
- 10 (h) obtaining the square root of the first intermediate value to give an imbalance value; and wherein the step (d) includes a step (i) of multiplying the imbalance value with a torque constant to obtain the magnitude of imbalance.
- 15 10. The method of claim 9 further comprising steps of:
- (j) dividing the second VCM current value by the first VCM current value to obtain a second intermediate value; and
- (k) applying a predetermined function to the second intermediate value to obtain an angle, such that the angle is
- 20 representative of an angular displacement of the center of imbalance from the X-axis.
11. The method of claim 10 further comprising steps of:
- (l) applying a cosine function to the angle obtained in step (k)
- 25 to give a third intermediate value;
- (m) multiplying the mass of the actuator with the third intermediate value to obtain a fourth intermediate value; and
- (n) dividing the first VCM current with the third intermediate value to determine a displacement of the imbalance torque
- 30 center from the pivot point.
12. The method of claim 10 further comprising steps of:
- (l) applying a sine function to the angle obtained in step (k) to give a third intermediate value;
- 35 (m) multiplying the mass of the actuator with the third intermediate value to obtain a fourth intermediate value; and



- 5 (n) dividing the second VCM current with the third intermediate value to determine a displacement of the imbalance torque center from the pivot point.
13. The method of claim 9 further comprising steps of:
- 10 (o) estimating the position of the center of imbalance to be in a first quadrant if Y_{ivcm} is greater than F_{ivcm} and if X_{ivcm} is greater than F_{ivcm} ;
- (p) estimating the position of the center of imbalance to be in a second quadrant if Y_{ivcm} is less than F_{ivcm} and if X_{ivcm} is greater than F_{ivcm} ;
- 15 (q) estimating the position of the center of imbalance to be in a third quadrant if Y_{ivcm} is lesser than F_{ivcm} and X_{ivcm} is less than F_{ivcm} ; and
- (r) estimating the position of the center of imbalance to be in a fourth quadrant if Y_{ivcm} is greater than F_{ivcm} and if X_{ivcm} is less than F_{ivcm} , wherein the disc drive is placed in the horizontal plane with the pivot point coinciding with the intersection of the X-axis and the Y-axis, and wherein the first quadrant, the second quadrant, the third quadrant and the fourth quadrants are defined with reference to the X-axis and the Y-axis.
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14. A disc drive comprising:
- a disc formatted to store data;
- 30 a transducer head configured for reading data from and writing data to the disc;
- an actuator supporting the transducer head in proximity to the disc; and
- means for determining an imbalance torque of the actuator.