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METHOD AND APPARATUS FOR RECONFIGURING A MOTOR IN A DISK DRIVE

FIELD OF THE INVENTION

The present invention relates generally to the field of disk drive circuits and more particularly to a method and circuit for driving a hard disk drive spindle motor.

BACKGROUND OF THE INVENTION

As a consequence of recent technical developments, personal computers (PCs) such as desktop and notebook PCs are manufactured and available in the marketplace. A computer includes a central processing unit (CPU) and a memory. The CPU accesses the main memory to execute user requested tasks. Generally, application programs (APs), an operating system, and other programs are loaded into main memory for execution. The main memory also stores working data for the CPU. Since volatile semiconductor memory devices, such as random access memory, are relatively expensive, main memory capacity is substantially limited to a few megabytes (MB) to several tens of megabytes. Therefore, a nonvolatile external memory device with a large storage capacity, such as a disk drive, provides auxiliary memory for the computer system. Disk drives are also called hard disk drives (HDDs), direct access storage devices, or disks. The hard disk drive is one of the most popular external memory devices. Recently, HDD recording density and speed have substantially increased while the cost of HDDs, even HDDs with one gigabyte (GB) capacity, has substantially declined.

It is known to employ electronically commutated DC brushless permanent magnet motors as direct-drive spindle motors within the disk drives. These motors typically include a fixed cylindrical stator structure with laminated iron stator pole pieces

separated by slots facing a rotating cylindrical permanent magnet ring forming an inside structural portion of a disk spindle hub. Each pole piece has a coil of wire wrapped around it which receives switched driving currents from a motor driver circuit. The permanent magnet ring defines alternating north and south permanent magnet poles facing the stator pole pieces.

A hard disk drives generally includes a stack of rotating disks or platters, a spindle motor which causes the disks to rotate, read/write heads which fly above the surface of the disks, an actuator motor (known as a "voice coil motor" or VCM) which controls the positioning of the read/write heads, power circuitry to provide electrical power to the spindle and voice coil motors, control circuitry to control the operation of the spindle and voice coil motors. A read/write head reads data from the disk by sensing flux changes on the magnetic surface of the disk as it passes beneath the read/write head. To synchronize the data being read from the disk with the operation of the data processing circuitry, it is necessary to carefully control the speed of the rotation of the disks. This is accomplished by controlling the current delivered to the spindle motor.

Current control is generally effected in one of two ways. The first is pulse width modulation, in which the driving current is modulated by a square wave. Current is delivered to the spindle motor only when the square wave is high. The duty cycle of the pulse width modulation signal therefore determines the average current delivered to the spindle motor. The other mode of current control is known as linear current control. In this mode, an analog voltage input signal is provided which is proportional to the current to be delivered to the spindle motor. The spindle motor control circuitry processes this input signal and adjusts the level of the current delivered by the power circuitry accordingly.

Fig. 3 illustrates the connections of HDD motor wirings connected in a "Y" configuration. This "Y" configuration is accomplished by shorting CT_a, CT_b and CT_c.

together to form a center tap. The motor is subsequently driven by applying voltages to the A, B, C nodes by driver circuits. Typically, the speed of the motor is controlled by controlling the voltage applied across each of the windings. However, to provide faster speeds of the motor, the center tap CT is removed and a driver is connected to each terminal. For example, a driver is connected to terminal C and CT_c . It is necessary to bring six wires out of the motor, three wires from terminals A, B, C and three wires from terminals CT_a , CT_b , and CT_c . Necessarily, these six wires must be attached to six drivers. This adds to the cost and control considerations for each of these drivers. It is required to reduce the number of drivers and reduce the number of wires coming out of the motor.

SUMMARY OF THE INVENTION

The present invention includes an apparatus and method for configuring a HDD motor. More particularly, the present invention employs a delta connection of the motor windings. This delta connection of the motor eliminates the need for six wires attached to the motor and six drivers for the motor. More specifically, only three wires are required for connection to the motor of the present invention, and only three drivers are used to drive the motor.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates a system drawing of the present invention;

Fig. 2 illustrates a schematic of a motor;

Fig. 3 illustrates a Y connection;

Fig. 4 illustrates a delta connection of the windings in accordance with the present invention;

Figs. 5 and 6 illustrate winding currents in a delta-connected motor;

Figs. 7 and 8 illustrate waveforms with a delta connection;

Fig. 9 illustrates a waveform of a Y-connected motor;

Fig. 10 illustrates a waveform of a delta-connected motor;

Figs. 11-15 illustrate waveforms of a delta-connected motor;

Figs. 16-20 illustrate waveforms of a Y-connected motor;

Figs. 21-25 illustrate waveforms of a delta-connected motor;

Figs. 26-30 illustrate waveforms of a Y-wound connected motor;

Figs. 31-35 illustrate waveforms of a Y-wound connected motor; and

Figs. 36-40 illustrate waveforms of a delta-connected motor.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

Fig. 1 illustrates the disk drive architecture 10 of the present invention. The disk drive architecture 10 includes a DC brushless spindle motor 14 which is driven by spindle motor and voice coil actuator driver (ASIC) 12 and which rotates at least one data storage unit disk 16 at a predetermined angular velocity relative to base 21. A head slider 18 supporting a data transducer in close proximity to the data storage surface of disk 16 is rotationally supported by a head arm 20 including a load beam and gimbal (not shown). The head arm 20 is rotated relative to the base 21 and the disk 16 by, for example, a rotary voice coil actuator motor 22. The spindle motor 14 and the voice coil actuator motor 22 are both controlled by the spindle motor and voice coil actuator driver circuit 12 over power/control paths 24 and 26, respectively. The disk drive architecture 10 also typically includes a read preamplifier/write driver 28, a read/write channel (ASIC) 30, a disk drive controller (ASIC) 32, and a DRAM buffer chip 34 for the temporary storage of user data blocks and for the storage of instructions for an embedded disk drive supervisory microcontroller 38. The disk drive controller (ASIC) 32 includes a host interface circuit presenting a suitable interface for connection of the drive 10 to a host computing environment via the interface bus 36, a data sequencer/manager circuit for handling data transfers to and from the disk 16 via the read/write channel 30 and the read preamplifier/write driver 28, a memory controller for controlling addressing and refresh operations at the buffer memory 34, and an interface to the drive microprocessor 38. User data paths are shown in bold lines ending in arrows and these paths enable blocks of user data to be transferred between the host and the disk storage surface in a controlled way. Control lines, such as a microprocessor control bus 40 and a DRAM memory address, refresh and control bus 42, are shown by regular lines and they pass control and status values throughout the disk drive architecture.

As illustrated in Fig. 2, a spindle motor includes a shaft 2 which is supported by a bearing at the center of a housing 1 mounted on a set base, a hub 4 which is

provided with a magnet 5 and installed on a shaft 2 so as to support a disk, a stator coil 6 disposed between the housing 1 and the hub 4, a connector 7 installed at the housing 1 and a sealing member 803 disposed at the upper end of the bearing 3.

The hub 4 disposed on the housing 1 rotates about the shaft 2 by the interaction between the stator core 6 and the magnet 5, so that the disk mounted on the hub 4 may reproduce information therefrom or record information thereon while rotating together with the hub 4.

Turning now to Fig. 4, Fig. 4 illustrates a motor connected in a delta with each terminal of the delta connection being connected to a driver circuit. As illustrated in Fig. 4, driver circuit 400 is connected to terminal 408, and driver circuit 402 is connected to terminal 410. Driver circuit 404 is connected to terminal 406. The motor 14 is connected to a spindle to rotate disks 16 of a HDD architecture 10. Coil 416 is connected between terminal 408 and terminal 410. Coil 418 is connected between terminal 406 and terminal 410. Lastly, coil 414 is connected between terminal 406 and terminal 408. Additionally, motor 412 includes terminals 420, 422, 424, 426, 428 and 430. These terminals can be used to isolate and de-energize coils (416, 418 and 414) of motor 412. For example, terminal 420 and terminal 422 can be opened to isolate coil 414. In a similar way, terminals 424 and 426 can be opened to isolate coil 418, and terminals 430 and 428 can be opened to isolate coil 416. Driver circuit 400 is used to apply a voltage on either coil 416 or coil 418 to raise the voltage across either coil 416 or coil 418 so as to drive the motor in a particular direction at a particular speed.

Each coil is energized with a sinusoidal voltage, for example, a PWM sinusoid signal. Two terminals of the delta are modulated with the third terminal being grounded by the driver. Windings are sets of coils.

A 12v 5400 RMP 8-pole 2-platter motor was rewired to make the three center-tap wires available. The motor could then be connected in either Y or delta configuration.

Performance of the two configurations was compared. By using the delta connection, the motor was able to operate at 9950 RPM with 12v supply and 7200 RPM with 9.4v supply instead of 5400 RPM with a Y connection. Additional evidence of improved speed capability is the fact that VMAG reduces to 60% of its previous value when the motor is converted to delta connection.

Two experiments were run.

First Experiment

Step 1. Operate the motor at 5400 RPM in Y configuration and verify proper operation with 12v supply.

Step 2. Increase the speed of the motor until some clipping of the drive current occurs. This was determined to be 6000 RPM. See Fig. 9.

Step 3. Change the configuration to delta and increase speed to 7200 RPM. No clipping occurs. See Fig. 10.

Step 4. Raise the speed further and attempt to match the distortion in Step 2. Since the distorted waveforms don't have the same shape, it is difficult to determine when the distortions are similar. Fig. 7 shows distortion at 9950 RPM. This is a 65% speed increase.

Second Experiment

Operate the delta motor at 7200 RPM and lower the 12v supply to determine margin. The 12v fault check was disabled. At 9.4v, there is no clipping. See Fig. 8.

Winding Current Waveforms

Figs. 5 and 6 show the winding currents for the delta-connected motor at 7200 RPM and 10.8v power supply. The currents shown in previous photos were the driver currents. The 6-state winding current shows a 4-level waveform similar to what was predicted by the simulation. Note that the driver current (not shown) was identical to a standard three-level 6-state waveform.

The simulations in the form of waveforms illustrated in Figs. 5-8 and 10 were obtained by using the delta connection in Fig. 4 and by using the same motor windings, same motor torque constants, same external components, and same driver circuit (Avalanche/Banyan) as the Y connection in Fig. 9. They compare performance with Y-connected and delta-connected motor windings in both 6-state and sine wave. In each simulation, the motor is running at 480Hz which corresponds to 8-pole, 7200 RPM. At time=0, the motor is at full speed and the VCO is off-frequency. In all cases, the PLL and VMAG loops in read channel 30 acquire their final values and are settled by 30ms.

Nomenclature

<i>nbemfa</i>	normalized bemf of "a" winding.
<i>ia</i>	current in "a" winding.
<i>va</i>	voltage at "a" driver. This is not the voltage across the "a" winding.
<i>ipha</i>	current at "a" driver. This is not displayed in these results.
<i>vmag</i>	controls the PWM duty cycle. 1.0v—0%, 3.0v—100%.
<i>isupplylp</i>	low pass filtered supply current. Should be equal to <i>icmd</i> .
<i>isupply</i>	instantaneous supply current.
<i>atorque_z</i>	torque contributed by the "a" winding. The <i>_z</i> signifies that the torque has been averaged over the previous PWM cycle in order to remove PWM noise.
<i>torque_z</i>	total torque, averaged over the previous PWM cycle.

Wave simulations

The primary difference between the two results is the lower *vmag* voltage in the delta connection. *Vmag* is lower because the *bemf* voltages in delta-connected windings are not in series. The lower *vmag* causes a lower duty cycle which means *isupply* has wider "holes" which means both *vmag* and *ia* have more PWM related ripple. If a motor is connected in the delta configuration, it should either be run faster or be redesigned for higher torque constant to provide optimal results.

6-State simulations

The winding current, *ia*, shows three levels when Y-connected and four levels when delta-connected. In spite of this difference, the overall torque shape, *torque_z*, is similar. The torque contributed by winding a, *atorque_z*, is substantially different in the two cases, but shows significant jerk and therefore should portend noisy drivers. As in the sinusoid cases, *vmag* is lower for the delta configuration, causing higher PWM ripple.

Thus, in the present invention each leg of the motor 412 is driven sequentially by driver circuit 400, driver circuit 402 and lastly, driver circuit 404.



CLAIMS

1. A motor apparatus for rotating a disk, comprising:
a motor having at least three windings, said three windings being connected in a delta, to rotate said disk; and
a driver circuit to energize said at least three windings.
2. A motor apparatus for rotating a disk, as in Claim 1, wherein said driver circuit is operable to energize said at least three windings by a Pulse Width Modulated (PWM) signal.
3. A motor apparatus for rotating a disk, as in Claim 2, wherein said PWM signal includes a demodulated voltage difference signal between each terminal.
4. A motor apparatus for rotating a disk, as in Claim 3, wherein said demodulated voltage difference signal is a sinusoidal signal.
5. A system for rotating a disk, comprising:
a motor having at least three windings, said three windings being connected in a delta, to rotate said disk;
a driver circuit to energize said at least three windings; and
a read channel circuit to receive data recorded on said disk.
6. A system for rotating a disk, as in Claim 5, wherein said driver circuit is operable to energize said at least three windings by a Pulse Width Modulated (PWM) signal.
7. A system for rotating a disk, as in Claim 6, wherein said PWM signal includes a demodulated voltage difference signal between each terminal.



8. A system for rotating a disk, as in Claim 7, wherein said demodulated voltage difference signal is a sinusoidal signal.