Identity Control for Spindle Motors in Hard-Disk Drives

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Abstract - **A novel control technique for hard-disk spindle motor is presented that improves the efficiency of the motor drive system. A spindle motor is first characterized by its 'identity', which is the per-phase torque profile, and then the identity is used to generate an optimal drive current or voltage for driving the spindle. The harmonic content in the drive current is also significantly reduced.**

I. INTRODUCTION

Reduction in form-factor and increase in storage capacity present several challenging issues in spindle motor designs. These issues include space constraint, run-out requirement, torque ripple demands, acoustic noise generation and bearing selection. This paper reports a highly optimized drive controller for spindle motors and describes the development of a control strategy for high-torque spindle motor drives used in hard-disk drives (HDDs).

II. CONCEPT OF 'MOTOR IDENTITY' FOR TORQUE ANALYSIS AND CONTROL

The concept of 'Motor Identity' is first proposed by Bi et. al [1,3] for application in permanent-magnet synchronous motors (PMSMs). Using this concept, the motor is characterized by its 'identity', which is the per-phase dynamic torque profile of the motor. The identity of the motor can be obtained either by indirect measurement of the motor inductances,or by direct method of measuring per-phase dynamic torques [4].

Manuscript received Jan 1, 1995
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This concept eliminates the use of conventional lumped parameter models of the motors. The identity of the motor can be captured by simple experiments and the identity contains all the necessary information for the construction of a current controlled or voltage controlled torque controller. The identity control algorithm [2,4], developed from the motor identity, produces an optimal current to meet specified torque performance. The 'optimality' of the current is defined here as the production of a constant torque with minimum rms current. This control strategy is applied to HDD spindle motors.

III. IMPLEMENTATION OF IDENTITY CONTROL IN HDD SPINDLE MOTORS

Current hard-disk spindle motors are voltage controlled where the voltage input excitation to the stator windings are rectangular shape of width 120^{o} [5]. This voltage excitation is aimed at achieving rectangular shaped phase currents by assuming the rectangular or trapezoidal back emf and the inductances negligible.

To implement identity control on spindle motors, the identity of the motor is obtained experimentally. The dynamic torques produced when the A-phase and both A-phase and B-phase are excited by unity

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currents are characterized and used to determine the identity of the motor [4]. The results are used to determined the identity of the motor [2], as shown in fig. 1.

Based on the identity control algorithm, optimal current to produce maximum and ripple-free torque is first generated by considering harmonic cancellation between the currents and airgap fields. However, since all the HDD spindle motors are voltage controlled and therefore only three parameters can be manipulated : the input dc link voltage (V_d), the duty cycle control angle (ϕ) and the load angle (γ) (see fig.2). Optimization for these parameters are carried out based on the generated optimal current waveforms. Once these three parameters are determined programmed into HDD spindle controller, proper voltages can then be feed to the motor in order to achieve the optimality previously defined.

IV. Results

The identity controller is implemented for a 3.5" HDD spindle motor and it is compared with a conventional brushless dc (BLDC) motor driver [5] on a commercial 3.5" hard-disk drive. Fig. 3 and Fig. 4 show the phase current and back-emf waveforms for the identity controller and the BLDC controller respectively. It is observed that the currents for both controllers are different from the theoretically assumed rectangular currents. The results, with the drive at 3600 rpm, were spectrum analyzed. Several sets of readings were taken and the averaged results are tabulated in Table 1. The results show that the fundamental current of the conventional control is larger than that for the identity controller. The fifth harmonic of the BLDC controller is positive in sign while that of the identity controller is negative. This difference in sign accounts for the higher fundamental current in the conventional BLDC spindle when compared with the identity controller. The negative fifth harmonic produces a positive sequence torque that helps to sustain load torque.

The efficiencies of the motors are also compared as tabulated in Table 2, with the motor running at 3600 rpm. The efficiency of the motor with identity controller is shown to be better by an average of 6 %.

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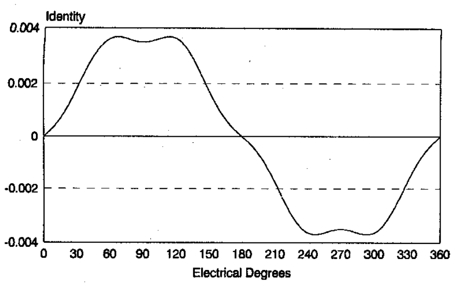

Fig.1 Motor Identity
Units : identity/Nm, Electrical Degrees/Degree

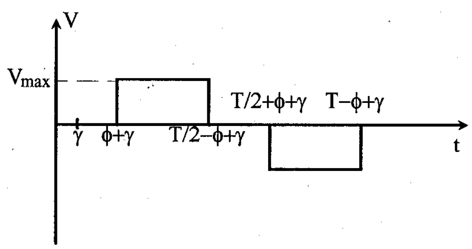

Fig.2 Input voltage to spindle motor
Units : V/volts, t/sec

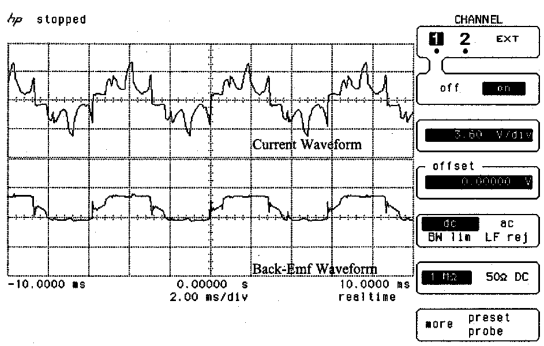

Fig.3 Waveforms for Identity Controller
Unit and Scale :
Upper trace - Current/A, 80 mA/div
Lower trace - Voltage/v, 3.60 v/div

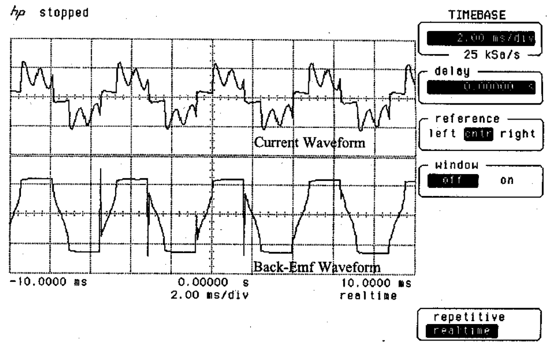

Fig.4 Waveforms for BLDC Controller
Unit and Scale :
Upper trace - Current/A, 80 mA/div
Lower trace - Voltage/v, 1.80 v/div

	Identity Current	Conventional Current
Fundamental	0.1308	0.1336
Second	-0.0023	-0.0007
Third	0.0006	-0.0015
Fourth	-0.00004	0.0019
Fifth	-0.0278	0.0604
Sixth	-0.0008	0.0024
Seventh	0.0457	0.04938
Eighth	-0.0007	0.00226

Table 1. Current Harmonics Of Both Controllers

Identity Controller		
Input Power	Motor Losses	Efficiency
0.479	0.081	83.15%
0.480	0.082	82.92%
0.481	0.082	82.91%
0.488	0.084	82.82%
Overall Efficiency		82.95%

Conventional BLDC Controller		
Input Power	Motor Losses	Efficiency
0.548	0.131	76.08%
0.542	0.132	75.56%
0.529	0.121	77.06%
0.525	0.113	78.44%
Overall Efficiency		76.79%

Table 2. Power Efficiencies For Both Controllers