The Improvement of the Dynamic Behaviour of a Spindle Motor for a CD-ROM Drive

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The demand for CD-ROM drives with higher rotation speeds has increased in recent years. As a result, it is becoming more and more difficult to design a spindle motor to perform within a certain vibration level limits. In this work, the effect of different design variables on the forced vibration of a spindle motor was investigated in order to design an optimal new spindle. The target of the optimisation was to design a new spindle motor with a minimum axial vibration level at the periphery of the turntable or disk. The theoretical results show that the axial vibration of the proposed new spindle can be significantly reduced. The theoretical result was verified by experiments.

1. INTRODUCTION

Brushless dc motors are widely used in data storage devices, such as HDD, CD-ROM or DVD. The demand for a spindle motor with higher rotation speeds and reduced vibration levels is an engineering challenge. Therefore, it is more important today than ever that the dynamic behaviour of the spindle motor should be well understood. The spindle of the motor is generally supported with either ball bearings, hydrodynamic bearings or sintered porous bearings. A typical spindle motor is shown in Fig. 1. Due to the gyroscopic effect and the small dimension of the spindle, the dynamic behaviour of the spindle is very difficult to investigate by the traditional vibration-testing method. Leuthold and Murthy used an impact test to study the dynamic behaviour of a spindle motor.[1] The method was not very reliable, however, because the impact was performed by dropping a ball onto the spindle motor. Jennings, Leuthold and Nagarathnam have measured the natural frequencies of a spindle motor by shaking the base support of the motor.[2] The effect of the disk on the natural frequencies of a spindle motor with a hydrodynamic bearing has been investigated by Ku and Jennings theoretically.[3] Due to the low cost and easy installation, sintered porous bearings and frictional plates are widely used in CD-ROM drives. The effect of the friction force from the frictional plate on the steady and transient dynamic behaviours of spindle motors has been investigated by Wang and Chang[4], and by Wang and Sheu[5].

One knows that large radial vibrations of the spindle may cause tracking errors while too large axial vibrations may cause focus and jittering problems in CD-ROM and DVD-ROM. Because the disk is placed on the turntable of the spindle, even a little tilting vibration of the spindle will induce a large axial vibration at the periphery of the disk. Therefore, it is very important, but also difficult, to design a spindle motor with minimum axial vibration at the periphery of the disk. As best as we know, no paper or report has been published which discusses and demonstrates the possibility of an improvement of the axial vibration of an existing spindle by the modification of the structure of the spindle.

In this work, the effect of design variables on the forced vibration of an existing spindle motor was investigated in order to design a new spindle having minimum axial vibration. An experiment was then conducted to demonstrate that the forced vibration of an existing spindle motor can be significantly reduced by a simple structural modification.

2. THEORETICAL FORMULATION

The spindle motor investigated in this work was an existing product found in the market, as shown schematically in Fig. 1. The rotating parts include a shaft with a nominal diameter of 3 mm, a turntable with an outside diameter of 30 mm, and a permanent magnet attached to a yoke at the bottom of the turntable. The shaft was supported by two porous bearings in the radial direction and by a frictional plate in the axial direction. Because the frequency range of interest is below 200 Hz, the rotating parts were considered to be rigid. In other words, the spindle was modelled as a rigid body. In order to define the position of the rigid spindle at any given instant, the Eulerian angles ϕ, θ, ψ were adopted, as shown in Fig. 2. The co-ordinate system $OXYZ$ is a fixed frame, and $O'X'Y'Z'$ is a translational system with X', Y', Z' always being parallel to X, Y, Z axes. The origin O' is located at the mass centre of the spindle. The moving frame $oxyz$ is attached to the spindle but without spinning about the z axis. The x, y and z axes are chosen to coincide with the principal axes of inertia of the spindle. The derivatives of the Eulerian angles, i.e., $\dot{\phi}, \dot{\theta}$ and $\dot{\psi}$, represent the rate of precession, rate of nutation and rate of spin. The angular velocity of the spindle can be expressed as:

$$\omega = \dot{\phi}K + \dot{\theta}j + \dot{\psi}k = -\dot{\phi}\sin\theta i + \dot{\theta}j + \left(\dot{\psi} + \dot{\phi}\cos\theta\right)k \,. \quad (1)$$

The moving frame $oxyz$ is attached to the spindle, but without spin, $\dot{\psi}$, so the angular velocity of the moving frame is:

$$\Omega = -\dot{\phi}\sin\theta i + \dot{\theta}j + \dot{\phi}\cos\theta k \,,$$