International Journal of Computer and Information Technology (ISSN: 2279 – 0764)
Volume 02– Issue 05, September 2013

Estimation of Disk Slip Position Error for Mobile Hard Disk Drives

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Abstract—**Mechanical vibration on mobile hard disk is inevitable in the practical usage, and violent vibration may cause disk slip with significant position error, which will degrade the servo control performance, prolong time to ready (TTR) of servo and lower reading and writing speed of the magnetic head. The servo tracking accuracy of hard disk drive actuator with respect to various mechanical disturbance levels was considered. So this paper proposes an analytic method based on the motion law of magnetic head against the media in order to effectively estimate the resulting position error prior to the seeking operation and reduce servo burden with control performance improved.**

Keywords—hard disk*; *slip*; *position error

I. INTRODUCTION

Along with the development of computer science and technology, hard disk is becoming an important storage medium [1]. Hard disk servo systems play a vital role for meeting the demand of increasingly high density and high performance hard disk drives. The servo system must achieve precise positioning of the read/write head on a desired track, called track following, and fast transition from one track to another target track called track seeking[2]. With the continuous increasing capacity, performance demands and track density of the hard disk, therefore we should put forward higher requirements to the control technology of the hard disk track following and track seeking[3]. Then, the amount of information that the head read of data also increased in the same time. Track seeking discourses the hard disk head implement the motion control of the addressing between tracks in the shortest time[4][5]. And track following focuses on the head tracks accurately the center position of the magnetic track in a particular track.

In the production process of Hard disk, there is a process to write servo tracks using servo track writer (STW) technology is very important[6]. The disc may be preinstalled within a disc drive, which in turn is loaded within the STW.These read-only system information usually write in STW in the hard disk production process[7][8]. The position between the disk and head relatively fixed in the STW of Hard Disk, Pre-recalibration and compensation of head skew error among multiple heads are required, so that position error during head switching seeks can be minimized[9][10]. However, due to all kinds of accidents or improper handling hard disk will inevitably produce vibration and lead to disk slip in the products practical application[11][12]. It makes head read error information owing to head skew probably deviates from the factory-calibrated value. So it is very important that to research the motion law of disk and head in the disk sliding process [13].

We have engaged in the research field of disk error compensation for a few years. Previously, when disk slippery occurs during operation, the actual position error is offline measured, which is followed by proper calibration methods. However, it can not provide satisfactory servo performance against accidental shock or vibration [14]. Therefore, an analytical method based on the motion law of hard disk is proposed in this paper, and the head position error due to disk slippery can be estimated effectively, so that online compensation without calibration can be realized.

II. MOVEMENT RULES OF HEAD

Due to the traditional mechanical hard disk manufacturing cost is only 1/3 - 1/50 that of the Solid State Disk (SSD), so mechanical hard disk is still the mainstream products of data storage. Mechanical hard disk usually consists of base plate, disk, parking mechanism, read/write head, voice coil motor (VCM), drive head and spindle motor.

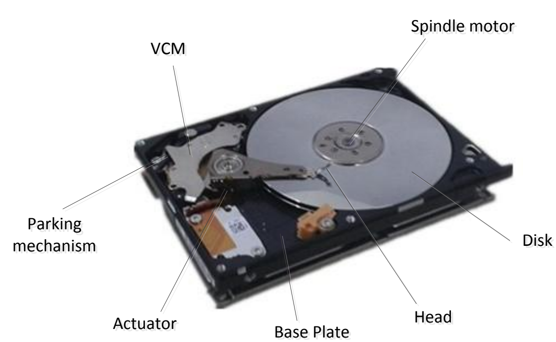

Figure 1. Physical structure of mobile hard disk.

For example, SGTSD4TU2A hard disk produced by Seagate, Fig.1 show the structure of the hard disk, and it usually integrated many pieces of disk and multiple head.

With spindle motor center for coordinates origin O, drawing the rectangular coordinates x-y, showing as Fig. 2. The radius of track is R, and the length of magnetic arm is L_a. X_a is the distance between disk center and the magnetic arm fulcrum. Set A as the fulcrum of the head group cantilever, the center of disk and spindle coincide, then set ID as the minimum track diameter of disk , set OD as the biggest track diameter; Then the internal radius of disk is R_i , and R_o is the external radius.

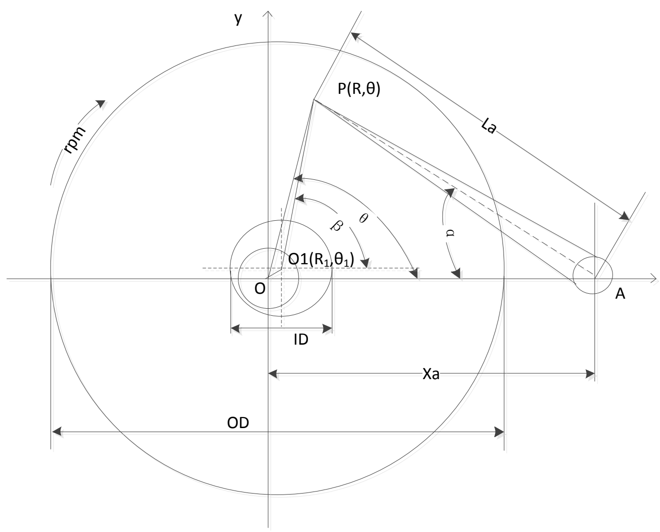

Figure 2. Diagram of head movement after sliding.

For the head located any point on the track $P(R,\theta)$, the Radius of track is calculated by

$$R=\sqrt{X_a{}^2+L_a{}^2-2X_aL_a\cos\alpha}\ ,\ R\in(R_i,R_o) \qquad (1)$$

As

$$\frac{R}{\sin\alpha}=\frac{L_a}{\sin\theta} \qquad (2)$$

We have

$$\beta=\theta+\sin^{-1}\left(\frac{R_1\sin(\theta-\theta_1)}{\sqrt{R^2+R_1^2-2RR_1\cos(\theta-\theta_1)}}\right)$$

$$\theta=\sin^{-1}\left(\frac{L_a\sin\alpha}{R}\right) \qquad (3)$$

Thus,

$$\cos(\theta_1-\theta)=\cos(\theta-\theta_1)$$

$$\arcsin(-\theta)=-\arcsin\theta$$

$$\alpha=\cos^{-1}\left(\frac{X_a{}^2+L_a{}^2-R^2}{2X_aL_a}\right) \qquad (4)$$

So the position of the point P in x-y plane is

$$O_1P=\sqrt{R^2+R_1^2-2RR_1\cos(\theta_1-\theta)}$$

$$\begin{cases} x=R\cos\theta \\ y=R\sin\theta \end{cases} \qquad (5)$$

Now, if the disk is slipped, the head along the track will deviate from the trajectory which servo information written to the track, which will increase the control burden of servo controller.

$$\beta=\theta+\sin^{-1}\left(\frac{R_1\sin(\theta-\theta_1)}{\sqrt{R^2+R_1^2-2RR_1\cos(\theta-\theta_1)}}\right)$$

III. THE POSITION ERROR MODEL OF DISK SLIP

For the disk slip to the first quadrant as an example, now $\theta_1\in\left(0,\frac{\pi}{2}\right)$ .When the disk slipping happens, or the centers of disk and spindle do not coincide due to assembly error, then the center of the physical disk is changed

$$\beta=\theta-\sin^{-1}\left(\frac{R_1\sin(\theta_1-\theta)}{\sqrt{R^2+R_1^2-2RR_1\cos(\theta_1-\theta)}}\right)$$

to $O_1(R_1,\theta_1)$, at this time, the distance of point P to the new disk center is

$$O_1P = \sqrt{R^2 + R_1^{\ 2} - 2RR_1\cos(\theta - \theta_1)} \qquad (6)$$

The angle of the point P and the new disk center is

$$\beta = \theta + \angle OPO_1 \qquad (7)$$

$$\frac{R_1}{\sin\angle \mathrm{OPO}_1} = \frac{O_1P}{\sin(\theta_1 - \theta)} \qquad (8)$$

That is equivalent to

(9)

If $\theta_1 \in \left(\frac{\pi}{2}, \frac{3\pi}{2}\right)$, we can obtain

(10)

If $\theta_1 \in \left(\frac{3\pi}{2}, 2\pi\right)$, it has

(11)

(12)

(13)

(14)

Therefore, whether disk slips to any quadrant, the angle β is given by

$$\beta = \theta + \sin^{-1}\left(\frac{R_1\sin(\theta - \theta_1)}{\sqrt{R^2 + R_1^{\ 2} - 2RR_1\cos(\theta - \theta_1)}}\right) \qquad (15)$$

To sum up, the position and angle errors cause by disk slipping can be expressed as

$$\Delta R = O_1P - OP = \sqrt{R^2 + R_1^2 - 2RR_1\cos(\theta - \theta_1)} - \sqrt{X_a^{\ 2} + L_a^2 - 2X_aL_a\cos\alpha} \qquad (16)$$

$$\Delta\theta = \beta - \theta = \sin^{-1}\left(\frac{R_1\sin(\theta - \theta_1)}{\sqrt{R^2 + R_1^2 - 2RR_1\cos(\theta - \theta_1)}}\right) \qquad (17)$$

So, as long as the eccentricity of the disk $O_1(R_1,\theta_1)$ can be measured, we can estimate of the position and time deviation of any point on the disk, and then by the feedforward control method the addressing error can be reduced and the servo control performance can improved.

IV. DESIGN OF THE SIMULATION PROGRAM

The simulation program is designed by MATLAB/Simulink to study the change of trajectory before and after disk sliding. Firstly, there are some known parameters of the simulation program. Such as, R is the radius of disk, the internal and external diameter of disk are R_i and R_o. Then, (R,θ) stand for the location polar coordinates when the head moves on disk, and the others are α, θ etc. Secondly, the outputs are parameters of X-Y coordinate, Disk slip before and after head trajectory curves of contrast and several corresponding curves of eccentricity in different quadrant.

A simulation designed using Simulink software, and the block diagram as shown in Fig.3. According to the size of the actual hard disk produced by Seagate, the length of magnetic arm is set as La = 35 mm, the distance of disk center and the magnetic arm fulcrum Xa = 39.5 mm, inner diameter ID = 22 mm, outer diameter OD = 66 mm, the disk radius R = 22mm, the system simulation time 10 s is set, and the offset of disk slip R1 = 1mm is assumed, and the angles θ_1 of slip are assigned to π/6, 2π/3, 7π/6, 5π/3, respectively. It can simulate the situation of disk slip to different quadrants, when take track density TPI = 300 k, it also can simulate the position error after disk slip and it is equivalent to the number of the deviation track.

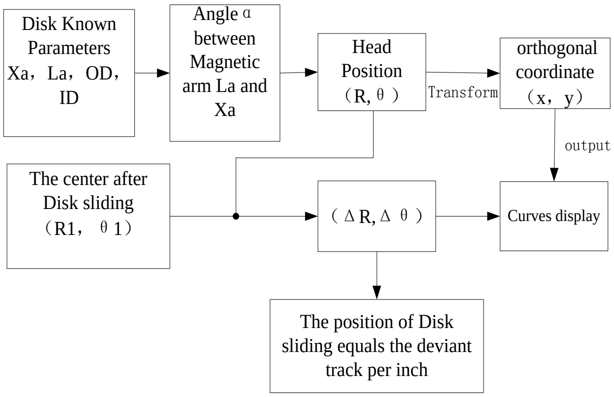

Figure 3. The block diagram of simulation program principle.

V. RESULT ANALYSIS

The head motion trails in rectangular coordinate changes with the trajectory are showed in Fig.4. The head moves from the inner to outer diameter, when disk slips to first or third quadrant. When the error caused by disk skewing is close to the outer diameter, the error became smaller. However, the head moves from inner to outer diameter, the error changes not obviously, when disk slip to second or fourth quadrant. It will provide direct basis for the position error compensation amount after the disk slip.

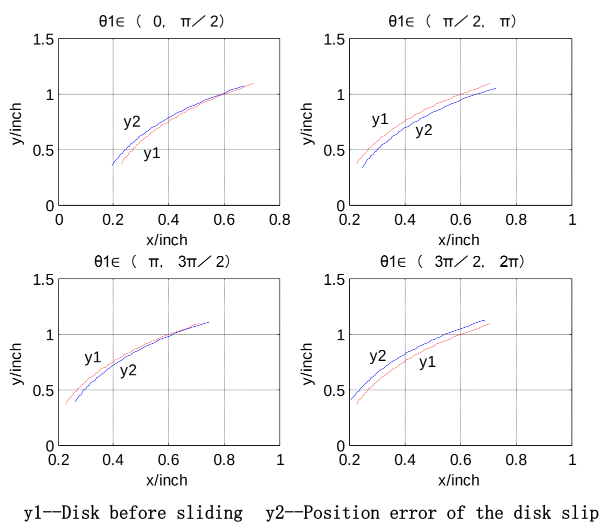

Figure 4. The contrast of disk head slip motion trajectory before and after.

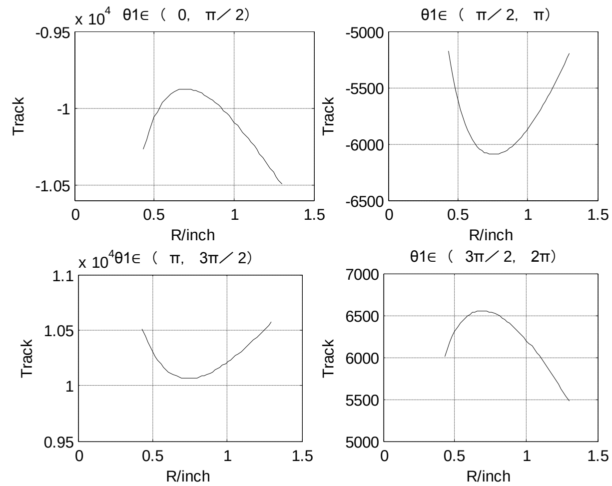

Figure 5. The position error corresponding track number when disk slip to different quadrant.

Figures 5 and 6 are the simulation results, which show that the head position deviation and the angle deviation change over track. This shows, the track direction of disk in the opposite while disk slips to first or fourth quadrant with the second or third quadrant. As the head moves from the inner to outer diameter, the deviation track numbers follow to the parabolic law, when the disk slippage to occur the position error in the second or third quadrant, the deviation track number gradually increases followed by decreasing, and in first or fourth quadrant, the deviation track number gradually decreased and then increases. From the comparison in different quadrants, a conclusion that the range of the deviation track numbers and the angle error in second or forth quadrant changes more obviously than that in first or third quadrant.

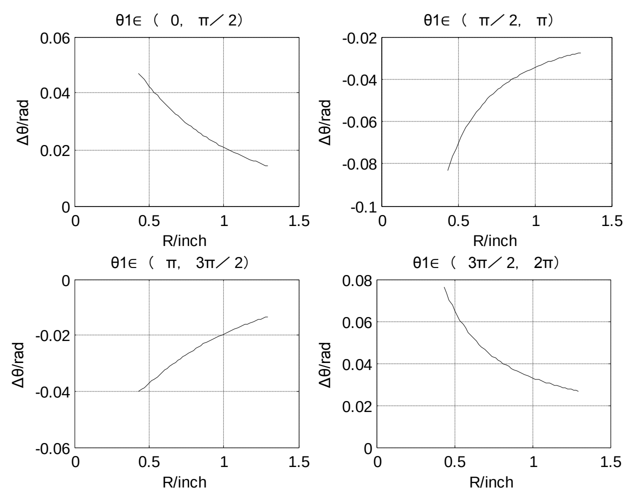

Figure 6. Angle error corresponding disk slip to different quadrant.

VI. CONCLUSIONS

For a model of arbitrary mobile hard disk, the parameters Xa, La and inner and outer diameters of disk are positive constants, they are known in the design process. However, the disk radius R can also be calculated. In reality, the offset（R_1，θ_1）, can get the accurate value through the sensor. In view of the limited conditions, that is to say, this paper completes the model simulation by assign a value to known quantity.

According to the motion law of disk and disk offset, mathematical model based on above mentioned method can be established, and the relative position of mobile hard disk slip away from head can be estimated. When the head skew happen to hard disk in use, it can provide the basis for corresponding compensation and possible calibration control algorithm, and the failure rate of hard disk can be reduced. In other words, the working life of the hard disk would be prolonged.

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