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Mixed-Sensitivity H_∞ Control for Optical Pickup Systems

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Abstract

Focus and tracking servo control plays an important role in the optical storage systems and the control precision could directly affect the read/write performance of the system. Due to the non-uniformity of the space magnetic field in the optical pickup system, the crosstalk movements among the focus, tracking and rolling direction are generated by the unbalanced magnetic induction forces. In the traditional DVD systems, the servo control in the focus and tracking movement are studied separately without considering possible crosstalk to the rolling movement, which could bring up the undesired tilt angle error. In this paper, the crosstalk effects are studied and a multi-input-multi-output (MIMO) model is developed for the optical pickup systems. Then a mix-sensitivity H_∞ *controller design approach is proposed for the servo control system so that not only the control precision requirements in the focus and tracking direction are satisfied, but also the tilt angle error caused by the crosstalk effect is effectively reduced. Finally, the control performance is verified in an experimental setup system by the comparison with the traditional lead-lag controller. The experimental results show the effectiveness of the proposed optimal control approach to satisfy the even tighter optical tolerance requirement in the next generation optical storage systems.*

Keywords: *Crosstalk, rolling movement, optical storage, mixed-sensitivity,* H_∞ *controller*

1. Introduction

With the continuous increase of the density and the data transfer speed in the optical disk storage systems, the precision requirements for the optical tolerance become higher and higher, which demand the better performance for the servo control system to offer a more accurate position ability in the optical pickup systems. For example, the distance between the objective lens and disc will drop down to less than 100 *nm* for the next generation near field optical storage systems, which requires the servo control system to have a more demanding position accuracy to prevent collisions between the lens and the disk surface and thus achieve a stable read/write performance [1, 2].

The traditional control method in the DVD systems is to study the focus and tracking movement of the pickup systems separately and design the individual controller for the focus and tracking servo systems independently. Normally, the lead/lag controllers are designed to make the open-loop system have a desired bandwidth with proper frequency properties. However, in the optical pickup systems, the space magnetic field in the actuator is symmetric, but is not uniform. The deviation of the actuator from the geometric center could bring up the serious crosstalk movements generated by the unbalanced magnetic induction forces among the focus, tracking and rolling directions. The traditional control method designed based on the single-input single-output (SISO) model can deal with the crosstalk movements in the focus direction and

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tracking direction effectively, however, it cannot attenuate the crosstalk in the rolling direction properly, which could lead to the decline of the read/write performance and even result in a collision between the objective lens and the disk surface in the next generation optical storage systems [3]. In order to deal with the crosstalk effect in the rolling direction, the pickup systems with the additional control degree in the rolling direction have been considered. For example, the 3-dimensional (3-D) structure has been proposed to offer the control ability in the direction of radial tilt and the 4-dimensional structure to offer the control ability both in the direction of radial tilt and tangential tilt. Usually, the design and manufacture of these 3-D or 4-D pickup systems are complex and costly [4, 5]. In this paper, a mix-sensitivity H_∞ controller design approach based on the multi-input multi-output (MIMO) model of the actuator system is proposed so that the resulting closed-loop system not only can deal with the crosstalk movements in the focus and tracking directions, but also can reduce the crosstalk effect in the rolling direction effectively.

In the following, the crosstalk effect in the pickup system is first studied and a corresponding MIMO model is developed in section 2. Then the mix-sensitivity H_∞ controller design approach is proposed in section 3. Finally, the control performance is verified in an experimental system to shown the effectiveness of the proposed control method in section 4, followed by the conclusion in the section 6.

2. MIMO Modeling of the Optical Pickup Actuator

The optical pickup system is one of the most important parts in DVD systems, in which the voice coil actuator is used to drive the object lens in the focus and tracking directions. The schematic block diagram of the widely used 2-D optical pickup system is shown in Figure 1, where the movable part including the objective lens is supported by the four suspension wires and the electromagnetic forces generated by the voice coils drive the movable part to move in the focus and tracking directions. The focus movement makes the objective lens move in the direction perpendicular to the optical disc surface to ensure the laser beam spot focusing on the disc surface accurately and the tracking movement makes the objective lens to move in the direction parallel to the optical disc surface [6, 7]. The electromagnetic forces exerted on the actuator are decided by the distribution of the space magnetic field inside the actuator. Generally, the overall magnetic field inside the pickup actuator is generated by two permanent magnets, the focusing coil and the four tracking coils, as shown in Figure 2. The picture of a typical 2-D optical pickup system (Sanyo SF-HD850G) is shown in Figure 3.

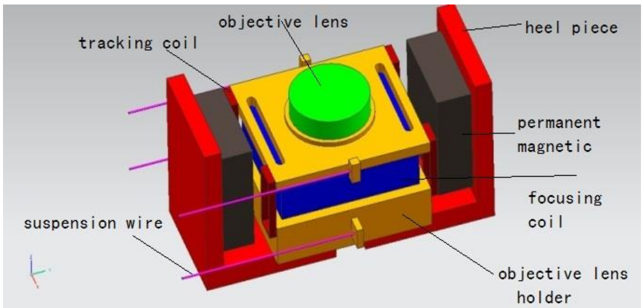

Figure 1. Schematic Diagram of the Two-dimensional Pickup Actuator with Four Suspension Wires

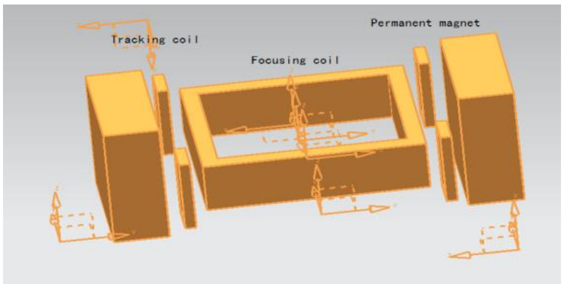

Figure 2. Schematic Diagram of the Actuator Coils

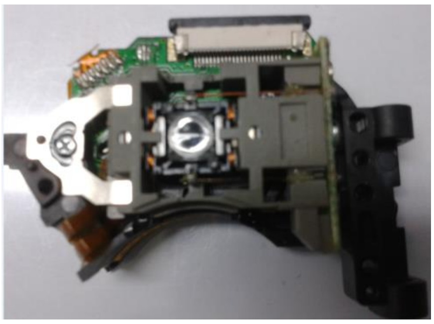

Figure 3. The Sanyo SF-HD850G Optical Pickup System

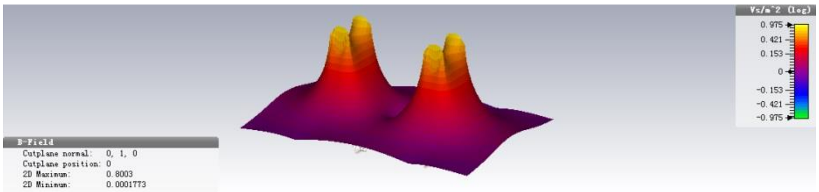

Figure 4. The Overall Magnetic Field Simulated in CST Software

The spatial magnetic field inside the actuator can be analyzed based on the magnetic field models of the permanent magnets, the focus coils and the tracking coils, respectively [8]. The distribution of the overall magnetic field can be observed through numerical simulation based on the synthesis of these models. One example of the overall magnetic field with respect to the specific driving currents in the voice coils is shown in Figure 4, which is simulated using the CST software based on finite-difference time-domain (FDTD) principle. It can be seen that the magnetic field inside the actuator is symmetric to the center of the actuator, but not uniform. When the movable part moves in the non-uniform magnetic field, they could deviate from the geometric center position. Therefore, the movable part is not only actuated in the expected direction, but also is actuated in other directions caused by the asymmetric magnetic field, which results in the crosstalk movements [9].

In the traditional control approach for the DVD systems, the dynamic models of the actuator in the focus and tracking directions are separately considered as the mass-spring-damper systems [2], as shown in Figure 5. Its dynamics and electrical equations are established as follows:

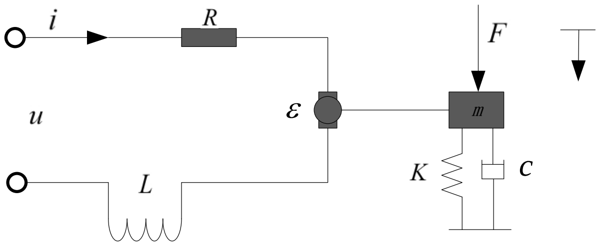

Figure 5. Simplified Mass-spring-damper Model of the Pickup Actuator

$$\begin{cases} F = m\dfrac{d^2x}{dt^2} + c\dfrac{dx}{dt} + kx \\ u = \varepsilon + Ri + L\dfrac{di}{dt} \\ F = Ki \\ \varepsilon = K\dfrac{dx}{dt} \end{cases} \tag{1}$$

where m is the mass of the moving part, x is the actuator displacement from the equilibrium position in the movable direction under the coil ampere force F, c the damping coefficient, k the spring stiffness, u the coil input voltage, ε the coil induced electromotive force, R the coil resistance, L the coil inductance (in the working frequency range, L is normally neglected as 0), $K = Bl$ the scale factor (B is the magnetic induction density and l is the equivalent length of the coil), and i the coil instantaneous current. Then the simplified model can be given by a two order system as:

$$G_u(s) = \frac{X(s)}{U(s)} = \frac{K}{mRs^2 + (cR + K^2)s + kR} \tag{2}$$

where $G_u(s)$ is the transfer function of the actuator system from the control voltage input to the displacement output. However, this model is developed based on the assumption that the magnetic field inside the actuator is uniform. Therefore, the crosstalk movements among the focus, tracking and rolling directions are ignored. However, the movement in the focus or tracking direction could bring up the tilt angle error of the object lens due to the crosstalk effect so that the optical tolerance of the near field recording in next generation optical storage systems cannot be satisfied.

In the following, a MIMO dynamic model considering the crosstalk coupling effect is established for the pickup actuator system, where the focus control signal and tracking control signal are considered as the input vector, and the focus error, tracking error and tilt angle error signals are considered as the output vector. To facilitate the modeling, the physical frame is considered as a rigid body and the suspension wire as an elastomer, thus, the overall input of the actuator system is the driving current $\{i\} = [i_F, i_T]^T$. where i_F and i_T are the focus and tracking driving current, respectively. The output of the actuator system is defined as $\{q\} = [y, z, \alpha]^T$,where y , z , α are the displacements in the focus direction, the tracking direction and the tilt angle in the rolling direction, respectively.

Four center points will be considered as the reference position for the modeling of the pickup actuator system, *i.e.*, the optical center, the center of the mass, the center of the driving force and the center of the support force (the geometry support center of the suspension wire). The optical center is the center of the objective lens of the pickup actuator and its displacement reflects the effective movement of the actuator. Therefore, the optical center is set to be the origin of the absolute coordinate system O_{xyz}. Thus, the coordinates of the four center points could be written as $O(0,0,0)$ for the optical center, $C(l_{cx},l_{cy},l_{cz})$ for the center of mass, $D(l_{dx},l_{dy},l_{dz})$ for the center of driving force and $P_i(l_{ix},l_{iy},l_{iz})$, $i=1,2,3,4$ for the center of support force in the four suspension wires.

Based on the coordinate transformation, the coordinate of the mass center in the absolute coordinate system is then given by:

$$\begin{cases} y_c = y + l_{cy} - l_{cz}\cdot\alpha \\ z_c = z + l_{cz} + l_{cy}\cdot\alpha \end{cases} \tag{3}$$

Similarly, the coordinate of the fixed center point of the suspension wires are given by:

$$\begin{cases} y_i = y + l_{iy} - l_{iz}\cdot\alpha \\ z_i = z + l_{iz} + l_{iy}\cdot\alpha \end{cases} \tag{4}$$

and the deformation of the suspension wire is given by:

$$\begin{cases} \Delta y_i = y - l_{iz}\cdot\alpha \\ \Delta z_i = z + l_{iy}\cdot\alpha \end{cases} \tag{5}$$

Assuming that the equivalent stiffness coefficient of three degrees of freedom for each suspension wire is $(k_{iy},k_{iz},k_{i\alpha})$, and the equivalent damping coefficient is $(c_{iy},c_{iz},c_{i\alpha})$. Therefore, the kinetic energy T, potential energy V and dissipated energy E can be given as follows [10]:

$$T = (1/2)m\dot{y}_c^{\,2} + (1/2)m\dot{z}_c^{\,2} + (1/2)J_x\dot{\alpha}^2 \tag{6}$$

$$V = \sum_{i=1}^{4}\frac{1}{2}k_{iy}\Delta y_i^{\,2} + \sum_{i=1}^{4}\frac{1}{2}k_{iz}\Delta z_i^{\,2} + \sum_{i=1}^{4}\frac{1}{2}k_{i\alpha}\alpha^2 \tag{7}$$

$$E = \sum_{i=1}^{4}\frac{1}{2}c_{iy}\Delta y_i^{\,2} + \sum_{i=1}^{4}\frac{1}{2}c_{iz}\Delta z_i^{\,2} + \sum_{i=1}^{4}\frac{1}{2}c_{i\alpha}\alpha^2 \tag{8}$$

The force generated by the driving currents on the focus and tracking coils is represented as $\{f\} = [F_y, F_z, M_x]^T$, where F_y is the focus driving force, F_z the tracking driving force and M_x the crosstalk torque generated in the rolling direction. The overall driving force vector of the pickup actuator system then can be expressed as:

$$\{f\} = [D]\{i\} \tag{9}$$

where $[D] = \begin{bmatrix} d_{Fy} & d_{Ty} \\ d_{Fz} & d_{Tz} \\ d_{F\alpha} & d_{T\alpha} \end{bmatrix}$. Combine the terms (3-9) into the following Lagrange equation of the second kind as:

$$\frac{d}{dt}\left[\frac{\partial T}{\partial \dot{q}_j}\right] - \frac{\partial T}{\partial q_j} + \frac{\partial V}{\partial q_j} + \frac{\partial E}{\partial \dot{q}_j} = f_j \quad (j=1,2,3) \tag{10}$$

Then we obtain the following dynamic equation:

$$[M]\{\ddot{q}\} + [C]\{\dot{q}\} + [K]\{q\} = [D]\{i\} \tag{11}$$

where the coefficient matrices are as follows:

$$
\begin{aligned}
&[M]=\begin{bmatrix} m & 0 & -ml_{cz} \\ 0 & m & ml_{cy} \\ -ml_{cz} & ml_{y} & J_x+ml_{cy}^2+ml_{cz}^2 \end{bmatrix} \\
&[K]=\begin{bmatrix} \sum k_{iy} & 0 & -\sum k_{iy}l_{iz} \\ 0 & \sum k_{iz} & \sum k_{iz}l_{iy} \\ -\sum k_{iy}l_{iz} & \sum k_{iz}l_{iy} & \sum k_{iz}l_{iy}^2+\sum k_{iy}l_{iz}^2+\sum k_{i\alpha} \end{bmatrix} \\
&[C]=\begin{bmatrix} \sum c_{iy} & 0 & -\sum c_{iy}l_{iz} \\ 0 & \sum c_{iz} & \sum c_{iz}l_{iy} \\ -\sum c_{iy}l_{iz} & \sum c_{iz}l_{iy} & \sum c_{iy}l_{iz}^2+\sum c_{iz}l_{iy}^2+\sum c_{i\alpha} \end{bmatrix} \\
&[D]=\begin{bmatrix} d_{Fy} & d_{Ty} \\ d_{Fz} & d_{Tz} \\ d_{F\alpha} & d_{T\alpha} \end{bmatrix}
\end{aligned} \tag{12}
$$

Denote the variables of the output and driving current input in Laplace domain as $Q(s)$ and $I(s)$, then the dynamic model in Laplace domain can be expressed as:

$$\left([M]s^2+[C]s+[K]\right)Q(S)=[D]I(s) \tag{13}$$

The corresponding current-displacement transfer function matrix of the system is given by:

$$\left[G(s)\right]=\left([M]s^2+[C]s+[K]\right)^{-1}[D] \tag{14}$$

where the transfer function matrix $[G(s)]$ has 3×2 matrix terms as:

$$\left[G(s)\right]=\begin{bmatrix} G_{FF}(s) & G_{TF}(s) \\ G_{FT}(s) & G_{TT}(s) \\ G_{F\alpha}(s) & G_{T\alpha}(s) \end{bmatrix} \tag{15}$$

where $G_{FF}(s)$ and $G_{TF}(s)$ denote the transfer functions from the focus current i_F and the tracking current i_T to the focus displacement y, respectively; $G_{TT}(s)$ and $G_{FT}(s)$ the transfer functions from i_F and i_T to the tracking displacement z; $G_{F\alpha}(s)$ and $G_{T\alpha}(s)$ the transfer functions from i_F and i_T to the tilt angle α.

3. The Mixed-sensitivity H_∞ Controller Design for the Optical Pickup Actuator

In order to effectively eliminate the crosstalk effects among the focus, tracking and rolling movements, in the following, the mixed sensitivity H_∞ controller design approach is proposed for the optical pickup system. The defined H_∞ performance based on the mixed sensitivity functions is optimized so that the closed-loop system could remain stable and meet the desired performance objectives in the presence of external disturbances and possible model uncertainties.

The augmented closed-loop control structure of the mixed sensitivity H_∞ controller for the optical pickup actuator is shown in Figure 6. G denotes the model of the 2-D pickup actuator system. The diagonal matrix $F=fI_{2\times 2}$, where f is a scalar low-pass filter introduced before the controller K, and is used to attenuate the high-frequency measurement noise before being fed to the controller. In order to minimize the performance error $\hat{e}$, including tracking error $\hat{e}_1$, focus error $\hat{e}_2$ and tilt angle error $\hat{e}_3$, effectively in the desired frequency range, a weight function $W_e = w_e I_{3\times3}$, where w_e is a weight function with a low-pass feature, is used to shape the closed-loop sensitivity function S_c, that is, the transfer function form the input signal to the performance variable $\hat{e}$ in the closed-loop system, and expressed as

$$S_c = (I + FGK)^{-1} \tag{16}$$

The weight function $W_u = w_u I_{2\times2}$ is such that w_u is a scalar high-pass filter with a corner frequency approximately equal to the desired bandwidth of the closed-loop system. The weight function contributes toward the robustness of the closed-loop system by minimizing the controller output in the frequency range beyond the desired closed-loop system bandwidth [11]. The integrator shown in Figure 6 is introduced to ensure that the errors with respect to the static reference signals are driven to zero. With the integrator block included, the overall controller becomes:

$$K = \frac{z}{z-1} K_\infty \tag{17}$$

where K_∞ is the H_∞ controller to be designed. The successful cancellation of the disturbance r by the closed-loop system can be achieved if the maximum singular value of the sensitivity function S_c is made small over the desired frequency range. In order to limit the input control currents to the actuator and increase the robustness of the closed-loop system, the transfer function from the disturbance signal r to the weighted controller output $\tilde{u}$ is included in the transfer function to be shaped, hence the mixed sensitivity design approach. With the structure of the closed-loop system selected as described above, the mixed-sensitivity H_∞ controller design problem is formulated as follows:

$$\min_K \left\| \begin{bmatrix} W_e S_c F \\ W_u K S_c F \end{bmatrix} \right\|_\infty \tag{18}$$

where $W_e S_c F$ and $W_u K S_c F$ are the transfer functions from r to $\tilde{e}$ and from r to $\tilde{u}$, respectively. The controller is obtained by minimizing the H_∞ norm of the transfer function from the disturbance signal r to the error signal $\tilde{e}$ and to the weighted controller output $\tilde{u}$. The state space representation of G, which can be obtained from (15), is denoted as $G: \begin{bmatrix} A_g & B_g \\ C_g & 0 \end{bmatrix}$, where $A_g \in R^{m\times m}$, $B_g \in R^{m\times 2}$, $C_g \in R^{3\times m}$ and m the corresponding number of state variables.

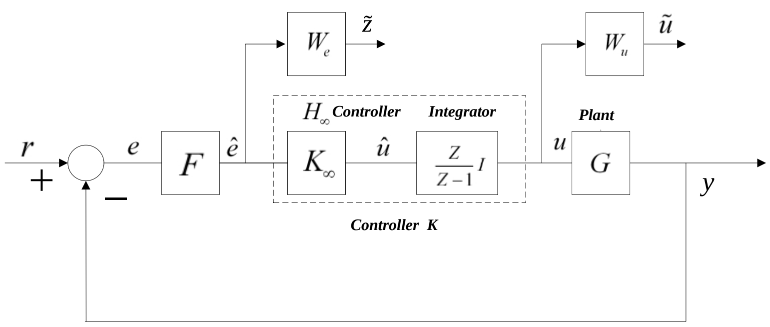

Figure 6. Closed-loop System Structure for the Mixed Sensitivity H_∞ Controller Design

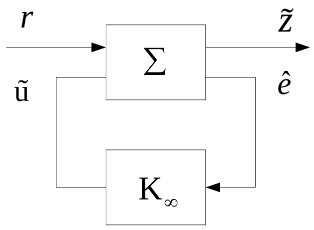

Figure 7. Block Diagram of the Closed-loop System in a Standard Feedback Configuration

Let state-space representations of W_e , W_u and F be $W_e : \begin{bmatrix} A_{we} & B_{we} \\ C_{we} & D_{we} \end{bmatrix}$, $W_u : \begin{bmatrix} A_{wu} & B_{wu} \\ C_{wu} & D_{wu} \end{bmatrix}$, $F : \begin{bmatrix} A_f & B_f \\ C_f & D_f \end{bmatrix}$, and that of the integral term $\dfrac{z}{z-1} I$ be $\begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix}$. Define the weighted performance variable $\tilde{z}$ be $\tilde{z} = \begin{bmatrix} \tilde{e}^T & \tilde{u}^T \end{bmatrix}^T$. Then the problem of minimizing the H_∞ norm of the mixed sensitivity function $\begin{bmatrix} W_e S_c F \\ W_u K S_c F \end{bmatrix}$ with respect to the parameters K_∞ can be properly formulated by rearranging the closed-loop system as shown in Figure 7. The open-loop system Σ from $\begin{bmatrix} r^T & \hat{u}^T \end{bmatrix}^T$ to $\begin{bmatrix} \tilde{z}^T & \hat{e}^T \end{bmatrix}^T$, as shown in Figure 7, can be written in state-space form as

$$\Sigma : \begin{cases} x(k+1) = Ax(k) + B_1 r(k) + B_2 \tilde{u}(k) \\ \tilde{z}(k) = C_1 x(k) + D_{11} r(k) + D_{12} \tilde{u}(k) \\ \hat{e}(k) = C_2 x(k) + D_{21} r(k) + D_{22} \tilde{u}(k) \end{cases} \tag{19}$$

which can also be expressed as follows:

$$\Sigma := \left[\begin{array}{c|cc} A & B_1 & B_2 \\ \hline C_1 & D_{11} & D_{12} \\ C_2 & D_{21} & D_{22} \end{array} \right] = \begin{bmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{bmatrix} \tag{20}$$

where:

$$A = \begin{bmatrix} A_g & B_g C_i & 0 & 0 & 0 \\ 0 & A_i & 0 & 0 & 0 \\ -B_f C_g & 0 & A_f & 0 & 0 \\ 0 & B_{wu} C_i & 0 & A_{wu} & 0 \\ -B_{we} D_f C_g & 0 & B_{we} C_f & 0 & A_{we} \end{bmatrix},$$

$$B_1 = \begin{bmatrix} 0 \\ 0 \\ B_f \\ 0 \\ B_{we}D_f \end{bmatrix}, \quad B_2 = \begin{bmatrix} B_g D_i \\ B_i \\ 0 \\ B_{wu} D_i \\ 0 \end{bmatrix},$$

$$C_1 = \begin{bmatrix} -D_{we}D_f C_g & 0 & D_{we}C_f & 0 & C_{we} \\ 0 & D_{wu}C_i & 0 & C_{wu} & 0 \end{bmatrix}, \quad D_{11} = \begin{bmatrix} D_{we}D_f \\ 0 \end{bmatrix},$$

$$D_{12} = \begin{bmatrix} 0 \\ D_{wu}D_i \end{bmatrix}, \quad C_2 = \begin{bmatrix} -D_f C_g & 0 & C_f & 0 & 0 \end{bmatrix}, \quad D_{21} = D_f, \quad D_{22} = 0$$

Note that the control objective is to find a stabilizing controller K_∞ to minimize the H_∞ norm of the transfer function from r to $\tilde{z}$. According to Figure 7, we can have:

$$\begin{aligned} \tilde{z} &= [P_{11} + P_{12}K_\infty(I - P_{22}K_\infty)^{-1}P_{21}]r \\ &=: F_l(\Sigma, K_\infty)r \end{aligned} \tag{21}$$

where $F_l(\Sigma, K_\infty)r$ is defined as the lower linear fractional transformation of Σ and K_∞. Therefore, the H_∞ optimization problem (18) is equivalent to:

$$\min_{K_\infty} \|F_l(\Sigma, K_\infty)\|_\infty \tag{22}$$

4. Experimental Results

The proposed mixed sensitivity H_∞ control approach is evaluated on an optical storage setup system as shown in Figure 8. The optical pick-up head SF-HD850 from Sanyo Corporation and the servo control chipset AM5668 are used to actuate the optical lens. The focus and tracking errors are obtained based on the astigmatic method using FPGA chipset EPIC20FBGA400 from ALTERA Corporation. The Polytec OFV552/5000 is used to measure the tilt angle error of the optical lens. The simulated disk surface fluctuation and force disturbance signals are added to the measurement of the performance errors and the output of the controller, respectively. The controller algorithm is implemented in a PC with the Matlab/Simulink/Real-time Windows Target environment at a sampling rate 10KHz.

Figure 8. The Photo of the Experiment System

For the design of the parameters of the proposed optimal controller, the model of the pickup actuator is first identified using the system identification method by sweeping the sinusoidal signals to the actuator drive circuit. Then based on the sweeping input signal and the measured output error signals, the corresponding subsystem in (15) are obtained as:

$$G_{FF}(s)=\frac{2479.73}{s^2-19.42s+2479.753},\quad G_{FT}(s)=\frac{4.14s+51.49}{s^2-28.51s+5013.08}$$
$$G_{TF}(s)=\frac{0.10322s+1201.54}{s^2-418.3s+790940},\quad G_{TT}(s)=\frac{5693.95}{s^2+1.5959s+5948.13}$$
$$G_{F\alpha}(s)=\frac{380.36}{s^2+107.3s+47485},\quad G_{T\alpha}(s)=\frac{15.831}{s^2+17.124s+1532}$$

For the traditional control approach in the optical data storage systems, the focus servo control loop and the tracking servo control loop are designed independently without considering the crosstalk effects on the rolling movement. For example, the typical control block diagram of the focus servo loop is shown in Figure 9, which is simply considered as a SISO system control problem. In order to specify the servo control system for the focus (axial) operation in DVD specifications, the following open-loop gain H_{FF} in the focus servo loop is normally desired [6]:

$$H_{FF}=\Omega\cdot C_F(s)\cdot G_{FF}(s)=\frac{1}{3}\times\frac{4\pi^2 f_0^{\ 2}}{s^2}\times\frac{1+\dfrac{3s}{2\pi f_0}}{1+\dfrac{s}{6\pi f_0}} \tag{23}$$

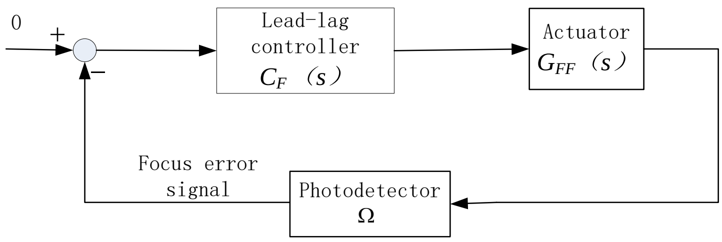

Figure 9. Schematic Block Diagram of the Focus Servo Control Loop

where f_0 is the crossover frequency of the open-loop transfer function at 0 dB, Ω the scalar ratio of the measured focus error signal, and $G_{FF}(s)$ the transfer function of the pickup actuator in the focus direction. Then based on the desired open-loop frequency property, the lead-lag controller can be formulated, which can be finally approximated as a two order compensator. The design approach for the radial tracking servo control loop follows the same rule. Based on the identified model $G_{FF}(s)$, the standard lead-lag controller for the focus servo control loop is then obtained as:

$$C_F(s)=\frac{3.235\times10^{-7}s^2+0.001915s+1}{1.989\times10^{-5}s^2+s} \tag{24}$$

Consider the external disturbance as a sinusoidal signal added at the focus direction with the amplitude 10 μm and the frequency 12 Hz. Using the designed lead-lag controller, the experimental results are shown in Figure 10 and 11. It can be seen that although an acceptable focus error is obtained in the servo control system, a tilt angle error up to 0.03rad exists due to the crosstalk coupling from the focus and tracking directions. In the following, the mixed sensitivity H_∞ controller will be considered and applied to the servo control system. The weight function w_e is chosen as a low-pass filter with a cutoff frequency at 20 Hz :

$$w_e(z) = \frac{z^2 + 2z + 1}{2.556\times10^4 z^2 - 5.066\times10^4 z + 2.511\times10^4} \quad (25)$$

The low- pass filter f is chosen to have a cutoff frequency at 30 Hz as:

$$f(z) = \frac{0.01867}{z - 0.9813} \quad (26)$$

The weight function w_u is chosen as a high-pass filter:

$$w_u(z) = \frac{z - 0.9982}{z - 0.718} \quad (27)$$

The parameters of the controller K_∞ could be obtained by minimizing the defined H_∞ norm of the transfer functions from the disturbance signal to the weighted error signal $\tilde{e}$ and to the weighted controller output $\tilde{u}$, which can be solved based on LMIs using the function *dhinflmi* in Matlab Robust Control Toolbox. The resulting experimental results with the designed H_∞ controller are shown in Figure 12 and 13. It can be seen that the control performance of the H_∞ controller in the focus direction is similar to the lead-lag controller, however, a better control performance is obtained with the H_∞ controller for the tilt angle error which has dropped down to below 0.0035rad. The experimental results show that the mixed sensitivity H_∞ controller designed based on the MIMO model is more effective than the traditional lead-lag controller to deal with the crosstalk effect in the pickup actuator system.

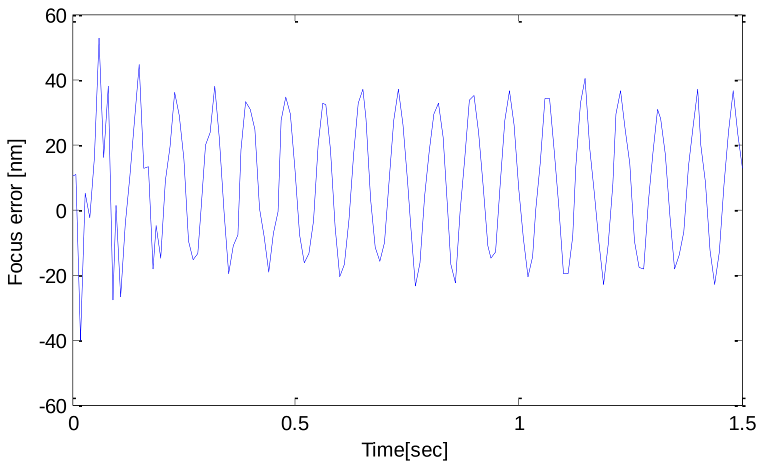

Figure 10. The Focus Error with the Lead-lag Controller

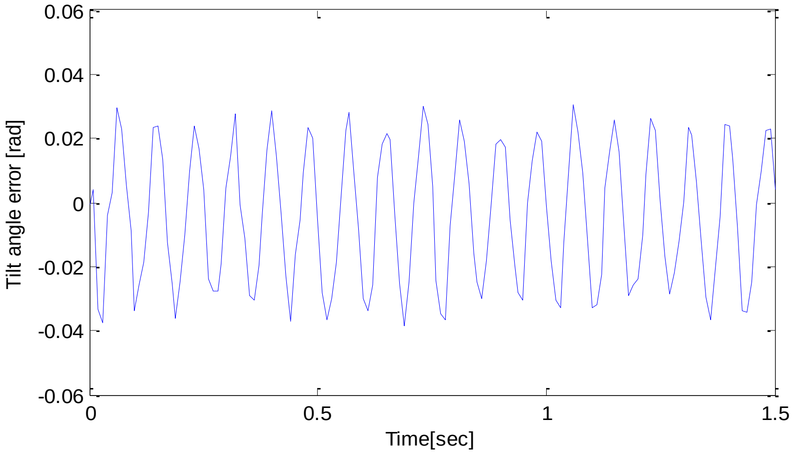

Figure 11. The Tilt Angle Error with the Lead-lag Controller

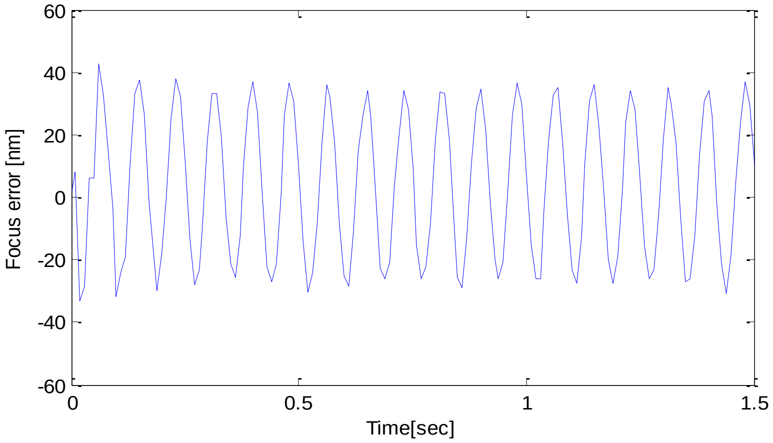

Figure 12. The Focus Error with the Mixed Sensitivity H_∞ Controller

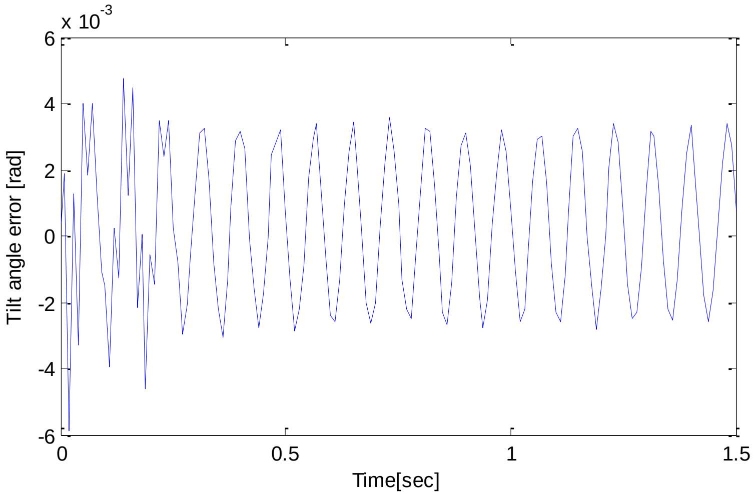

Figure 13. The Tilt Angle Error with the Mixed Sensitivity H_∞ Controller

5. Conclusion

The servo control system for the optical pickup system plays an important role in the next generation ultra-high density optical data storage systems. In this paper, the crosstalk effect of the pickup actuator is discussed and the MIMO model including the crosstalk coupling dynamics among the focus, tracking and rolling directions is developed. Then an H_∞ controller based on the optimization of mixed sensitivity functions is proposed to deal with the undesired crosstalk effects. The experimental results show that the optimal H_∞ controller designed based on the MIMO model is more effective in eliminating the crosstalk effect, *i.e.*, the tilt angle error, than the traditional SISO lead-lag controllers.

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