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# Discrete PID Control Scheme for a Hard Disk Drive ServoMechanism

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**Abstract**— The paper proposes a discrete time PID controller for a hard disk drive servo mechanism. The control objective is to precisely move the read/write head of a hard disk with minimum overshoot and settling time. For this application, a discrete time PID control scheme has been designed guaranteeing a system response close to that obtained through implementation of a continuous time PID control. The performance and robustness of the system is evaluated after implementing the control schemes. A continuous time PID controller is designed initially to understand the performance of the system before the design of discrete controllers. Finally, a comparison is made among the controllers keeping in view of the requirements of the plant. Simulation results validate that the discrete PID controller offers better results than the discrete PI controller.

**Index Terms**— continuous time, discrete time, servo mechanism, PID controller, PI controller, minimum overshoot, settling time.

## 1 INTRODUCTION

The hard disk drive is a typical example of the precision control of mechatronics systems. In a digital computer, a Hard Disk Drive (HDD) mechanism controls the positioning, reading, and writing of the hard disk, categorized as the dominant internal storage device for computers. The most sought after characteristics for a HDD are significantly high data transfer rates, reliability as well as lower latency and access times.

In most HDDs, rotating disks coated with a thin magnetic layer are written with data that are arranged in concentric circles or tracks. Data are read or written with a read-write (RW) head, which consists of a small horseshoe-shaped electromagnet [6]. Figure 1 shows a simple illustration of a typical hard disk drive servo system with a voice-coil-motor (VCM) actuator. The VCM is a rotary actuator which positions the read/write head on the disk. Data bits are stored in concentric circles called tracks which are read and written by the read and write heads respectively.

Besides their application in general purpose computers, HDDs are increasingly being used in Network Attached Storage Systems, RAID systems, Storage Area Network Systems and Consumer Application Systems[3]. Higher areal density and reduction of cost of HDDs are critical, more precise positioning of the HDD servo systems are essential to meet the increasing demand for areal density [4]. This trend has led to the need for improved performance of the head-positioning servo system which aims at accurately maintaining the selected head position along the center of the track and providing rapid movement of the head from one track to another selected track [5].

Track seeking and Track Following are the basic functions of read/write head positioning servo mechanism in disk drives. The read/write head is moved from the present track to a specified destination track in minimum time using a bounded control effort by Track seeking. The read/write head can be maintained as close as possible to the destination track center while read/write operation is being done using Track Following [2]. The positioning of the read/write head for a hard disk drive requires the design of an accurate control. This paper is aimed at designing a suitable discrete time controller that will improve the precision and efficiency of the Hard Disk Drive read/write head positioning servomechanism

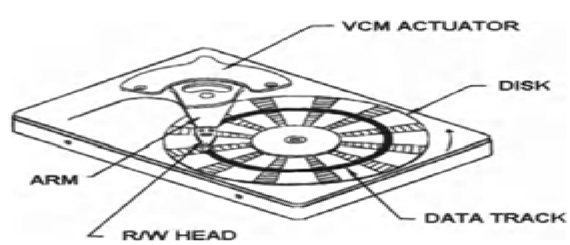


Fig. 1: Typical Hard Disk Drive Servo Mechanism

## 2 SYSTEM DESCRIPTION

### 2.1 Mathematical Model

Hard disk read/write head can be modelled using the differential equation

$$J\frac{d^2\theta}{dt^2} + C\frac{d\theta}{dt} + K\theta = 0 \quad (1)$$

where J is the inertia of the head assembly, C is the viscous damping coefficient of the bearings, K is the return spring constant, $K_i$ is the motor torque constant, θ is the angular position of the head, and i is the input current.

Taking Laplace transform, the transfer function from i to θ is

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$$G_p(s) = K_i/(Js^2 + Cs + K) \qquad (2)$$

Using the values J = 0.01 kg m2, C = 0.004 Nm/(rad/sec), K = 10 Nm/rad, and $K_i$ = 0.05 Nm/rad, the transfer function of the system becomes

$$G_p(s) = 0.05/(0.01s^2 + 0.004s + 10) \qquad (3)$$

On analyzing the system transfer function, it can be found that the open loop poles have very light damping and are located very near to the imaginary axis. For accurate positioning of the read/write head, a discrete time controller can be designed which necessitates the discretization of the continuous plant.
On discretization using a ZOH function, the plant transfer function is obtained as

$$G_p(z) = 6.2328 \times 10^{-5} \times (z + 0.9993)/(z^2 - 1.973z + 0.998) \qquad (4)$$

The root locus plot of the uncompensated system is shown in Figure 2.

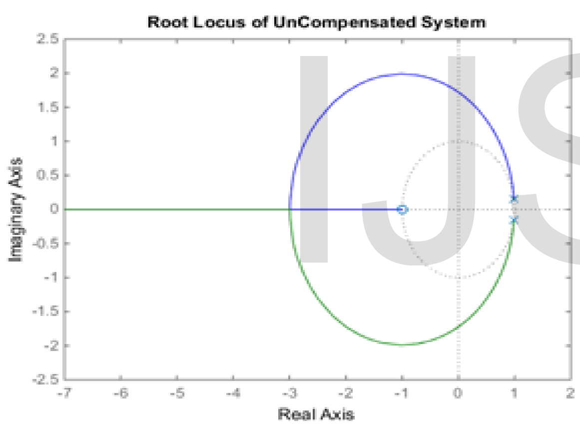


Fig. 2: Root Locus of Uncompensated System

From the root locus, it is evident that the poles leave the unit circle making the system unstable. The step response of the closed loop transfer function with ZOH is as shown in Figure 3.

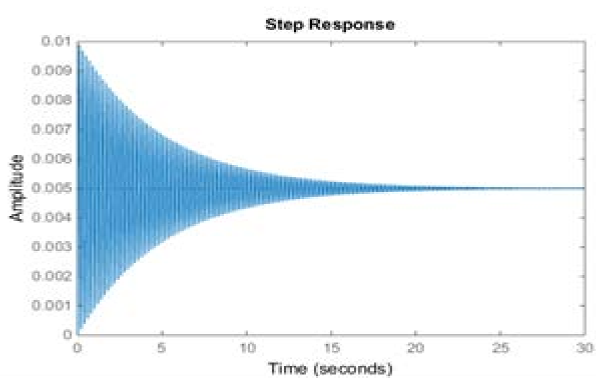


Fig. 3: Step Response of Uncompensated System

The system response is very oscillatory due to very light damping. The damping of the system is very light and found to be in the range of 6.23 x $10^{-03}$. The response also indicates that the settling time is slow, steady state error is too large. This necessitates the design of a compensator.

### 2.2 Design Solutions

The Hard Disk Drive System is expected to be fast and efficient to communicate with the high speed data processing ability of modern digital computers. There is a definite requirement for improved performance of the Hard Disk head-positioning servo system in order to accurately function to carry out Track Seeking and Track Following [5].Track seeking requires bounded control effort in minimum time while Track following maintains the head as close as possible to the destination track while information is being exchanged from and to the disk. A suitable compensator can be designed for this purpose by using digital control techniques to provide improved performance. The feasibility of a continuous time PID controller is investigated for the plant at first before designing a digital controller.

### 2.3 Design Specifications

The design specifications required for the compensator are as follows

a) Settling time less than 0.4 seconds
b) Overshoot less than 10%
c) Steady state error less than 1 %
d) The overall system must be stable.



## 3 CONTINUOUS TIME PID CONTROLLER DESIGN

To satisfy the specifications in settling time, peak overshoot as well as steady state error, a PID controller can be designed in continuous time domain for the system transfer function given by equation(1).

$$G_P(s) = K_p + K_i \times \frac{1}{s} + K_d \times s \qquad (5)$$

Initially a baseline tuning is done by choosing $K_p$, $K_i$ and $K_d$ values manually and further tuning of the controller is then carried out using pidtune object function in MATLAB to obtain improved performance. Table 1 indicates the gain values chosen for baseline tuning and the final gain values obtained after using pidtune object.

TABLE 1
CONTROLLER PARAMETERS FOR CONTINUOUS TIME PID CONTROLLER

| Controller Parameters | Tuned Values | Baseline |
|---|---|---|
| Kp | 13152.7756 | 350 |
| Ki | 81165.7416 | 300 |
| Kd | 63.0916 | 50 |

The step response of the closed loop system obtained as shown in Figure 4. The performance and robustness of the

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system with the continuous time domain PID controller is indicated in Table 2 for Baseline as well as Tuned Controller parameters

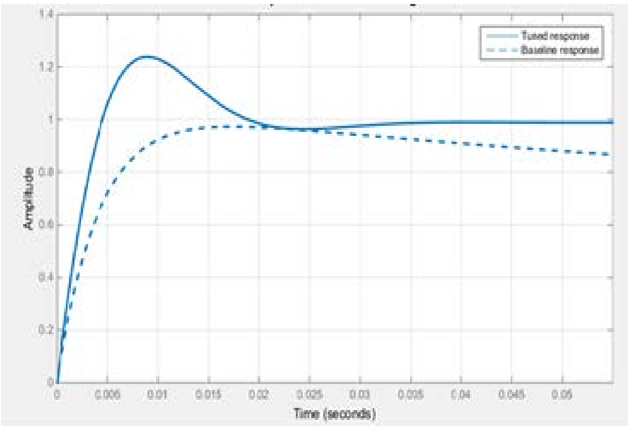


Fig. 4: Step Response of the closed loop system using PID Controller in Continuous time domain

TABLE 2
PERFORMANCE SPECIFICATIONS FOR CONTINUOUS TIME PID CONTROLLER

| Performance and Robustness | Tuned | Baseline |
| --- | --- | --- |
| Rise Time | 0.00346 seconds | 0.00856 seconds |
| Settling Time | 0.0317 seconds | 5.23 seconds |
| Overshoot | 23.9 % | 0 % |
| Peak | 1.24 | 0.998 |
| Gain Margin | Inf dB | Inf dB |
| Phase Margin | 60 deg | 88.5 deg |
| Closed Loop Stability | Stable | Stable |

The root locus plot for the PID compensated system with the tuned controller parameters is shown in Figure 5.

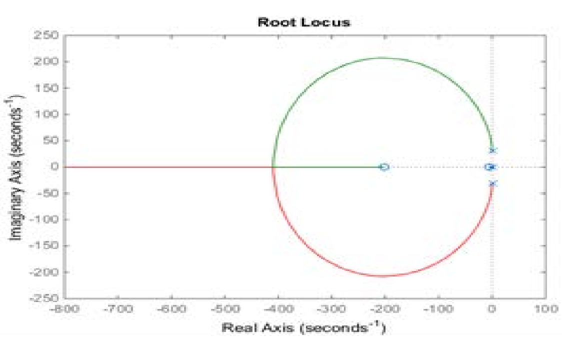


Fig 5: Root Locus for Continuous time PID compensated system

The closed loop system is found to be stable. As indicated by the step response, the system gives a faster response but this is obtained at a peak overshoot of 23.9% which is very high for a hard disk drive servo system application. To improve the high overshoot obtained in continuous design, controllers in discrete domain are designed.

## 4 DISCRETE PI CONTROLLER DESIGN

One of the design criteria is that the closed loop system should have less than 1% steady state error for unit step input. Hence a PI controller is designed which has the following transfer function in z-domain when forward Euler integration is used.

$$G_{PI}(z) = K_p + K_i \times T_s/(z-1) \quad (6)$$

where $K_p$, $K_i$ are proportional and integral gains respectively, $T_s$ is the sampling time. The sampling time for the plant is chosen as 0.005 seconds keeping in view of the plant dynamics.

The Matlab pidtune function for tuning PID controllers is used from command line to yield a discrete PI controller with the following parameter values

$K_p = 0.12268$, $K_i = 49.0703$

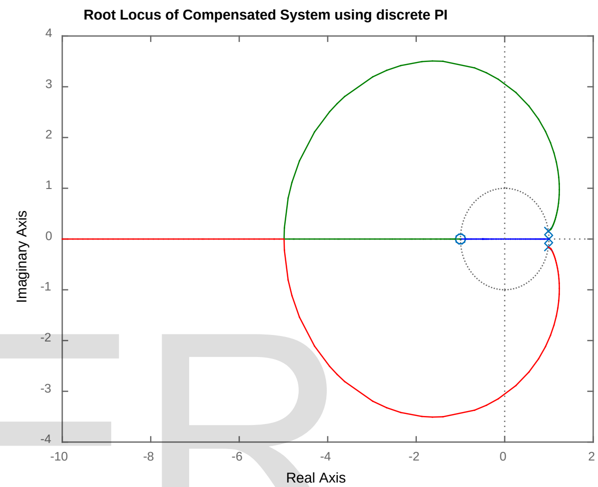


Fig 6: Root Locus of Compensated System using discrete PI

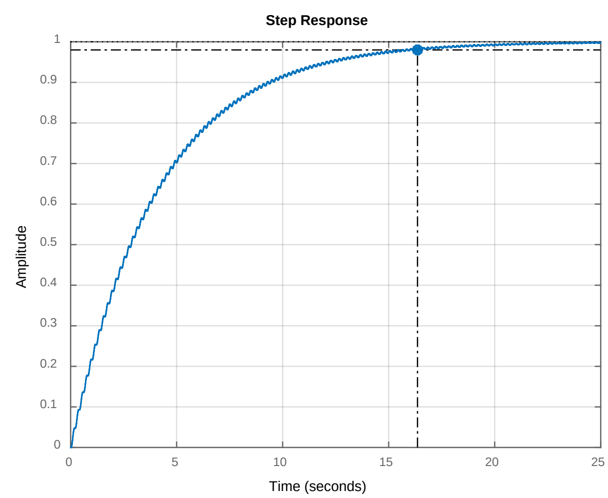


Fig 7: Step Response of Compensated System using discrete PI Control

From Figure 6, it is evident that the poles leave the unit circle and goes unstable. Even though overshoot is reduced at certain gain values, the performance criteria are not satisfied with this design.

The step response of the system with digital PI control is obtained as shown in Figure 7.

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The performance specifications achieved through discrete PI control are shown in Table 3.

TABLE 3
PERFORMANCE SPECIFICATIONS FOR DISCRETE TIME PI CONTROLLER

| Performance and Robustness | Tuned |
|---|---|
| Rise Time | 8.8 seconds |
| Settling Time | 16.4 seconds |
| Overshoot | 0 % |
| Peak | 0.999 |
| Gain Margin | 4.29 dB |
| Phase Margin | 90 deg |
| Closed Loop Stability | Stable |

Using Digital PI control, percentage overshoot and steady state error are reduced to zero. But the settling time is too long which is not acceptable for the hard disk read write process.

## 5 DISCRETE PID CONTROLLER DESIGN

PID Control is used for a wide range of applications in control problems in various industries. The controller minimizes the deviations from the selected reference values besides satisfying the specifications on overshoot, rise time, settling time etc. The main task involved is the tuning of the controller parameters so that the plant specifications are satisfied.

To obtain a digital PID controller, the continuous time model of the plant can be discretized by choosing appropriate sampling time. The sampling frequency should be fast enough compared to the dynamics of the system to capture the entire system behavior and hence Ts is chosen as 0.005 seconds. The transfer function of the discrete PID controller using Forward Euler integration can be written as in Equation (7)

$$G_{PID}(z) = K_p + K_i \times T_s/(z-1) + K_d \times (z-1)/T_s \quad (7)$$

where $K_p$, $K_i$ and $Kd$ are the proportional, integral and derivative gains respectively and $T_s$ is the sampling time. The sampling time for the plant is chosen as 0.005 seconds considering the plant dynamics.

$$G_p(z) = 0.41363 \times (z+0.9993) \times (z^2 - 1.845z + 0.8514)/((z-1) \times (z^2 - 1.973z + 0.998))$$

PID controller is used to tune the HDD system considering closed loop stability, design criteria and adequate robustness. The tuning algorithm yields a discrete controller with the following parameter values.
$K_p = 1025.7274$, $K_i = 7927.0348$, $K_d = 33.1813$

The transfer function of the modified system with the compensator is obtained as shown in Equation (8).

(8)

The root locus plot of the compensated system is shown in Figure. 8 which indicates that the closed loop system is stable.

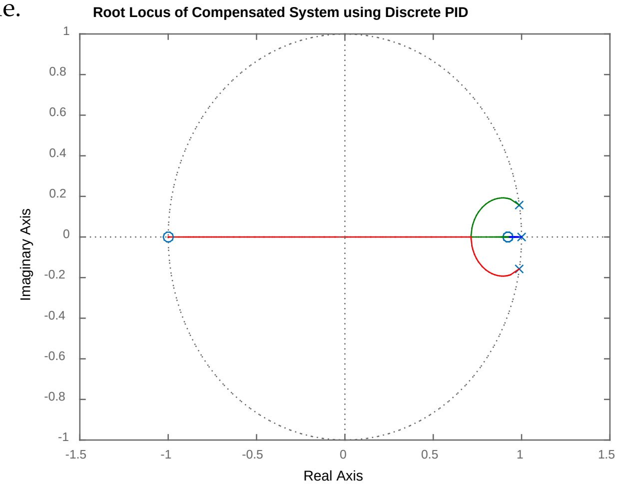


Fig 8: Root Locus of Compensated System using Discrete PID Control

The performance specifications achieved through discrete PID control are given in Table 4

TABLE 4
PERFORMANCE SPECIFICATIONS FOR DISCRETE TIME PID CONTROLLER

| Performance and Robustness | Tuned |
|---|---|
| Rise Time | 0.005 seconds |
| Settling Time | 0.365 seconds |
| Overshoot | 5.96 % |
| Peak | 1.06 |
| Gain Margin | Inf dB |
| Phase Margin | 78.8 deg |
| Closed Loop Stability | Stable |

With the PID control added to the system, the step response with unity feedback is obtained as shown in figure 9.

Overshoot of the system is reduced to 5.96 % which is better compared to the overshoot of 23.9 % obtained with the continuous time PID controller.

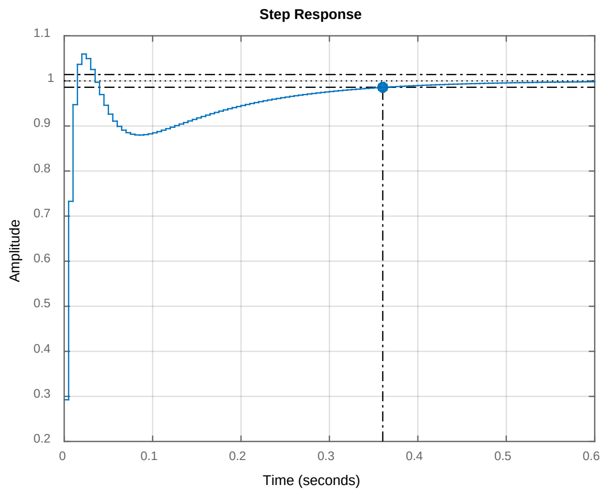


Fig 9: Step Response of Compensated System using discrete PID Control

All the design specifications are satisfied with the discrete PID controller. The settling time is found to be 365 milliseconds, and the result is satisfactory keeping in view of the very light damping of the original system.

## 6 CONCLUSION

This paper presents the results obtained on implementation of continuous time PID as well as discrete time PI and PID control schemes for the head positioning servo mechanism of a hard disk drive. Tuning of the controller gains are done to obtain the best possible transient and steady state performances. The overshoot obtained with discrete time PID control is much less than that obtained with continuous PID control scheme. Furthermore, the settling time obtained is much lesser compared to discrete PI control scheme. It is verified that the performance of the discrete PID controller remains within acceptable specifications. Simulation has been carried out using standard functions provided by MATLAB and the results are validated by comparing with the desired specifications.

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