Chapter 14
H2 Guaranteed Cost Control in Track-Following Servos

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Abstract. This chapter presents two new control synthesis approaches for dual-stage track-following servo systems. Both approaches are based on $H_2$ guaranteed cost analysis, in which an upper bound on the worst-case $H_2$ performance of a discrete-time system with gain-bounded unstructured causal LTI uncertainty is determined by solving either a semi-definite program (SDP) or several Riccati equations. We review the results of a paper on $H_2$ guaranteed cost analysis and a paper on optimal full information $H_2$ guaranteed cost control and then use these results to develop two output feedback control synthesis approaches. The first approach is based entirely on the solution of SDPs whereas the second approach exploits Riccati equation structure to reduce the number and complexity of the SDPs that need to be solved. Throughout the paper, we apply the analysis and control techniques to a hard disk drive model with a PZT-actuated suspension and demonstrate that the approaches that exploit Riccati equation structure are faster and at least as accurate as their SDP counterparts.

14.1 Introduction

For several decades now, the areal storage density of hard disk drives (HDDs) has been doubling roughly every 18 months, in accordance with Kryder’s law. As the storage density is pushed higher, the concentric tracks on the disk which contain data must be pushed closer together, which requires much more accurate control of the read/write head. Currently available hard drives can store 2 TB of data on a 3.5” drive with three platters. This corresponds to an areal data density of 600 gigabit/in$^2$. The current goal of the magnetic recording industry is to achieve an areal storage density of 4 terabit/in$^2$. It is expected that the track width required to achieve this...
data density is 25 nm. To achieve this specification for track-following control, in which the read/write head is maintained as close to the center of a given data track as possible, the $3\sigma$ value of the closed-loop position error signal (PES) should be less than 2.5 nm.

To help achieve this goal, the use of a secondary actuator has been proposed to give increased precision in read/write head positioning. There are three classes of secondary actuators: actuated suspensions (6), actuated sliders (7), and actuated heads (17). Each of these proposed secondary actuator classes corresponds to a different actuator location in Fig. 14.1. In the actuated head configuration, a microactuator (MA) actuates the read/write head with respect to the slider mounted at the tip of the suspension. In the actuated slider configuration, an MA directly actuates the head/slider assembly with respect to the suspension. For both of these configurations, it is difficult to design an MA which can be easily incorporated into the manufacture and assembly of a HDD on a large scale. In the actuated suspension configuration, the MA actuates the suspension with respect to the E-block. This secondary actuator scheme is the least difficult to design and has been incorporated into some consumer products. We will use this secondary actuation scheme in this paper.

Since there tend to be large variations in HDD dynamics due to variations in manufacture and assembly, it is not enough to achieve the desired level of performance for a single plant; the controller must guarantee the desired level of performance for a large set of HDDs. Thus, we are interested in finding a controller which gives robust performance over a set of HDDs. One framework for solving this problem is guaranteed cost control. This methodology is a control design methodology whose objectives involve worst-case quadratic time domain costs over a modeled set of parametric uncertainty. Both the state feedback synthesis problem and the output feedback synthesis problem can be solved for discrete-time systems by using semi-definite programs (SDPs)—convex optimization involving linear matrix inequalities (LMIs)—as is done in (14) and (18), respectively.

As mentioned earlier, the relevant performance metric in a HDD is the standard deviation of the PES. Since the squared $\mathcal{H}_2$ norm of a system can be interpreted as