Case Study on Anti-windup Compensation - Micro-actuator Control in a Hard-Disk Drive

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Summary. This chapter demonstrates the use of anti-windup compensation in the control loop of a micro-actuator which is nominally controlled by a linear, discrete robust controller. The micro-actuator is part of a hard disk drive dual-stage servo-control system for positioning of the read/write head. The actuator inputs are constrained to retain the micro-actuator’s displacement range of less than 0.4 \( \mu m \) for mechanical protection.

In the first part of the chapter, the anti-windup compensation scheme exemplifies an approach suggested by Weston & Postlethwaite [29]. Here, the scheme is posed as a discrete full-order compensator and the closed loop analysis uses a generalized circle criterion approach. The design of the compensator is posed in LMI-form.

In the second part of the chapter, it is shown how the linear micro-actuator control loop with anti-windup compensation is incorporated into the non-linear servo-control scheme for positioning of the read/write head in a hard disk drive.

14.1 Introduction

Micro-actuators have been gaining in importance in practical systems during recent years. For instance, it is nowadays a target to integrate the actuator, sensor and associated electronics for powerful computations into one device of micro or nano-scale. These technologies can be useful in optical communication systems, in electromechanical signal processing systems or in healthcare systems, such as BIO-MEMS for microchip-lab diagnostics or micro-devices for therapeutic targeting and delivery. Mechanical micro-actuators for nano-positioning are of interest to the University of Leicester because of their importance in the servo-controller used in the positioning of the read-write head in hard disk data-storage systems [5, 8, 11]. The micro-actuator is being used in a dual-stage control system to achieve high-bandwidth positioning control.

Significant research effort on hard-disk drive (HDD)-servo techniques has been invested in the area of dual-stage servo control [14, 17, 18]. The reason for this is the continuous increase in the track density and in storage capacity of HDDs. Recently, a track density of more than 420 kTPI (TPI-track per inch) has been demonstrated (see [2, 23]) in a laboratory environment.
and 149 kTPI density HDDs are nowadays available in the consumer market. In addition to the significant increase in data density, the increased demand for higher data rates requires the improved performance of the head-positioning servo system. A promising way to meet these demands is to augment the conventional voice coil motor (VCM) actuator with a second-stage, high bandwidth micro-actuator. Dual-stage servo systems in HDDs are now a feasible alternative to the single stage VCM-servo system. PZT-based micro-actuators using PZT-elements embedded in the head suspension are popular, e.g., the ‘FUMA’-actuator in [19] (Figure 14.1).

However, the displacement range of secondary actuators is very limited, typically less than 1-2 µm, and the input signal for the actuator is limited to prevent damage. In dual-stage servo-systems, the two actuators have to deal with the following servo-tasks: seek/settling and track following. Seek/settling control has to ensure a fast movement of the read/write head from one track to another. For track following, high bandwidth controllers are necessary to ensure good error rejection capabilities to counteract disturbances. Therefore, the primary VCM-actuator is required for large displacements and the secondary actuator provides large bandwidth.

For servo-control of such a dual-stage actuator system, the method of [11, 12] is employed. It is based on the well known decoupled dual-stage controller structure of [13], where design and stability for the primary VCM-control loop and the secondary PZT-control loop are guaranteed independently. It will be shown [11, 12] that the primary and secondary loop remain stable independently regardless of the seek/settling/track-following control method used for the VCM-loop, providing the secondary control loop is stable in the presence of saturation limits. Hence, it seems logical to use in the secondary loop an AW compensator to guarantee overall large and small signal stability despite actuator saturation limits. AW compensators are most suitable, as they have been developed to retain the nominal performance of the original control system [7,9,20], e.g., high-bandwidth tracking in the servo-control of hard disk drives.

This case study on AW-compensation will consider the following issues:

1. Controller design for the micro-actuator loop and wind-up problems due to actuator limits.