An Overview of the PES Pareto Method for Decomposing Baseline Noise Sources in Hard Disk Position Error Signals

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Abstract– This paper describes the PES Pareto Method, a useful tool for identifying and eliminating key contributors to uncertainty in the Position Error Signal (PES) of a magnetic disk drive[1, 2, 3]. Once identified and ranked according to their overall effect on PES, the top–ranking sources can be worked on first, either by finding ways to reduce their magnitude or by altering system components to reduce sensitivitity to the the noise contributors.

The PES Pareto Method is based on three ideas: (1) an understanding of how Bode's Integral Theorem[4] applies to servo system noise measurements, (2) a measurement methodology that allows for the isolation of individual noise sources, and (3) a system model that allows these sources to be recombined to simulate the drive's Position Error Signal. The method requires the measurement of frequency response functions and output power spectra for each servo system element. Each input noise spectrum can then be inferred and applied to the closed loop model to determine its effect on PES uncertainty.

The PES Pareto Method is illustrated by decomposing PES signals that were obtained from a hard disk drive manufactured by Hewlett-Packard Company. In this disk drive, it is discovered that the two most significant contributors to PES baseline noise are the turbulent wind flow generated by the spinning disks ("Windage") and the noise involved in the actual readback of PES ("Position Sensing Noise").

1. Introduction

A hard disk drive's Position Error Signal (PES) can be decomposed in the frequency domain into three categories[1]:

Synchronous or Repeatable Excitations are due to the rotation of the spindle and therefore synchronous with it or one of the spindle orders. While synchronous excitations may be large, standard practice in the disk drive industry includes using feedforward cancellers to reduce the effects of synchronous excitations.

Non-synchronous or Non-repeatable Excitations include sharp spectral peaks due to spindle bearing cage orders and structural resonances (which are less sharp but still narrow band). Recent work suggests that disturbances due to resonances or cage orders can be considerably reduced by the use of damped disk substrates and fluid bearing spindles.

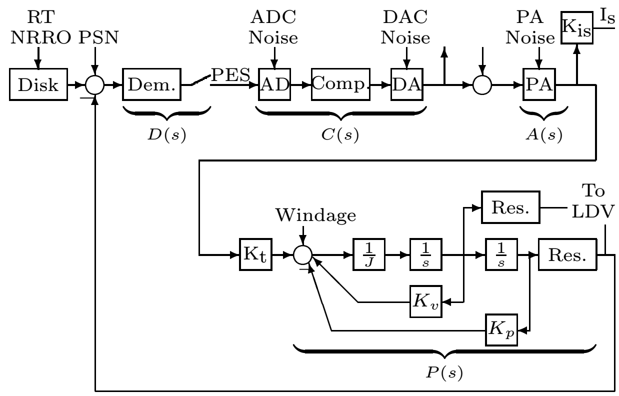

Figure 1: Generalized view of track following model.

Broadband or Baseline Noise is what remains when all of the narrow band components have been removed. Of the three categories, it is the hardest to dissect and therefore the hardest one for which to find solutions.

In order to achieve very high track densities, all sources of PES uncertainty must be reduced considerably. For the first two categories, it appeared that reasonable engineering solutions would be available. This was not true for the baseline noise; therefore, of the three categories, it was the one singled out for the work described in this paper.

2. Measurement Overview

A practical analysis of the contributors to PES begins by asking the question, *What can be measured?* While this may seem whimsical at first, it should be noted that in any real system, we will not have access to all the measurement points that we might desire. Furthermore, although many different analysis tools might theoretically be available, they are useless to us if they cannot make use of available laboratory measurements.

In order to guide our measurements and modeling, it is necessary to have a map of the system. The block diagram in Figure 1 will serve as the map for our tour of noises in the system. Starting at the left of this diagram, the reference position that the actuator arm must follow is the position of the magnetic track written on a disk, rotating on a spindle. Position Error—the difference between the reference track position and the readback head position—is sensed by the readback head, and this error signal is sent to the demodulator. The demodulator out-

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puts a set of numbers at the system sample rate, and these are combined electronically to form PES. PES is then converted to a digital format via an analog to digital converter (ADC), filtered by the compensator and then sent back out to the power amplifier via a digital to analog converter (DAC). The power amp converts the desired voltage into a current to drive the voice coil actuator (with torque constant K_t). The actuator itself has rigid body behavior as well as resonances. Through the actuator, the head position is set. Position Error is then sensed by the head. Absolute head position can be obtained in the laboratory by shining a laser spot from a laser Doppler vibrometer (LDV) off of the side of the head. Velocities measured with the LDV can be accurately integrated in time (for our frequency range of interest) to obtain position as a function of time.

Figure 1 also includes the available measurement points. These measurement points are (1) PES, the servo demodulator output; (2) X_{in}, a loop stimulus point; (3) X_{out}, the command current into the actuator power amplifier; (4) I_{sense}, a measurement of actuator coil current; and (5) LDV velocity, measuring the head's radial movement.

2.1 Noise Sources: There are several likely noise input points on a disk drive. First, there are the noises associated with the moving disk and the readback process. These all enter the loop at the same point, but have different root causes. The noise due to the motion of the disk attached to a ball bearing spindle creates both Repeatable Run Out (RRO) (at orders of the spindle rotational frequency) and Non-Repeatable Run Out (NRRO). An interesting property of servowritten disks is that one pass of the NRRO is locked into the servo position information when it is written. Thus, this written–in NRRO is repeated at every revolution of the disk. The other noise source that enters at this point is the noise from the readback process of position information, called Position Sensing Noise (PSN). This noise can be due to the magnetic domains on the disk, the behavior of the magnetic readback head, the interaction of these two, or the action of the demodulator. (We lump demodulator noise into PSN for our current analysis.) Further downstream in the loop, there are quantization noise sources at the ADC and DAC, noise at the power amp, and finally Windage. Windage is generated by the spinning disk, causing air to flow across surfaces of the disk, actuator arms, and readback head. This air flow generates forces which result in fluctuations in the relative position between the head and disk.

Given all these potential noise sources, there is a fundamental need to identify which of these—if any—are the most significant contributors to PES. With this information, the effort to reduce the noise in PES can be concentrated on the critical few.

2.2 Instrumentation and Data Processing: In addition to the device under test (3.5–inch disk drive) and associated control software and systems, the primary measurement toolset included a laser Doppler vibrometer (LDV, from Polytec), a 5-channel digital signal analyzer (HP 3567A), a digital storage oscilloscope (HP 54720D), and Matlab software running on a workstation.

Given these tools, there are three types of measurements on which we could base our analysis: power spectra, linear spectra, and time domain measurements. The specific tradeoffs involved in choosing one of these are discussed in [1]. For reasons mentioned there, power spectra (or PSDs, displayed in power spectral density units) appear to be the most promising measurements. All frequency response function (FRF) and power spectral density (PSD) data must be taken over the the same bandwidth and with the same resolution. What remains to be seen is how all of these noise sources affect PES. The fundamental concept that ties them together comes from what is known as Bode's Integral Theorem[4]. This paper gives a thumbnail sketch of Bode's Integral Theorem and discusses what its implications for measurements of control loops.

3. Applying the Steps of the PES Pareto Method

The PES Pareto Method involves four distinct steps:

- isolate measurement of each noise source ("common mode reject"),
- filter backwards to obtain the PSD of each noise source,
- filter forwards to obtain the effect of each noise source on the PES PSD, and
- compare these PES PSDs to each other and add them to produce the cumulative PES PSD.

In the example presented in the paper, it was determined that two noise sources dominated all others: Position Sensing Noise and Windage. The paper describes how the above steps were completed, and how we were able to confirm the estimates of each noise source's contribution.

References

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