# Track Linearity Measurements of DDS Helical-Scan Data Recorders

Carl Taussig
Hewlett Packard Laboratories, Palo Alto CA 94304

## I. INTRODUCTION

In a helical scan tape recorder the magnetic heads rotate on a spinning drum. The heads transduce electrical signals into regions of opposing magnetic polarization on layer of magnetic particles deposited on a plastic tape substrate . The tape is wrapped helically about the drum at a low angle and advances slowly in the direction which the drum is spinning, resulting in a sequence of parallel tracks of magnetic transitions. The straightness of these tracks and their deviation from a specified angle are critical manufacturing parameters. The readback process, like the write process, is essentially open-loop so it is necessary that the transducer pass directly over the recorded track for proper data reconstruction. Not only must tapes be read by mechanisms which wrote them but also by other mechanisms and even those made by other manufacturers. To insure successful tape interchange the manufacturers of 4mm helical scan data recorders have established a standard, DDS [1], to which all manufacturers must adhere. The straightness and angular acuity are combined in a single track linearity specification which requires that the leading edge of each recorded track fit within a rectangular box 5μ wide by 23.521 mm long inclined at 6°22′39.6″ to the edge of the tape (Fig. 1). Historically compliance with this specification was

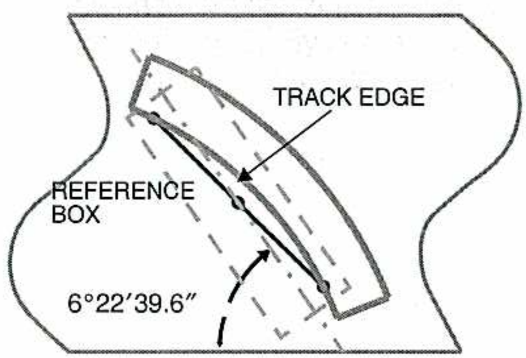


Figure 1: DDS linearity specification

determined by decorating a recorded track with a ferrofluid† then manually identifying points along the track edge and tape edge using a microscope and a coordinate measuring machine. Not only is this process time consuming and subject to operator error, but it is also too cumbersome to implement as a real-time process control on the manufacturing line. This paper describes the process developed at Hewlett Packard (HP). to measure and adjust track linearity in real-time on the manufacturing line.

## II. Magnetic Measurements

During playback the relative displacement of the centerline of the head normal to the centerline of a recorded track can be measured electronically using a specially recorded tape. Tracking error signals (TES) provide position information from AM detection of low frequency tones recorded on the home track and its two adjacent neighbors so that on playback the tones are demodulated in a nonoverlapping sequence. Cross track position is provided by the amplitude difference of the tones from the adjacent tracks normalized to the home track amplitude (Fig. 2). By repeating this pattern

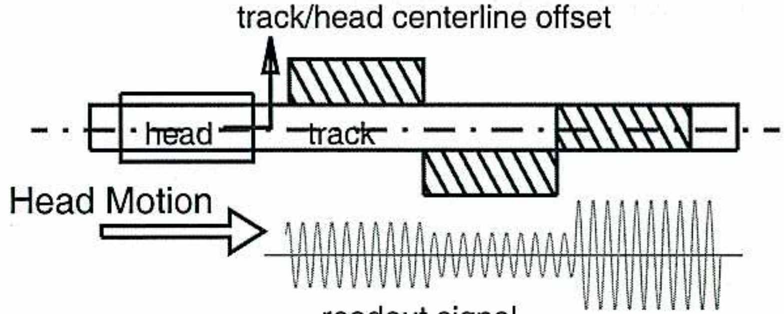

Figure 2: Magnetic tracking error signals

of tones position can be measured at 25 discrete locations along the track. If the shape of the recorded tracks is known and the TES are calibrated [2] then the relative amplitude measurement can be used to predict the absolute linearity which the mechanism will produce when recording.

---

†. a colloidal suspension of superparamagnetic particles which align with local magnetic field lines making magnetic transitions visible

HP has devised the Linearatron to perform these measurements and provide a video display of the linearity defect in real-time. This display is used by assembly line workers to adjust critical guides in real-time and then to verify the linearity of the adjusted mechanism. The key to the success of this measurement is that the track shape is dominated by guide alignment which is stable. Short time shape fluctuations due to tape edge damage, drum runout, or measurement errors are averaged out. The resolution of the Linearatron has been measured to be better than 50 nm using a special tape drive equipped with a drum mounted on an air slide whose position is controlled with a laser interferometer described in [2]. The accuracy of the measurements depends critically on how well the shape of the recorded tracks on the master tape is known.

## III. Optical Calibration

The absolute track shape of the master tapes is measured optically. A tape identical to those used in the magnetic measurements but with a different pattern of magnetic transitions is recorded on the master mechanism. The optical master tape is initially bulk DC erased, then a constant frequency tone at 25425 flux-transitions-per-inch is recorded on every other track. This tape is then processed with ferrofluid resulting in a high optical contrast boundary between the written and blank tracks. Samples of tape from various locations along its length are mounted on an air chuck. On each sample The coordinates of many points along the tape edge are measured as are points on the edge of a series of tracks. The data are processed and put in a file which the Linearatron uses to convert its relative measurements into absolute track shape.

In order to eliminate human error, increase the resolution of the measurements, and to increase the rate at which data can be collected, the optical measurement process has been completely automated. The coordinate measurement machine is a Moore model 3 whose X and Y axes have been fit with DC servo motors. Position is measured with an HP laser interferometer and the loop is closed with a digital servo controller and linear power amplifiers. The tape is imaged through a microscope objective to a standard NTSC video camera then displayed on a monitor, digitized and uploaded to the host computer in 8 bit gray scale. The tape edge and track edge are measured using the same algorithm. Starting at a reference location a group of pixels ($P_{ref}$) including the edge is stored in memory the stage then moves to a location further along the edge and acquires a second group of $N \times M$ pixels ($P_{local}$). The two regions are correlated in one direction producing the $C(k,j)$ then the indices of the maximum values of these one dimensional correlations are averaged resulting in the predicted pixel shift of the edge from the current to the reference location. This algorithm is

$$C(k,j) = \sum_{i=1}^{N} P_{local}(i,j)\, P_{ref}(k+i,j) \qquad \frac{-N}{2} \le k < \frac{N}{2}$$

$$\text{Pixel Shift} = \frac{1}{M}\sum_{j=1}^{M} k_{max}(j) \qquad k_{max}(j) \equiv \underset{k}{\mathrm{arg}max}\; c(k,j)$$

well suited to the application for three reasons. Averaging of the integer indices results in sub-pixel resolution. Comparison of different locations along the edge exploits the self-similar nature of the edge. Thirdly, a correlation based algorithm rejects edge noise because of its integral (smoothing) action whereas many edge detection schemes increase noise by taking derivatives or thresholding.

In order to calibrate the vision system a chrome-on-glass standard was manufactured using e-beam lithography. The standard is accurate to 100 nm and is traceable to the NBS. Fig. 3 shows optical measurements of the deviation of a sequence of chrome stripes from perfect straight lines inclined at 6°22′39.6″ relative to the reference edge.

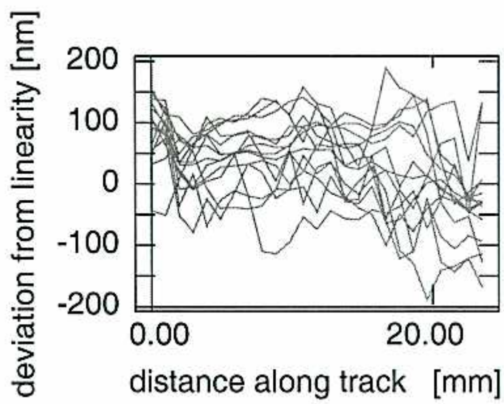


Figure 3: Optical calibration verification

## IV. References

[1] European Computer Manufactures Association, ***DDS** Format Standard*, ECMA-139 Standard ed., 1990

[2] C. Taussig and R. Elder, "Calibration of DDS servo tracking error signals," *IEEE Transactions on Magnetics*, vol. 29, pp.4053-4055, Nov1993