Measurements of Recorder Head Profiles and Changes in the Profile with Tape Speed

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Introduction

When tape is run over a magnetic recording head it wears down the head to produce a particular profile or shape. The profile depends on the thickness and elastic properties of the tape, the tape tension, the angle through which the tape wraps around the head, and the length of the arc over which there is contact. At high speed it is also possible that the profile is influenced by the formation of the air flow as it becomes trapped between the head and the tape to form an air bearing. This study was undertaken to determine the significance of any changes in profile which might occur at high tape speeds.

Motivation

The longevity and performance of magnetic recording head arrays is of prime importance to Very-Long-Baseline Interferometry (VLBI) because magnetic tape acts as a "data path super-highway" from the telescopes to the correlator where the images are produced. Average recording rates at the telescopes are 100 Mb/s and tapes for an average of 10 telescopes, containing a total of about 10 Terabytes, are shipped each day to the correlator.

The current headstacks last for about 5,000 hours and cost $8,000 each. With approximately 50 transports used worldwide for VLBI, the annual cost of replacing heads is about $400,000. The life of a head depends on a compromise between performance and wear rate. In general, good head-to-tape contact is only maintained at the expense of moderate to high wear rates. An understanding of the wear process and how it depends on tape speed and the head profile may lead to improved designs and significantly lower operating costs for VLBI.

Importance of good head-to-tape contact

If the tape separates from the gap of the playback head, the short wavelength signals are severely reduced. This is known as "spacing loss" and is 55 dB per wavelength of separation. For example, a head-to-tape separation of only 0.1 microns results in a loss of 6 dB for the 0.9 micron wavelengths of the MkIV VLBI data format. The extreme importance of close contact is the reason modern magnetic tapes are made with extremely smooth surface.

At low speeds, the effects of air flow and dynamics can be ignored so that the head profile is determined by simple statics. A stable equilibrium profile is reached when sufficient wear has taken place to equalize the pressure across the entire region of contact. If there remains a region of higher pressure, the wear rate will increase in this area until the "high spot" is worn down. In equilibrium the profile has a uniform radius of curvature and there is an especially simple expression for the radius of curvature *R* of the profile as follows:

$$R = (p + L) / \theta$$

where θ	=	the half wrap angle (radians)
L	=	half length of contact
p	=	"characteristic bending length" of tape

The characteristic bending length is given by

$$p = (Yt^3W/(12T))^{1/2}$$

where Y	=	Young's modulus for the tape
t	=	tape thickness
W	=	tape width
T	=	tape tension

For example, for the current operation parameters of MkIV

Y	=	4.8 GPa
t	=	16 μm
W	=	2540 μm
T	=	2 N
L	=	150 μm
θ	=	5 deg.
p	=	144 μm
R	=	3370 μm

High tape speeds

As the tape speed is increased the air flow at the entrance of the head exerts sufficient pressure to open a crack at the leading edge of the contact area. At sufficient speed this crack initiates a thin film. If the bearing number of the film is sufficient to support that tape load a film will be sustained across the entire length of the contact area. If this happens the tape is "flying" across the head and the spacing loss increases. With flying there would be no wear at all except that on a microscopic scale.

The tape is not perfectly smooth and contains abrasive particles needed to maintain a clean surface on the head. Unless the flying height is greater than the abrasive particle protrusion height the particles will still contact and abrade the head.

Wear at high speed

Under flying conditions the film thickness is greatest at the entrance and smallest at the exit. Thus one might expect the abrasion by the particles to be greatest at the exit, or trailing edge, as illustrated in figure 1. If this model is correct one might expect the profile to sharpen and the radius of curvature to decrease at high tape speed. If this happens it will further promote flying so that performance may degrade with sustained high speed operation.

Profile Acquisition

A fundamental part of this study is a head profile acquisition and analysis methodology which allows for accurate and quick head profiles to be measured and compared. This requirement is met using a Dektak stylus profilometer with a personal computer interface. The head stack is mounted on the Dual Block Assembly. The assembly is then mounted on a specially machined fixture which removes the five degree tilt inherent to the headstack. The fixture is then placed on the movable stage of the profilometer. The profilometer drags a 12.7 micron radius stylus across the surface of the head by moving the stage forward toward the operator. The up and down motion of stylus as it follows the surface generates a varying voltage. This signal is amplified, converted to a digital format for the computer, and placed in a file. The profile is then displayed and manipulated in a software package called S.A.M. (Surface Analysis Manager). With S.A.M. the contour can be leveled and any portion of interest can be enlarged. The location of the zero line can be chosen. Once conditioned the file is converted to a text format. Several profiles can be superimposed on one another to see any differences by converting the file to an Auto CAD polyline format using a short program. Then Auto CAD can be used to display the profiles. Alternatively, a short program written in BASIC removes all the data below zero and formats the file to be used by MinSQ. The MinSQ software uses the method of least squares to fit a quadratic polynomial equation to the data. This polynomial contains two constants to account for any translation and rotation of the contour. A third constant gives the radius of the profile in microns.

System Accuracy

To insure the accuracy of the profilometer a make-shift standard was constructed and the height of the step was measured using a micrometer and optical microscope. The profilometer was then calibrated to agree with these other instruments.

A test was conducted to check the repeatability of the methodology. The head profile radius was measured in the same location six times. The readings came to be +/- 3.2 % from the nominal value. Another test was performed to see if the location of the zero line might affect the measurements adversely. A profile was chosen at random and the zero line was varied grossly. The radii varied only +/- 0.6 %.

Despite the constant in the polynomial that accounts for any rotation of the contour a test was conducted in order to ascertain the affect of leveling on the radius. Again a profile was chosen at random and was leveled improperly five different times. The radii only varied +/- 0.8%.

Due to these tests a reasonable amount of confidence was gained in the accuracy of the profilometer and software.

Tape speed effects

The first test performed was to determine the effect of tape speed on profile radius at constant vacuum pressure. A spare recording head was worn using a Sony tape of 16 micron thickness at 7.5 inches of water and a tape speed of 320 ips until a stable profile was reached. The speed of the tape was changed to 80 ips keeping the vacuum constant and the head was allowed to wear for two days. The head assembly was removed and three profile traces were taken in different locations along the head to assure a more accurate knowledge of the 'true' radius. The head assembly was mounted back on the recorder. The tape speed was switched back to the high speed (320 ips) and the head was allowed to wear for another two days. This process was repeated seven times. Figure 2 shows head radius in microns versus tape speed on the right in ips. Initially it looks as if the radius does increase when the speed is reduced. However this trend does not continue and a question arises as to the reliability of this experiment. Several parameters which varied unintentionally were vacuum pressure and humidity, both of which contribute to errors. Also, the large time scale involved in the test is more conducive to errors.

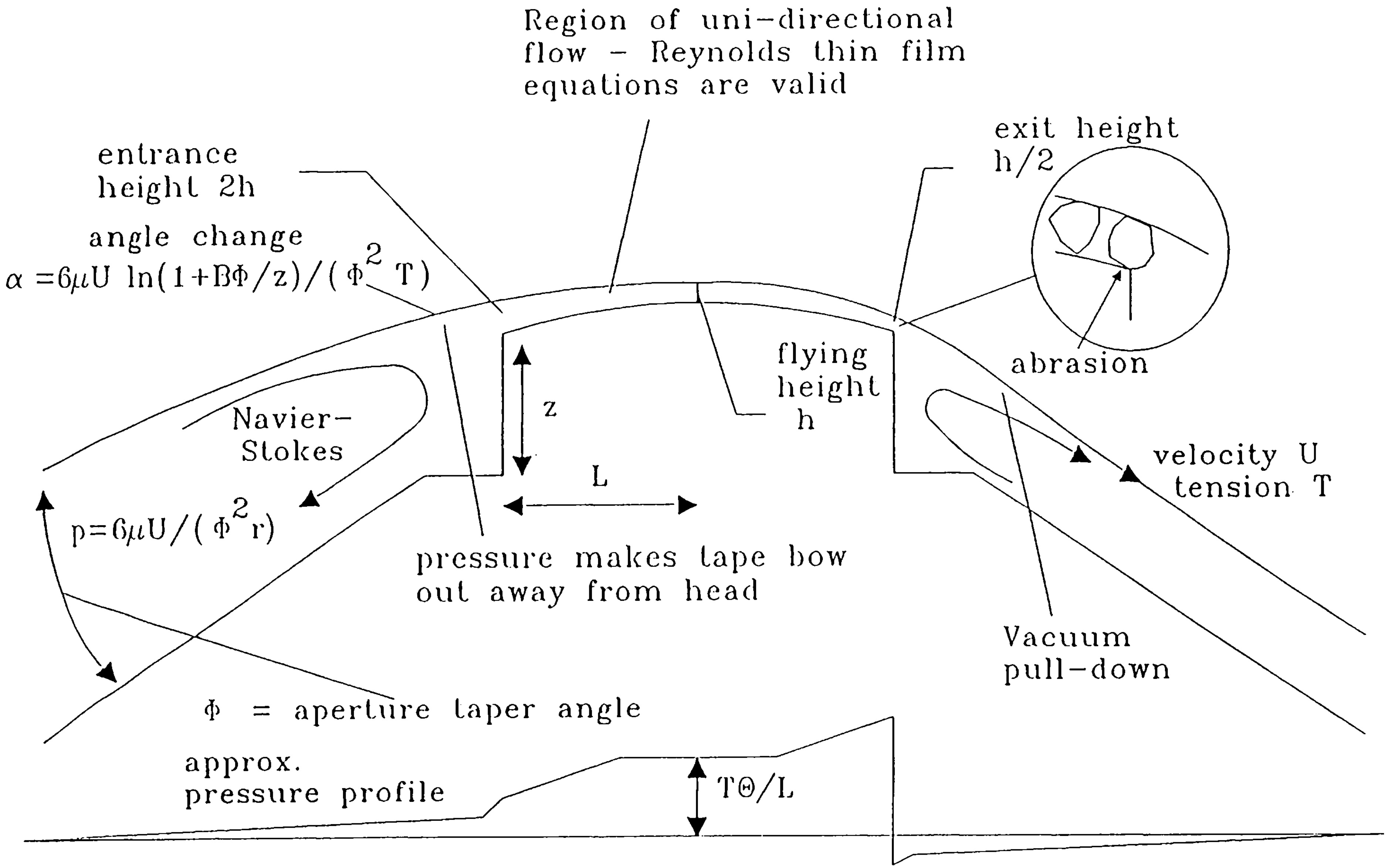
The question arises as to whether the head wears at all at high speed to vacuum ratios. The vacuum was changed to 4 " of water and contoured at high speed overnight using an abrasive lapping tape designed for increased wear rate. Since the radius did in fact change the vacuum was brought back up to its original value of 7.5" and the head was worn again taking a measurement every half hour. Figure 3 shows head radius versus wear time and definitively proves that at this speed to vacuum ratio the head experiences wear.

The alternating tape speed test was performed again with the same abrasive lapping tape to increase the wear rate and reduce the overall time required and reducing the change in any other unknown parameter which might influence the results. The procedure for taking measurements was altered. Since the interest is in the change in radius rather that the actual value, the three measurements were taken in the same location each time the head was worn. To reduce errors further, more wear cycles would be performed. Figure 4 shows head radius versus tape speed all performed at 7.5" of water. As can be seen from the figure the time scale is in hours rather than days. Although no significant pattern between high speed and low can be discerned there is a downward trend in the data. To statistically interpret the data a straight line was fit to the high data points and one to the low data points. These slopes were each taken out of the two data sets respectively. The mean and a the standard deviation was found for each data set. The difference between the mean radii is 118 +/- 308 microns. This error is 6% of the mean radius.

Conclusions

These results state that either the sought after effect of radius varying with speed does not occur or the magnitude of the change is less than 6%. This suggests that the cause of the playback degradation might not be due to radius changes but may be due to some other effects. For example, very small changes in profile having little effect on the average radius of curvature might occur only at the very edges of the headstep. Future work involves looking more closely at the edges.

The profilometer with computer interface provides reasonably accurate and quick measurements of head profiles at the sub-micron level.



Air flow in regions around the head-to-tape interface

Figure 1

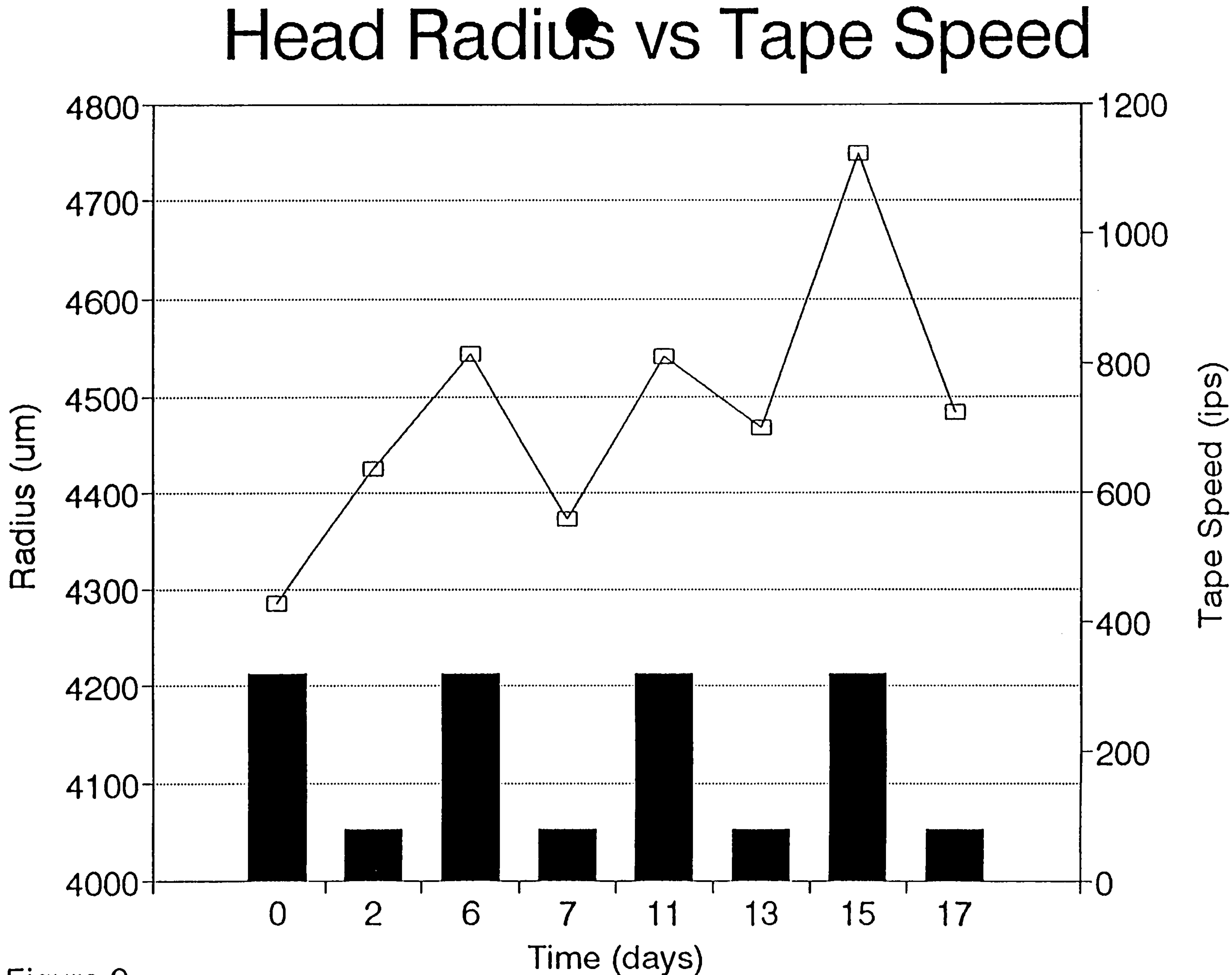

Head Radius vs Tape Speed
4800
4700
4600
4500
4400
4300
4200
4100
4000
Radius (um)
1200
1000
800
600
400
200
0
Tape Speed (ips)
0
2
6
7
11
13
15
17
Time (days)

Figure 2

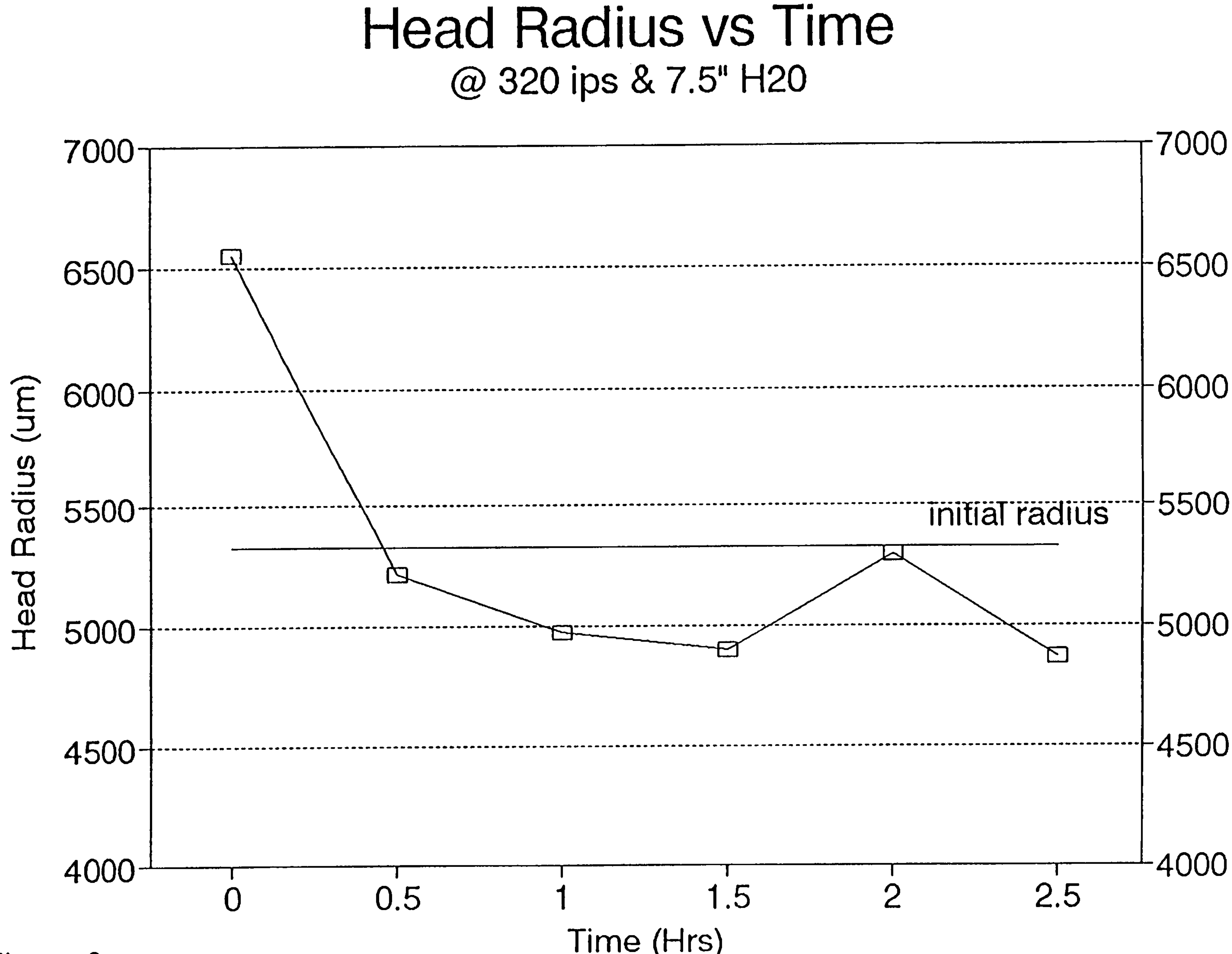

Head Radius vs Time
@ 320 ips & 7.5" H20
Head Radius (um)
7000
6500
6000
5500
5000
4500
4000
initial radius
0
0.5
1
1.5
2
2.5
Time (Hrs)

Figure 3

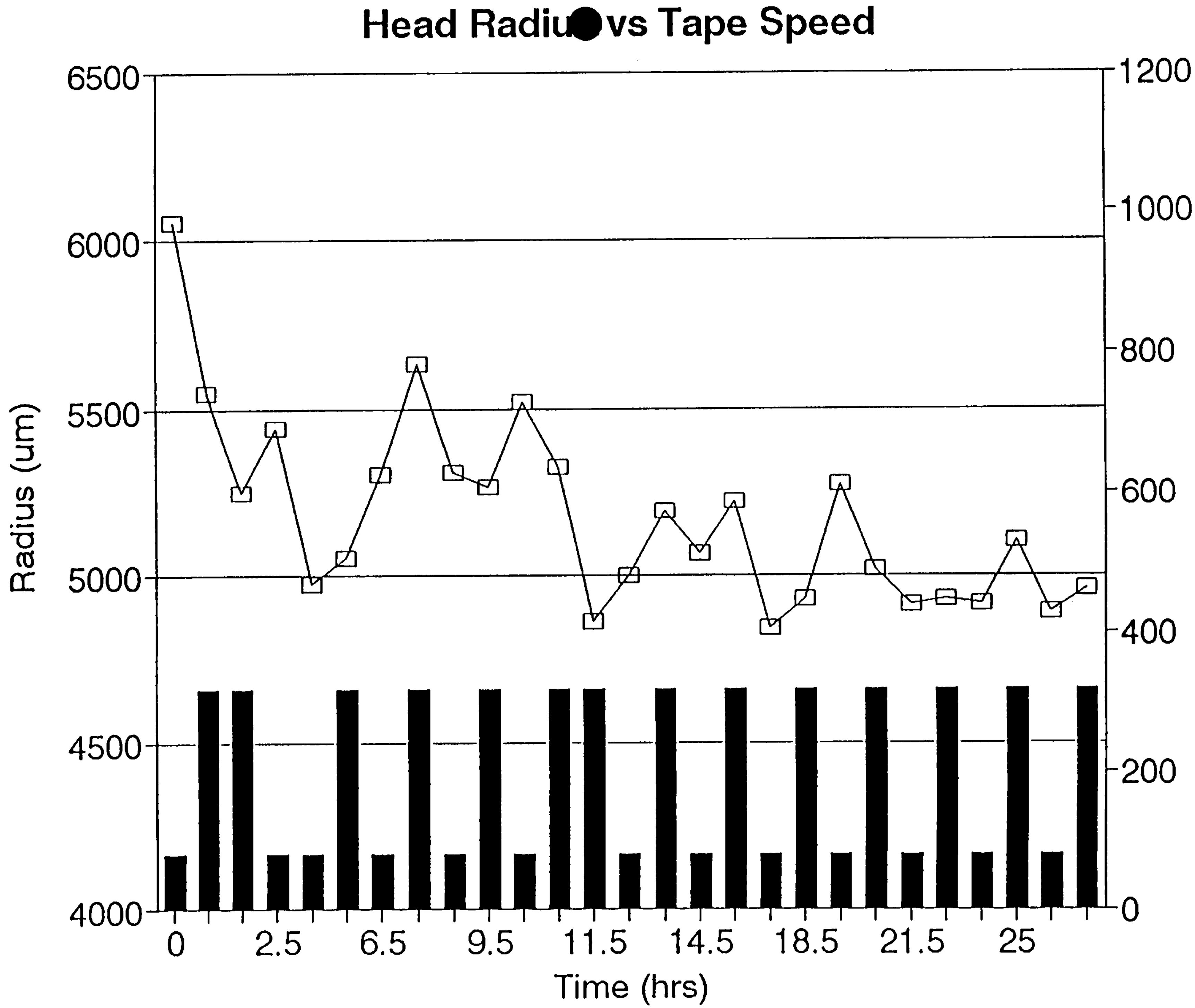

Head Radiu● vs Tape Speed
6500
6000
5500
5000
4500
4000
Radius (um)
1200
1000
800
600
400
200
0
Tape speed (ips)
0
2.5
6.5
9.5
11.5
14.5
18.5
21.5
25
Time (hrs)

Figure 4