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To: VLBA Data Acquisition Group, Mark IV Development Group
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 Subject: **Simulation of the Tape-Flat-Head Interface**
 for Phase-II, Part 1 of the TF-Project

Abstract

The head-tape interface of the flat heads used in the Phase-II, Part 1 evaluation of the Thin Film Project are analyzed numerically. The results obtained from the experimental evaluation of the head-tape spacing with tape speed and tension compare favorably with this numerical analysis [1]. Numerical evaluation of a pre-existing pole-tip recession on the mechanics of the interface showed that the tape would bend into the recessed area with an insignificant change in the head-tape spacing.

Introduction

The aim of this memo is to compare the experimentally measured head tape spacing values obtained in [1,4] to the results of the model [3]. The mechanics of the interface of a tape and a flat head has been explained in [2]. Air entrained in this interface creates a suction layer under the tape, pulling it down to contact the head. The magnitude of this subambient pressure increases asymptotically with increasing tape speed. The head-tape spacing h is limited by the roughness of the two surfaces¹.

A triple-bar head assembly was tested in Phase-II, Part 1 of the Thin-Film Project. The geometry of this assembly is given In Figure 1. In modeling the interface, only one of the three flat-bars of the head-assembly was considered. The parameters used in the model are as follows:

¹Asperity engagement height correlates with the statistical combination of the peak-to-valley (P-V) distance of the head and tape surfaces [3].

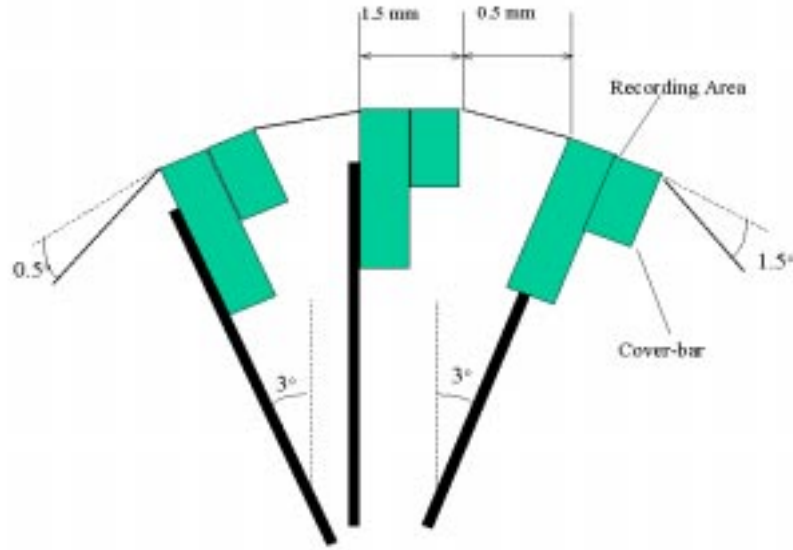


Figure 1: This figure shows a schematic depiction of the triple-bar assembly used in Phase-II, Part-1 tests of the Thin-Film Project.

Island width:	1.5 mm,
Wrap angle:	1.5° ,
Tape speed:	3.2-320 ips (0.08-8 m/s),
Tape tension:	5", 10" H ₂ O vacuum, (43, 87 N/m),
Tape thickness:	15 μm (thin VLBI tape),
Elastic modulus:	4 GPa,
Asperity engagement height:	48 nm.

Head-Tape Spacing as a Function of Tape Speed

The goal of this section is to demonstrate how the tape deforms as a results of the self-forming air suction at different tape speeds. Figure 2 shows the steady-state deformations of a tape pulled over the 1.5 mm wide flat head, under 43 N/m tension at different tape speeds. Note that the tape moves from left to right. In this figure the head is shown as a rectangular block with sharp corners. The effect of wear of these sharp corners is presented in the last section. Based on the results presented in this figure the mechanical interaction in the head-tape interface is summarized as follows:

- At $V = 0$ the tape is symmetrically "cupped" over the head and contact occurs only at the edges.

- At $V = 0.08$ m/s, the tape is still cupped but its shape is no longer symmetrical with respect to the middle of the head. Due to suction² generated under the tape, its upstream side is pulled more toward the head surface than the downstream side.
- At $V = 0.24$ m/s, tape starts to come in contact with the head on the upstream side.
- At $V \geq 0.8$ m/s, the suction created under the tape is sufficient to defeat the structural stiffness of the tape and cause it the contact completely over the mid-section of the flat surface. Near the two edges of the head, tape is still cupped and does not touch the flat surface.

The detail of the head-tape spacing h , in the 0-200 nm range above the head surface, for the cases discussed above, are given in Figure 3.

- Here we see that once the tape contacts the head (i.e., $V \geq 0.8$ m/s) the asperities are compressed by about 4 nm, and
- Once the tape is flattened on the head, the head tape spacing does not change significantly with increasing tape speed.

Head-Tape Spacing as a Function of Tape Speed and Tension

The read and write heads are located near the center ($x = 0.75$ m) along the running direction of the flat bar. By plotting the variation of head-tape spacing at this location as a function of tape speed and tension, in Figure 4, we can evaluate the mechanical factors affecting the read/write functions of the head. This figure shows that,

- For higher tape tension (e.g., $T = 87$ N/m) contact occurs at a lower speed, and
- After the tape is in full contact with the head, the spacing for the higher tape tension is only slightly lower than for the case of lower tape tension.

Figure 4 also shows the experimentally measured head-tape spacing values. More on this subject is given in the last section.

Initial Value of the Pole Tip Recession

Thin-film MR heads are made of mainly three different materials. The tape bearing surface is made of $\text{Al}_2\text{O}_3\text{-TiC}$ (*Altic*), and the head region³ uses *sputtered-alumina* and *Permalloy*. The hardness of Altic, sputtered-alumina and Permalloy are 23, 10 and < 6 GPa, respectively [2]. In general wear, of a material is inversely proportional to its hardness. It has been found that the manufacturing process of lapping the heads to a flat surface

²Note that the air pressure related to these cases are not shown here.

³The head region which spans approximately $40\ \mu\text{m}$ is composed of MR read and inductive write heads.

causes a differential wear in the head region or pole-tip recession (PTR). Scan of a typical head region from one of the samples tested in [1] is given in Figure 5. This figure shows that the permalloy and sputtered-alumina regions experienced approximately 100 nm, and 30 nm deep PTR.

Effect of the Pole Tip Recession on the Head-Tape Spacing

In order to construct a more realistic picture of the head-tape interface, effect of the initial pole tip recession is modeled. Figure 6 shows the simulated tape deformation for different tape speeds at $T = 43$ N/m, over a head with the PTR shown Figure 5. Note that in this figure the head contour is indicated by the \diamond 's. The head that is modeled has been subject to numerical wear with a contact pressure threshold of 150 kPa. As a result of this wear the corners of the head have been rounded as shown. This figure shows that,

- PTR does not affect the overall conditions of the interface and contact is maintained.

A detailed look into the PTR-region shows that,

- Tape bends into the opening of the PTR by approximately 4 nm.

This bending is caused by the additional suction created in the recessed region as shown in the air pressure plots given in Figure 7. The tape deforms slightly more into the PTR-region as tape speed is increased. But this effect is very small.

Figure 8 compares the head-tape spacing at the mid-point of the head obtained after including the PTR into the simulation with the values obtained without the PTR.

- Including the PTR into the simulation shows that the head tape spacing continues to decrease with increasing tape speed, because the tape bends into the open area. But this is a very small effect.

Comparison of Experimental Measurements with the Model

In this section the experimental measurements of the spacing change in the head-tape interface is compared to the results obtained by the model. The details of method used in measuring the spacing-change are given in [1]. A spacing change of 4 nm is detectable, at the recording wave length of $0.9 \mu\text{m}$, with this method. Two comparisons are made in this section. First, the heads tested recently for Phase-2, Part-1 are compared to the model [1]. As indicated above these heads are 1.5 mm wide and wrapped with 1.5° on each side. Second, the heads tested for the Feasibility Phase are compared to the model [4]. The electrical construction of these heads are nearly identical to the Phase-II heads. However, the island width of the Feasibility heads are 0.56 mm and the wrap angles are 2.5° .

Experimental evaluation of the heads modeled in here for Phase-II, Part-1, is reported in [1]. These results are plotted in Figure 4. The experiments showed no detectable "spacing-change" Δh in the 0.25-0.8 m/s (10-320 ips) speed range for 43 and 87 N/m (5", 10" H_2O

vacuum in Metrum tape drive). The method used for the experiments enables only measurements of a relative change in spacing. In the experiments the spacing change at different tape speeds are referred to 8 m/s tape speed. However, there is no information about the absolute magnitude of spacing at 8 m/s. Since the experimental results show no-detectable change in a wide speed range, it would be reasonable to assume that the tape is in full contact. Therefore, for plotting the experimental results on Figure 4 the 8 m/s of the experiments case is assumed to coincide with that of the model.

The results of the tests for the Feasibility Phase were reported in [4], and comparison of the model to head-tape spacing measurements were presented in [5]. This comparison, repeated here in Figure 9, had shown a maximum of 70 nm discrepancy between the tests and the model. Recently, the tests of the heads in Phase-II, Part-1 showed that there exists a “white noise” which cannot be attributed to spacing change⁴ [1]. If it can be assumed that this white noise were present in the tests of heads for the Feasibility Phase, then a correction can be made for the spacing change calculations. Figure 10 shows the head-tape spacing change measurements after such correction. It can be seen here that after the correction the experimental measurements and model predictions have better agreement.

References

1. Hinteregger, H.F., Müftü, S., “Evaluation of Phase-2, Part-1 Heads for the Thin-Film MR Head Project: Triple-Flat Assembly Contour Geometry Qualification Tests,” M.I.T. Haystack Observatory, Mark-IV Memo #: 269, February 1999.
2. Müftü, S., Hinteregger, H.F., “The Self-Acting, Subambient Foil Bearing in High Speed, Contact Tape Recording with a Flat Head,” *Tribology Transactions*, Vol. 41, No. 1, pp-19-26, 1998.
3. Müftü, S., “User’s Manual **p4** version 2.24, A Computer Program to Analyze the Mechanics of the Head-Tape Interface,” June 1998.
4. Hinteregger, H.F., “Progress Report on thin-film head development - (as of 7 April 1998),” M.I.T. Haystack Observatory, Mark-IV Memo #: 268, January 1999.
5. Hinteregger, H.F., Müftü, S., “Tests of Flat, Thin-film, Magnetoresistive Head Arrays for VLBI Tape Recorders,” TMRC '98 poster presentation, text available from M.I.T. Haystack Observatory, 1998.

⁴Currently, for the lack of a better explanation this white noise is attributed to frictional heating of the MR element. But this subject should be investigated more.

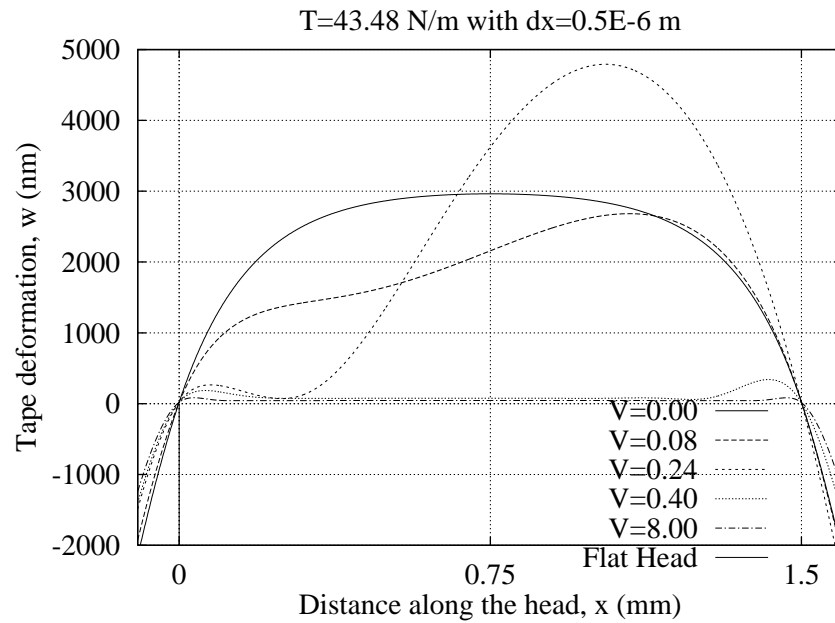


Figure 2: This figure shows the variation of head-tape spacing over the the flat island as a function of tape speed V for tape tension $T = 43 \text{ N/m}$ (5" H_2O vacuum) in the Metrum tape drive.

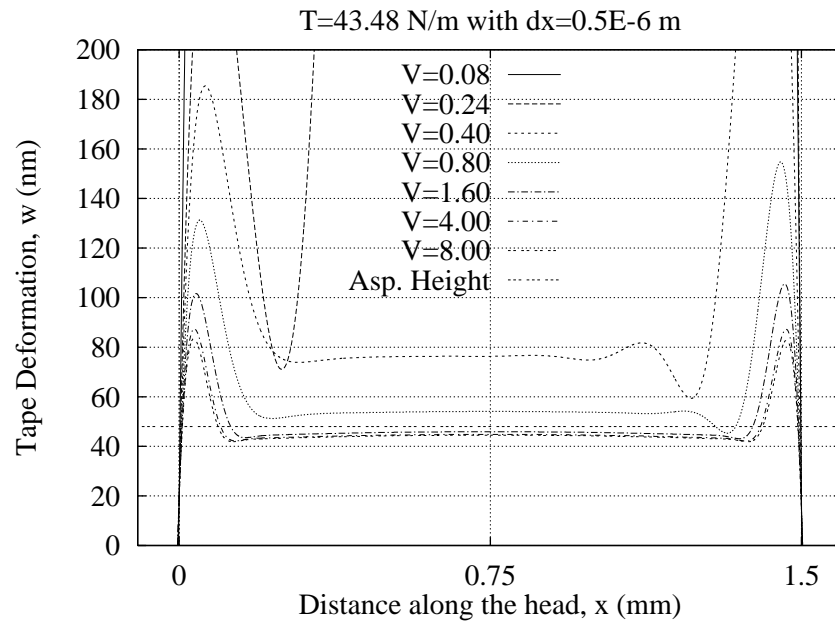


Figure 3: This figure shows the detail of Figure 2 in the 0-200 nm range.

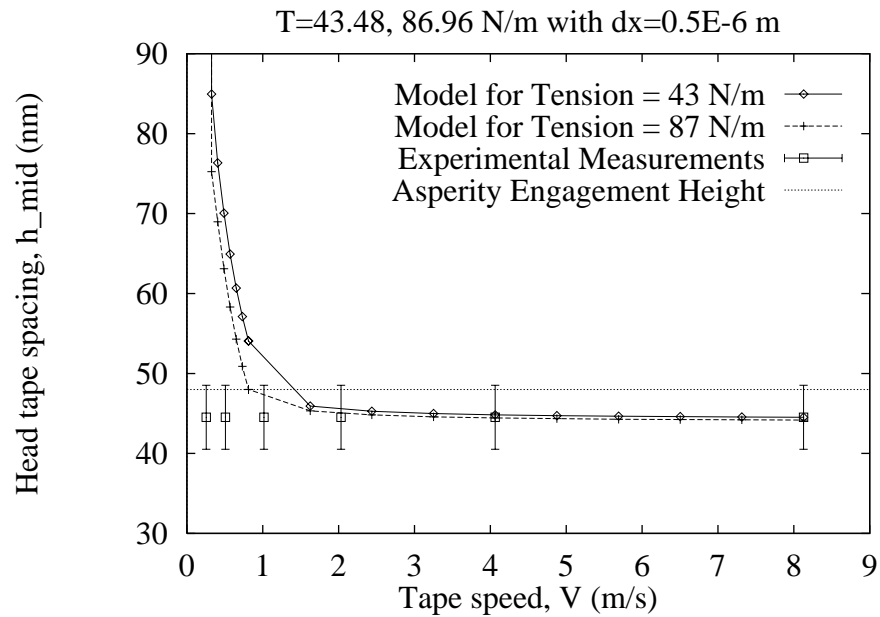


Figure 4: This figure shows the variation of head-tape spacing over the middle of the flat island, where the MR read and inductive heads are located, as a function of tape speed V for two different tape tensions $T = 43$ and 87 N/m (5" and 10" H_2O vacuum) in the Metrum tape drive. The model and the experimental results are related to Phase-II, Part-1 conditions.

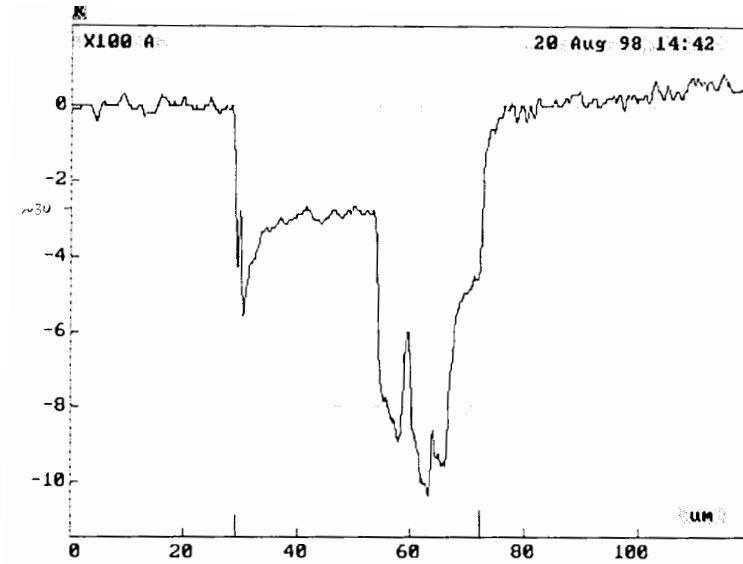


Figure 5: Measured pole tip recession (PTR) on one of the heads used in Phase-II, Part-1 tests.

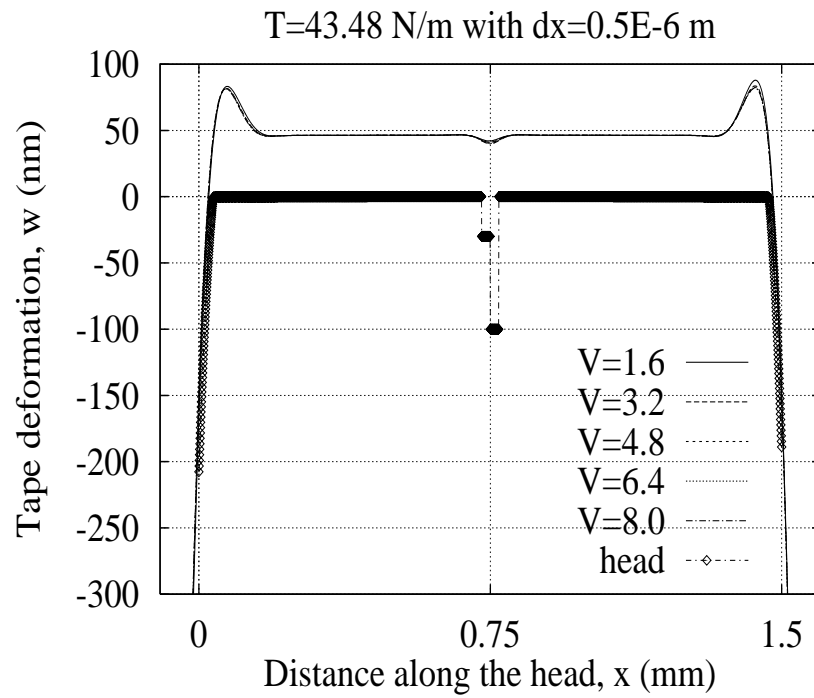


Figure 6: Simulated head tape spacing at different tape speeds over a head that has the initial PTR shown in Figure 4.

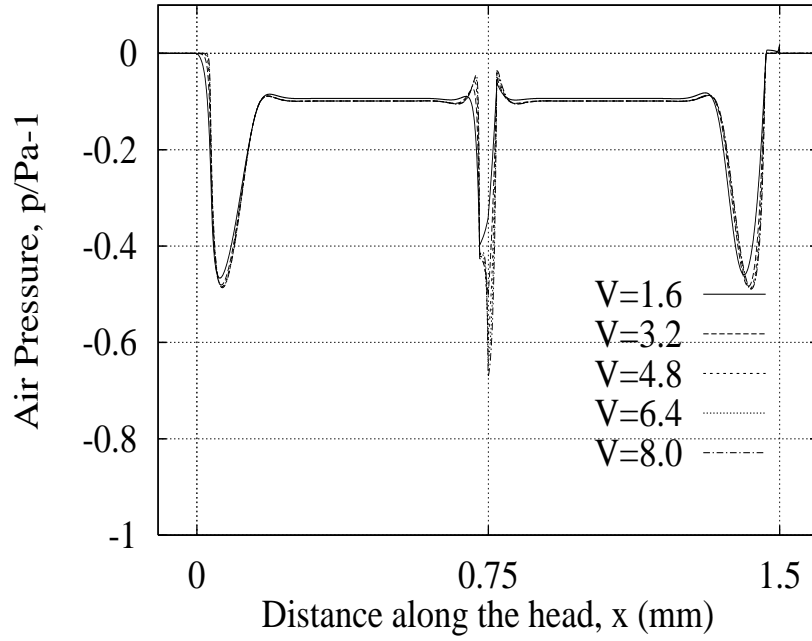


Figure 7: Simulated air pressure variation along the head-tape interface for the case presented in Figure 5, at different tape speeds, over a head that has the initial PTR shown in Figure 4.

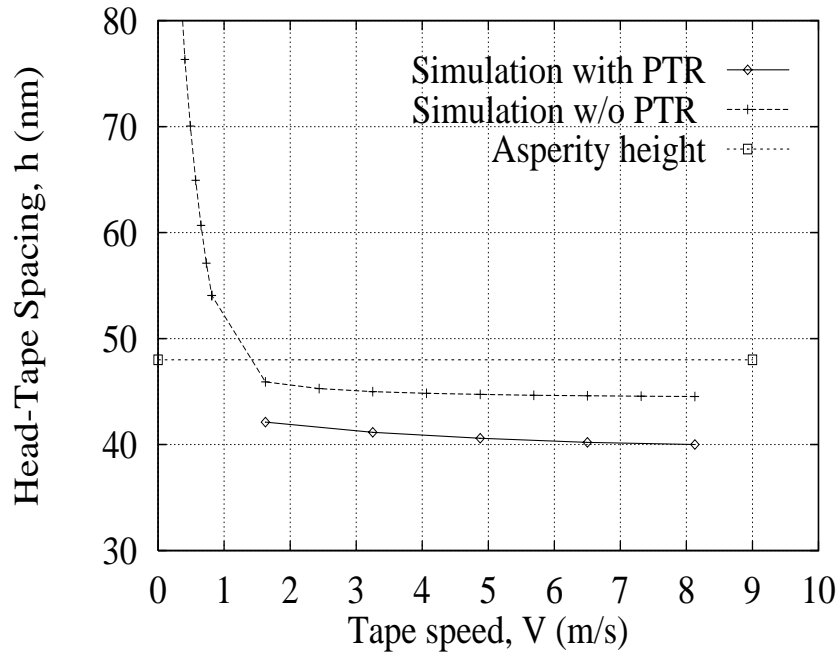


Figure 8: The change in head tape spacing, at the center of the head, as a function of tape speed for the simulations including and excluding PTR. Figure indicates that tape would slightly bend into the opening created by PTR. Figure is related to the geometry of Phase-II, Part-1.

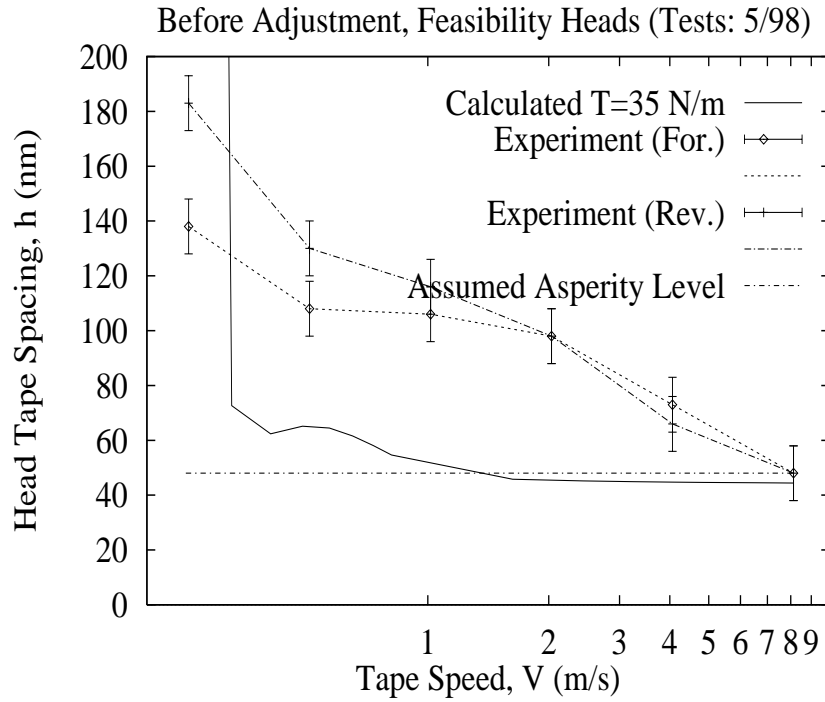


Figure 9: Comparison of experimental results with the model for the Feasibility Phase. The tape tension is $T = 4 \text{ N/m}$, head islnad width is 0.56 mm and the wrap angles are 2.5° . This figure gives the experimental results before the correction for the “white-noise” detected in [1].

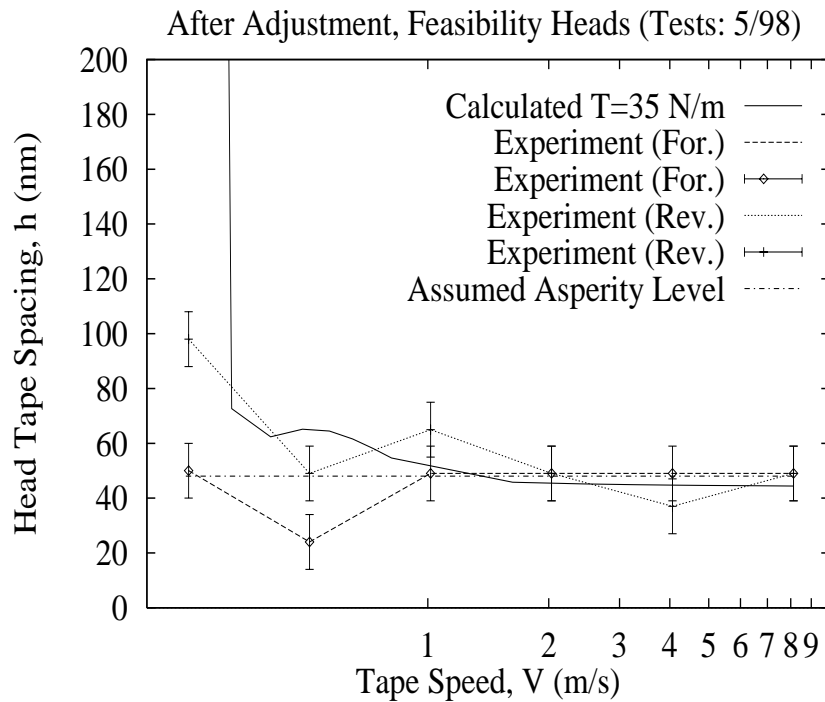


Figure 10: This figure shows the experimental results for the case given in the previous figure after the correction for the “white-noise.”