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Title : Wear testing of an experimental Metrum headstack
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To : Mark IV and VLBI distributions

Abstract

The results of the wear test of the new experimental VLBI headstack contour, recently suggested by Metrum [1] with the intent of achieving improved contact and wear characteristics, are presented. The wear rate of this new contour is measured to have an approximate upper bound of 3.8×10^{-5} μm/hour, which can be shown to correspond to 17,500 hours of useful headstack life.

Description of the Experimental Metrum Contour

Figure 1 shows a schematic description of the experimental Metrum headstack. This design came to be known in Haystack as the “wide-triple-flat” headstack, but it will be called the experimental Metrum headstack in this report.

Figure 2 shows the head contours, obtained with a stylus type profiler (Dektak 3^{ST}), in the running direction (RD) measured between heads 16-17, and cross-tape direction (CD) measured along the recording gap on the central step. The radius of the central step of the experimental headstack is approximately 25 mm, and the radii of the two outriggers are approximately 10 mm. The width of the central step is 1050 μm and the widths of the outriggers are ~380 μm. The central step is separated from the outriggers by a 500 μm wide and ~20 μm deep rectangular groove. The tangents at the inner edges of the outriggers and the outer edges of the central step are approximately 2.4^o and 1.3^o, respectively. This provides an “over wrap” angle of ~ 0.55^o on each side of the central step. Therefore, it is reasonable to expect the formation of a self-acting subambient foil bearing, or, so called, flat-head effect [2] over the central step.

Test Conditions

In order measure the head-wear, the change in the diagonal-length of the Knoop indentations, made on several locations on the headstack, were monitored periodically. The Knoop indentation’s diagonal-length to depth (*l/d*) ratio has a constant value. By monitoring the diagonal-length periodically during the test, the depth of material removed from the surface due to wear can be easily calculated [3].

The wear test of the experimental Metrum headstack was performed on a Metrum 96 tape transport under the operating conditions listed in Table 1. A worn out stepped head was mounted on the same head-mounting block as a control.

The electrical performance of the experimental Metrum head was monitored periodically to check that the tape was not losing contact. Due to mishandling before the tests the tape contact was not uniform across the width of the head: steady and good read-back signal was obtained on lower numbered heads (e.g. # 3). The signal was unsteady on the other end of the headstack (e.g., head # 27). This indicated partial flying over the latter group of heads. Nevertheless, wear was observed on this side. After ~1500 hours of testing, degradation of read-signal was seen on both ends of the headstack. Based on the characteristics of the change it is apparent that the tape was flying in the range of 40-120 nm over the heads depending on its location. Details will be provided in [7].

On both headstacks, six Knoop indentations were made on heads numbered 1, 12, 23 and 34 according to VLBA/Mark IV convention. Thus, a total of twenty-four indentations were made on each headstack as shown in Figure 2 [4]. The lengths of the long-diagonals of these indentations are listed in Table 2. The depths of the indentations were measured using an Atomic Force Microscope and it was found that $d/l = 42$ [5].

The diagonal lengths of indentations in both headstacks were measured with approximately 200-hour shuttling intervals. We estimate that the accuracy of reading the diagonal length with the microscope is ± 1 m m. This corresponds to ± 0.024 m m in assessing depth change.

During the test, thin-VLBI-tapes were shuttled for a total of 2450 hours. In the first half of the test the tape was not changed. In the second half, a new tape was used after each ~72 hour of shuttling.

Surface profiles of the heads were measured using the surface profiler, before the test (0-hour), 114 hours after the start, and at the end of the test (2450-hours).

Results

In order to evaluate the test results the *wear rate* m and the *wear constant* k of the experimental Metrum headstack were compared to that of the control headstack. The change in the shape of the experimental headstack profile was also investigated.

<u>Wear rate and wear constant</u>

In order to calculate the wear rate, the wear depth measurements on each head were averaged and least-squares-line-fit was used represent the data as,

$$d\,d = m.t \tag{1}$$

where m is the *wear rate* (µm/hour) and t is the elapsed time (hour) and $d\,d$ is the wear depth (µm). The wear rates calculated this way, for each headstack are given in Table 1.

In general, wear is a function of sliding distance $L\left(=V.t\right)$, contact force F, material hardness H, and some environmental conditions such as humidity. The dry air kit, on the drive we used, keeps the humidity approximately at 20% level, where the wear due to this effect alone is expected to be low [6]. Therefore, no attempt was made to take the humidity effects into consideration. In this case, Archard's wear law, which is commonly used to establish the relation between the wear volume $d\,d.A$ and the parameters L, F, and H,

$$d\,d\;.\;A = kL\frac{F}{H} \qquad (2)$$

can be used. In this relation k is the, so-called, *wear constant* and A is the contact area.

Equation (2) can be recast in terms of the contact pressure F/A. A good first order approximation for the contact pressure is the *belt-wrap pressure, T/R,* where T is the tape tension per unit width and R is the head radius[1]. The radii of two heads used in this test have been measured using the profiler. As given in Table 1: The radius of the stepped head is $R_{\text{stepped}} \simeq 3.6\text{ mm}$ and the radius of the central area of the experimental head is $R_{\text{ExpMet}} \simeq 25\text{ mm}$.

The m and k values obtained from this test are given in Table 3. An error in the lateral-tilt of the control-headstack may have caused the head-1 not be in good contact with the tape during the experiment. Therefore, the m and k values for this head are kept out of the evaluations, but they are reported in Table 3. In general, the following observations are made based on the results given in this table,

a) Heads near the tape edges appear to wear faster than the heads near the center. This confirms earlier experience based on optical measurements of stepped heads.
b) When the wear rate m for the experimental Metrum headstack and the stepped head are compared, it is seen that,
   - In the central region; the wear rate of the experimental Metrum head is approximately two orders of magnitude lower than that of the stepped head, with $m_{\text{12 and 23}}^{\text{Exp. Metrum}} = \mathrm{O}\left(10^{-6}\right)$ and $m_{\text{12 and 23}}^{\text{Stepped}} = \mathrm{O}\left(10^{-4}\right)$.
   - Near the lateral edges of the headstack; the wear rate of the experimental Metrum headstack is apparently only one order of magnitude lower than that of the stepped head, with $m_{\text{1 and 34}}^{\text{Exp. Metrum}} = \mathrm{O}\left(10^{-5}\right)$ and $m_{34}^{\text{Stepped}} = \mathrm{O}\left(10^{-4}\right)$.
c) The wear-constant k for the experimental Metrum headstack may be significant near the lateral edges as compared to the central area:
   - In the central region : $k \approx 3.9\times10^{-10}$.
   - Near the lateral edges of the headstack: $k \approx 1.8\times10^{-9}$.
d) The wear-constant for the stepped headstack for heads 12, 23 and 34 is $k \approx 7.7\times10^{-9}$.

<u>Change of surface profile</u>

Figures 5 and 6 show the change in the surface profile of the experimental Metrum headstack measured at 0, 114 and 2450 hours, in CD and RD, respectively. Note that Figure 5 has been obtained by shifting the lateral profiles by 1.5 m m in the vertical direction. This figure shows no significant change (<0.1 m m) in the lateral direction profile between 5,000-to-20,000 m m span of the headstack. On the other hand, the edges of the profile show ~0.5 m m wear near 1,000 and 25,000 m m locations where opposite tape edges have cut into the headstack.

The alignment of the RD profiles at different times given in Figure 6 was made with respect to the wear marks of the bond lines near ±150 m m locations. The plot on the

[1] For the parameters of this application (Table 1) the subambient air pressure, which is due to the self acting subambient foil bearing effect, was seen to be a small fraction of the belt-wrap pressure, *T/R*.

top shows the entire width of the central step of the experimental head, and the bottom plot shows the detail near the apex of the central step. In both plots, the left-axis is used to measure the head profile and the right-axis is used to measure the difference Δ_{profile} between the profiles as indicated on the labels. Note that the magnetically active parts of the heads are located on the apex of the profile. This figure shows that, at the end of the test, no significant wear occurred near the apex region. Largest wear occurred on the bond lines: ~0.15 m m. There is some evidence of rounding of corners or “extra” wear within 100 m m of the edges of the central-step.

Discussion and Conclusions

The wear rate of the experimental Metrum headstack is shown to have an upper bound of 3.8×10^{-5} m m/hour. Compared to the wear rate of the control headstack, which has an upper bound of 9×10^{-4} m m/hour, the new contour seems to promise ~23 fold improvement of the wear rate.

The average wear rate measured on the stepped headstack, m = 8.4×10^{-4} m m/hour, seems to suggest that the life of a stepped headstack with an initial depth-of-gap of 25 m m would be 30,000 hours! Experience shows, 5,000 hours to be a reasonable expectation. This difference can be due to two main factors; uncontrolled relative humidity and thin-thick tape interchange. Thus prudence suggests a “safety factor” of 6 to be used in making the life predictions, based on the results obtained here.

Considering an initial depth of gap of 4 m m, using the highest wear rate (measured at the edges of the headstack), and the applying the safety factor given above, the life of the experimental headstack can be estimated to be 17,500 hours.

References

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Tape thickness, (mm) thin-VLBI-tape	15
Relative humidity with DryAir kit	<20%
Tape speed, V (m/s)/(ips)	6.658/270
Tape tension, T (N/m)/(in. H20)	86.96/10
Hardness[1] of Mn-Zn Ferrite, $H_{Ferrite}$ (GPa)	5.52
Hardness[2] of $CaTiO_3$, H_{CaTiO3} (GPa)	9.3

Table 1 Experimental parameters. [1]: Our measurements [4], [2]: From Bhushan [3].

Head Numbers	**Locations on each head**	**Approximate length of long diagonal,** μm
Stepped Head		
1,12,23,34	a1, a2, c1, c2	25
	b1, b2	15
Experimental Metrum Head		
1,12,23,34	a1,a2	8.7
	b1,b2	16.5
	b1,c2	25.2

Table 2 The initial diagonal lengths of the Knoop indentations.

	head-1	head-12	head-23	head-34	Contact pressure T/R (Pa)	Head radius R (mm)
Stepped-Head-2					24155.6	3.6
Wear Const, k	3.6E-10	6.9E-09	8.0E-09	8.4E-09		
m (um/hr)	3.9E-05	7.4E-04	8.6E-04	9.0E-04		
Metrum Exp Triple Cap					3478.4	25.0
Wear Const, k	1.1E-09	2.9E-10	4.9E-10	2.4E-09		
m (um/hr)	1.8E-05	4.6E-06	7.6E-06	3.8E-05		

Table 3 The wear rate m, and the wear constant k for the stepped and experimental Metrum headstacks.

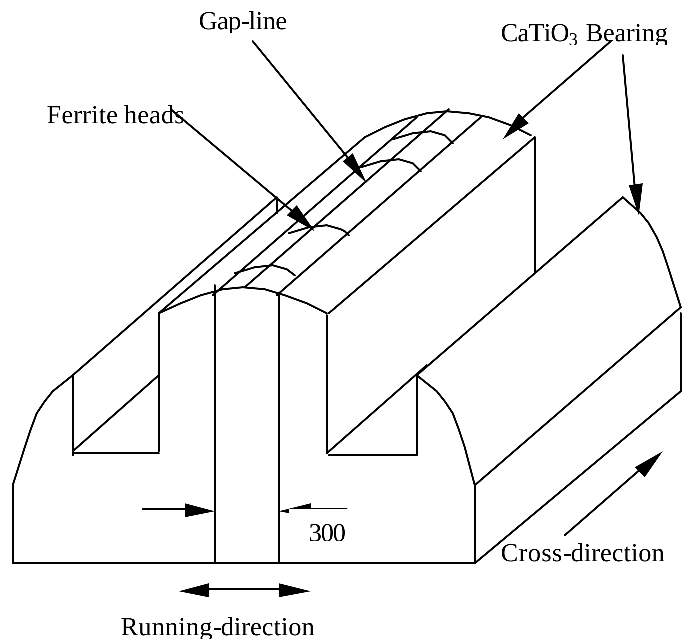

Figure 1 Schematic picture of the experimental Metrum head showing the Ferrite and CaTiO3 surface.

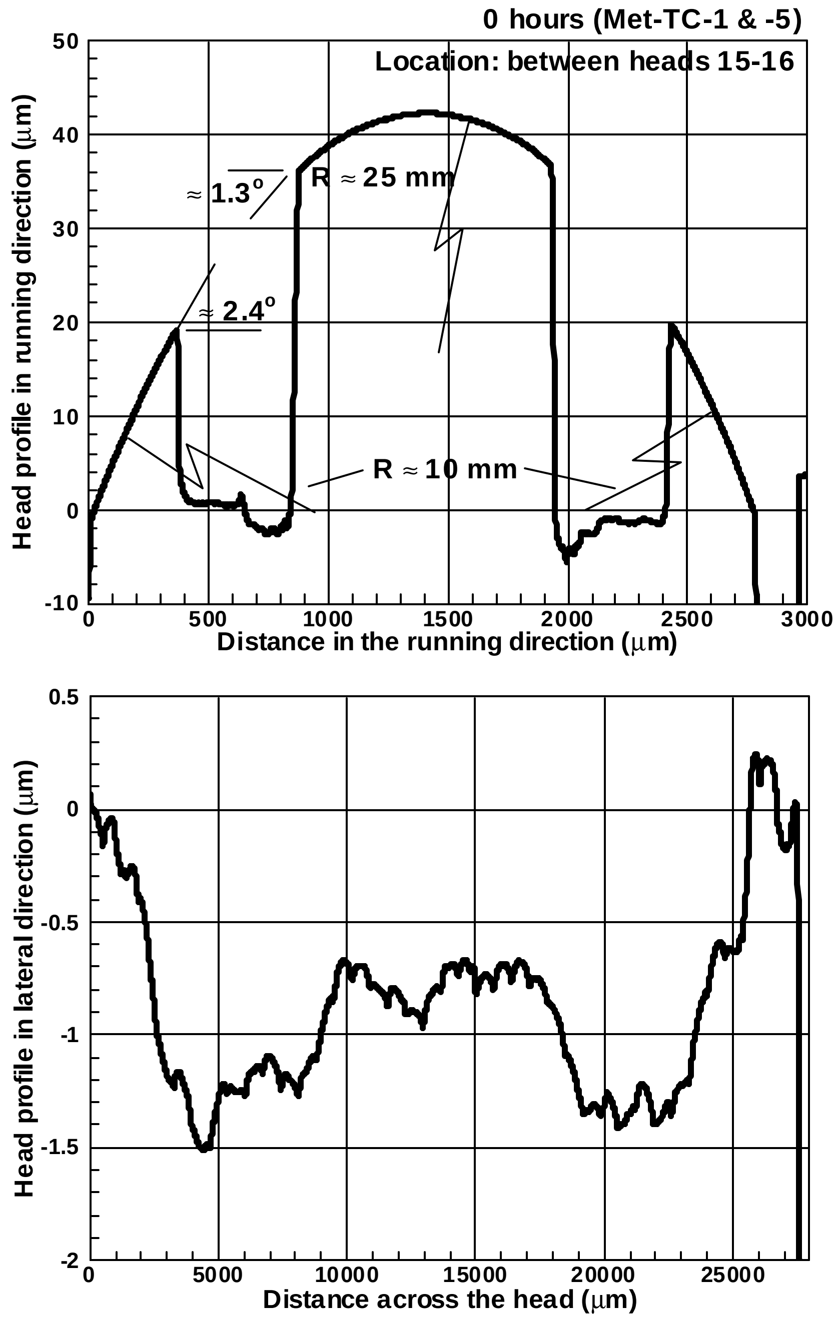

Figure 2 The surface profile of the experimental Metrum head in the running direction (top figure) and in cross-tape direction (bottom figure).

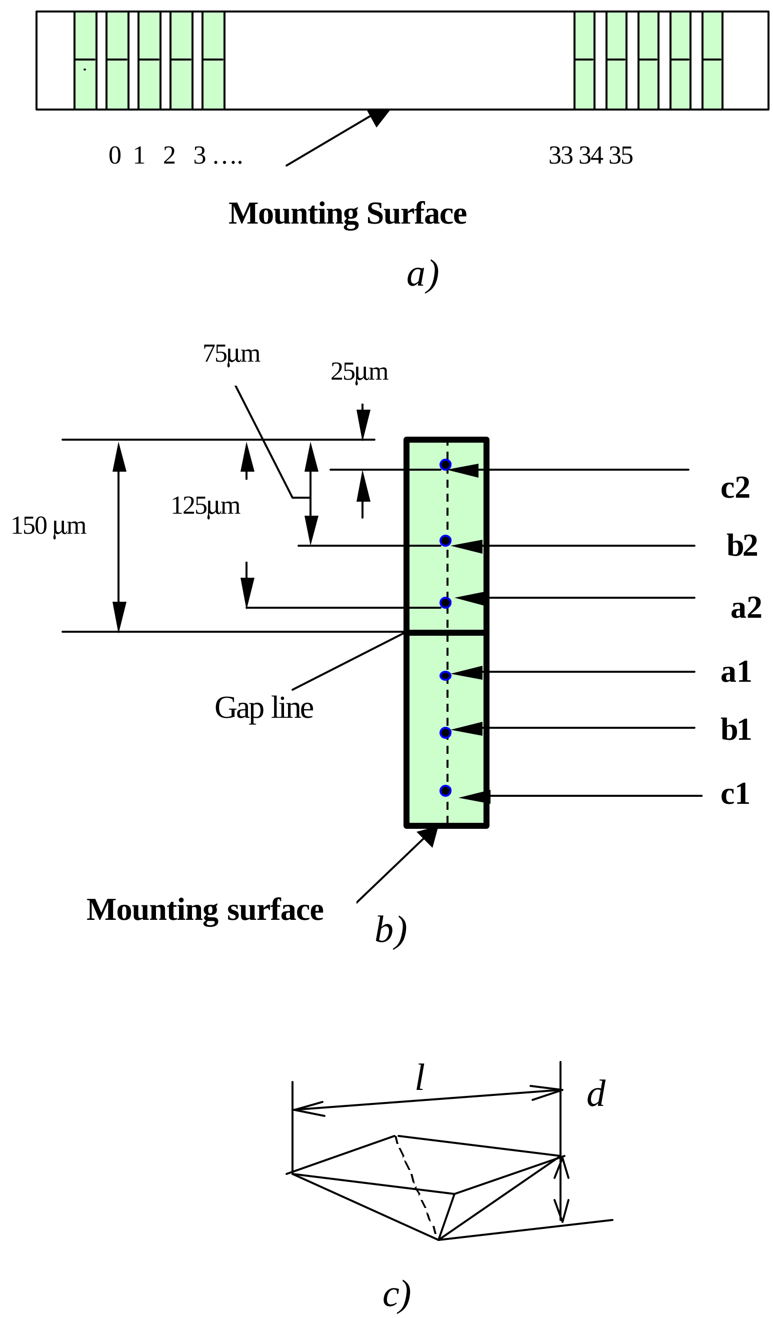

Figure 3 Schematic representation of the locations of the Knoop indentations a) on the headstack, b) on each head. c) The shape of an idealized indentation.

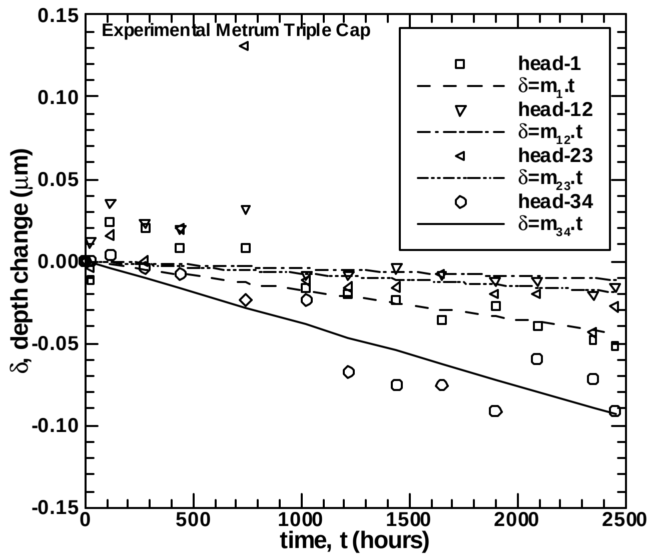

Figure 4 Wear depth as a function of sliding time for the Experimental Metrum Triple Cap Head (ExpMet).

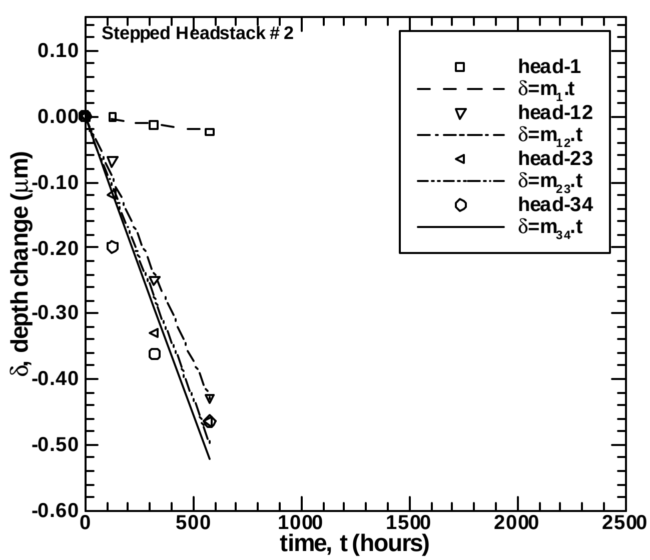

Figure 5 Wear depth as a function of sliding time for the stepped head mounted on the same head mounting block.

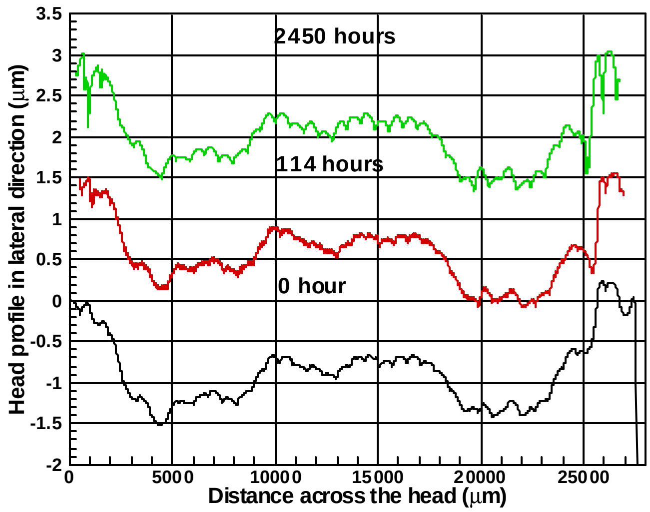

Figure 6 The surface profiles in CD, measured at beginning of the test (0 hour), 114 hours later and 2450 hours later (at the end of test). The figure is obtained by shifting the 114-hours-profile by 1.5 µm and the 2450-hours-profile by 3 µm with respect to the 0-hour.

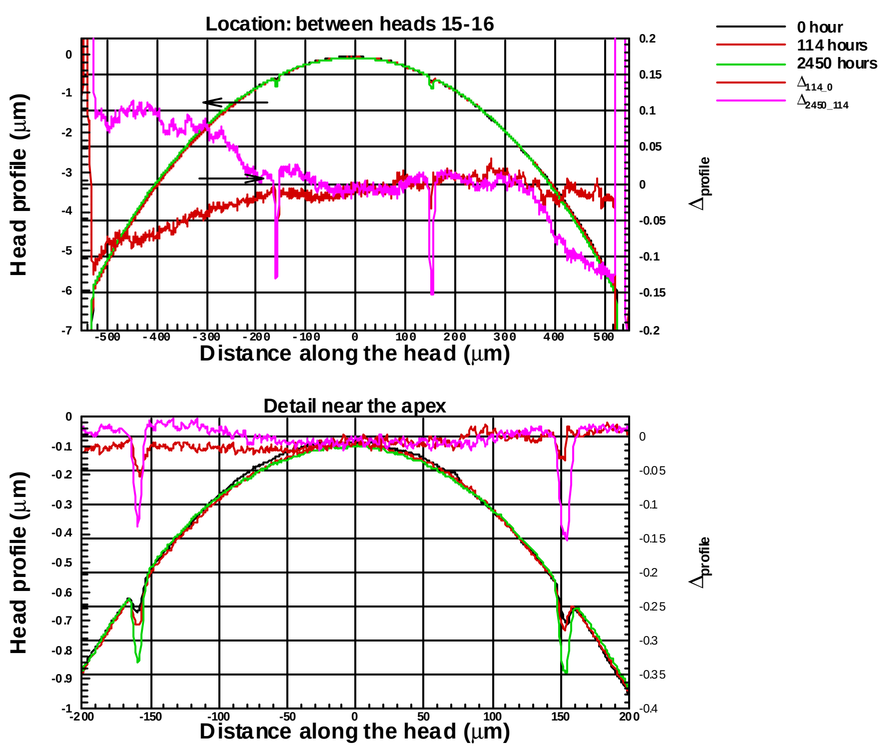

Figure 7 Detail of the running direction profile between heads 15 and 16 at 0, 114 and 2450 hours of tape lapping. This location corresponds to $CaTiO_3$ surface. The right hand side axis, $\Delta_{profile}$, on both figures shows the difference of the profiles obtained at 114-and-0 hours and 2450-and-114 hours.