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Feasibility Study of Using TiCN and CrN Thin Film Coatings to Enhance Lifetime of Grippers Used in Hard Disk Drive Assembly Line

T. Sangkla, S. Bland*, and K. Tuchinda

***Abstract*—This work investigates the use of TiCN and CrN thin film coatings to increase the lifetime of high precision grippers used for aligning a slider in hard disk drive manufacture. Experimental study to characterize wear performance and properties of the coatings and finite element analysis of the coated grippers were carried out. The macro-micro scale FE models of the coated grippers which take into account the surface profile were developed in order to calculate contact stresses and in-service sliding distance. Wear depth and lifetime of the coated grippers were then estimated using a classic Archard wear equation. It was found that the lifetime can increase greatly with the use of coatings, e.g. 10 times using TiCN coating and 20 times using CrN coating. Life improvement can also be achieved with some control of the slider initial position before making contact with the grippers.**

***Index Terms*—Thin film coating, Wear, Hard Disk Drive, Finite element**

I. Introduction

During the assembly of a head gimbal assembly (HGA) in hard disk drive manufacturing, a randomly orientated slider has to be aligned to the correct initial position so that it can be assembled precisely to the HGA. This pre-alignment process is done using a pair of grippers (namely Gripper A and B). The grippers move in and align the slider to correct position (namely a reference position), as shown in Fig. 1. The damage such as wear of the grippers not only results in imprecise position of the slider but also causes contamination from loose particles. These lead to subsequent problems in the assembly line. Worn grippers have to be replaced incurring high cost since grippers are very high precision tool. Furthermore, replacement of grippers causes disruption to the manufacturing line and reduces productivity. This work therefore aims to investigate the use of thin film coatings to reduce wear and enhance the life of the grippers. Wear resistant thin film coatings are widely used in many applications [1] but there is no report of using it in high precision tools such as those in hard disk drive manufacture [2]. Microscopic examination of the damaged grippers revealed abrasive wear of surface asperity as the damage mechanism [2]. The criteria for the choice of thin films are their strength, hardness, toughness and adhesion [1, 3] as well as cost and, for this case, their availability to coat with domestic companies. Preliminary study resulted in TiCN and CrN as suitable coatings and they were successfully coated on stainless steel grippers. In this work, the mechanical properties of TiCN and CrN coatings are examined and finite element models of coated grippers are developed. The experimental results, together with finite element analysis are used to estimate the wear level and the lifetime of the TiCN- and CrN- coated grippers.

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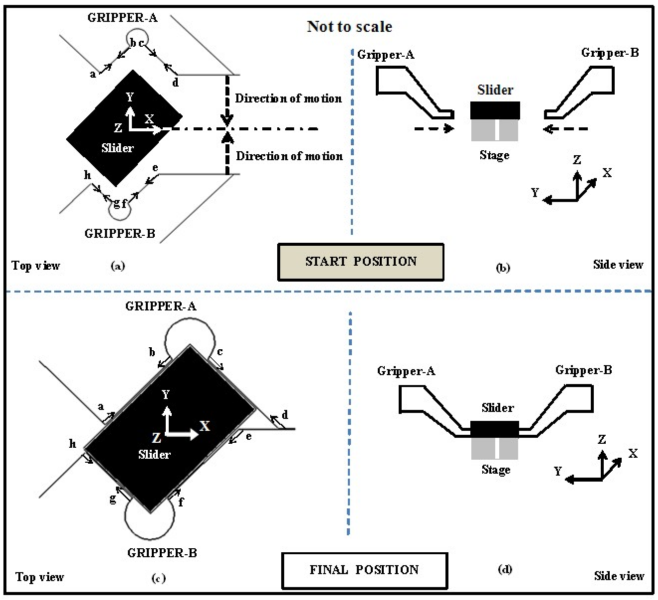

Fig. 1. Initial and final positions of the grippers and slider

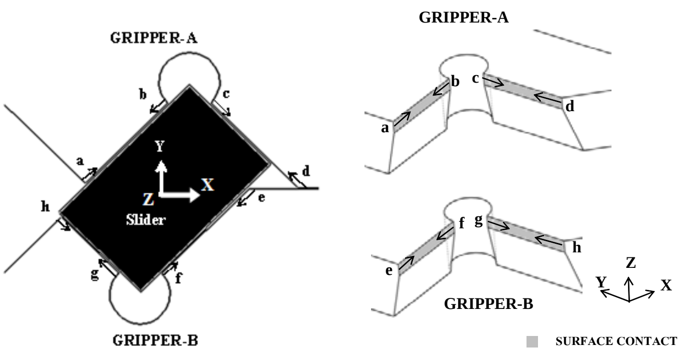

Fig. 2. Contact areas on the grippers (namely 'a'-'h')

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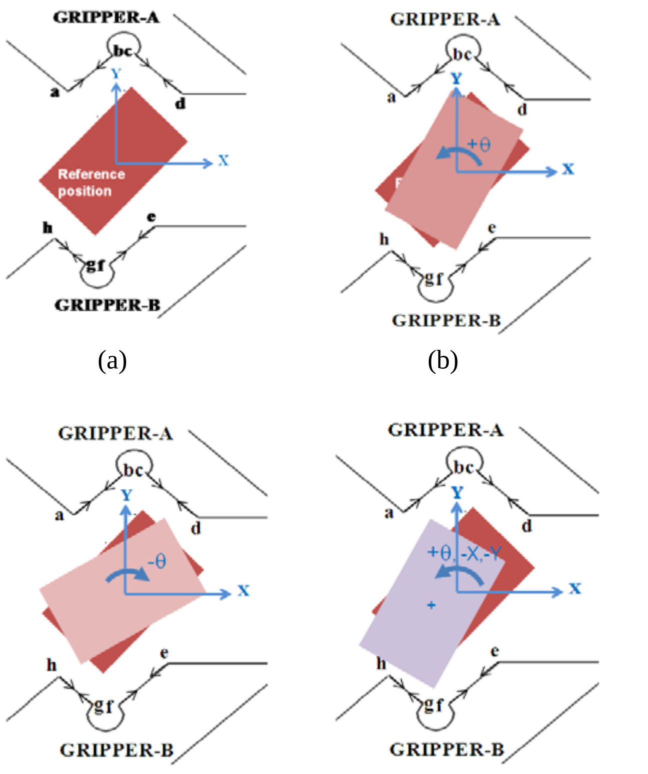
The contact area on the grippers is divided into 8 zones (namely a-h) as shown in Fig. 2. Recent work [2] has examined the damage of the non-coated grippers and found that wear was most severe in area 'b'. This corresponds to high level of contact stresses analyzed using finite element method. Furthermore, their work found that the stresses and wear on different area of the grippers depend on the initial position of the slider before being in contact with the grippers. In the actual manufacture, a slider initial position can deviate, from the reference position, within the range of ±6.75° in rotation and ±0.0185 mm translation in in-plane directions (see Fig. 3 for notations). The cases considered in this work will therefore be ±4°, ±5°, ±6°, ±6.75°, and ±6.75° coupled with translation.



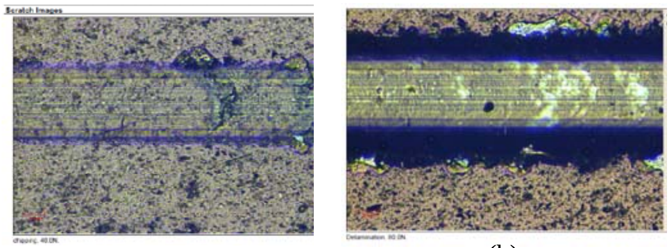
(a) (b) (c) (d)

Fig. 3. Notations for slider initial position: (a) reference position: (b) +θ° rotation: (c) -θ° rotation: (d) +θ° rotation coupled with – X, –Y translation

II. Experimental Investigations

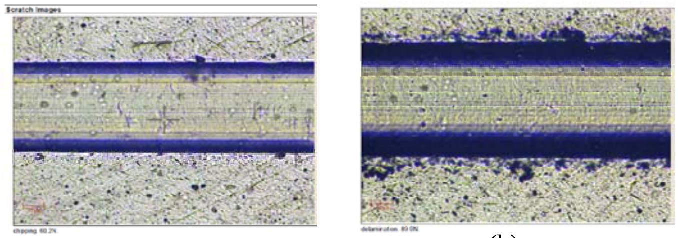
A. Determination of coating adhesion properties

Preliminary study on adhesion strength using a scratch test was carried out on different abrasive resistance coatings domestically available, i.e TiN, TiAlN, TiCN and CrN. A brief discussion is reported here (full details can be found in [4]). A stainless steel substrate representing non-coated grippers was used. The applied load is varied from 0.9 N. to 100 N. The distance traveled is 10 mm. at the speed of 10 mm./min. CrN and TiCN films showed good adhesion property compared to the rest indicating that they can withstand the load required for this application before delamination takes place. TiCN film shows sign of chipping when the applied load is 40 N. and is fully delaminated when the load is increased to 80 N. No sign of chipping and full delamination was observed for CrN film for the load smaller than 90N. Fig. 4 and 5 show the scratched image of chipping and delamination of TiCN and CrN coatings, respectively. The study of the wear behavior and the characteristic of wear debris suggested that CrN is more appropriate because particle contamination is highly controlled. However, TiCN has a greater surface hardness and shows great potential to be used in this application if internal defect can be minimized. A full analysis and discussion is reported in [4].



(a) (b)

Fig. 4. TiCN coating undergoing scratch test: (a) chipping; (b) delamination



(a) (b)

Fig. 5. CrN coating undergoing scratch test at the load of (a) 60 N; (b) 90 N

B. Determination of coating mechanical properties

TiCN and CrN coatings were tested for their hardness and their stress-strain relationship. Nanoindentation hardness test was carried out and Young's modulus was determined following the method of [5,6]. The hardness of TiCN and CrN coatings were found to be 18,854 MPa and 30,639 MPa, respectively. For comparison purpose, the hardness of stainless steel representing non-coated grippers is 5,545 MPa [2]. The stress-strain relationship of the coatings and Al_2O_3-TiC (slider material) was developed using nanoindentation test results and FE models following the method reported in [7-9]. They will be used in the FE models of the coated grippers described in Part III.

C. Determination of coating surface roughness

Since wear of materials is influenced by its surface roughness, a test to measure the roughness of the coated grippers and the slider was carried out using an Atomic force microscopy. Fig. 6 shows the roughness measurement of TiCN- and CrN-coated grippers. Both show a wave-form surface which will be parameterized [10] and used in the FE models described in Part III. The slider shows a relatively smooth surface as can be seen in Fig. 7.

D. Determination of wear coefficient

A pin on disc test was conducted to determine the wear coefficient between a slider-TiCN and slider-CrN. The wear coefficient (k) was calculated using Archard's wear equation [11], i.e.

$$V = \frac{kF_nS}{H} \qquad \text{(Eq. 1)}$$

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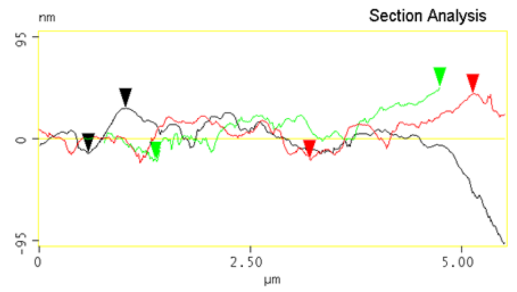
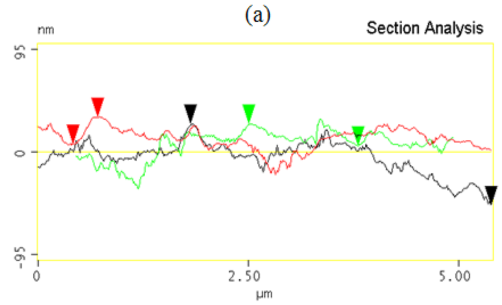
where V is wear volume measured in mm^3. F_n is applied normal force (in this test = 1, 2, 3, 4 Newton), S is sliding distance (=5000 m.) and H is material hardness in MPa. An example of the relationship between wear volume and applied load is shown in Fig. 8 (the case of slider-TiCN). The maximum wear coefficients will be used in the estimation of wear depth and they are found to be 3.397×10^{-6} and 1.668×10^{-6} for TiCN and CrN, respectively. The coefficient of friction of both coatings were also analyzed and equal to 0.17 and 0.13 for TiCN and CrN films, respectively.



(a)



(b)

Fig. 6. Surface roughness analysis of (a) TiCN- and (b) CrN- coated grippers

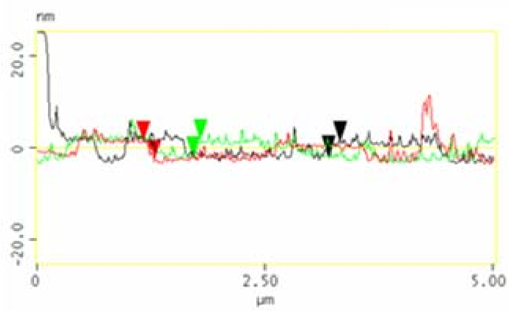


Fig. 7. Surface roughness analysis of the slider

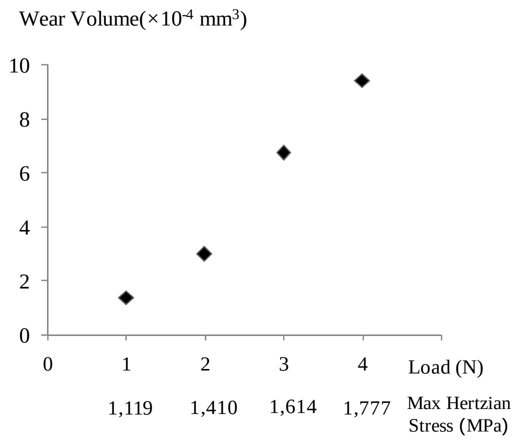
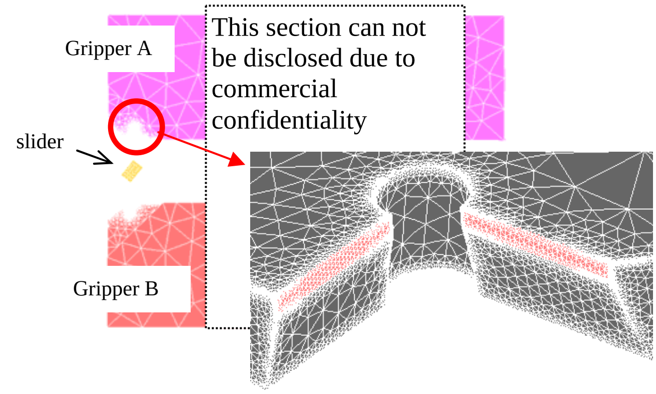


Fig. 8. Wear volume at various applied load for slider-TiCN pin on disc test.

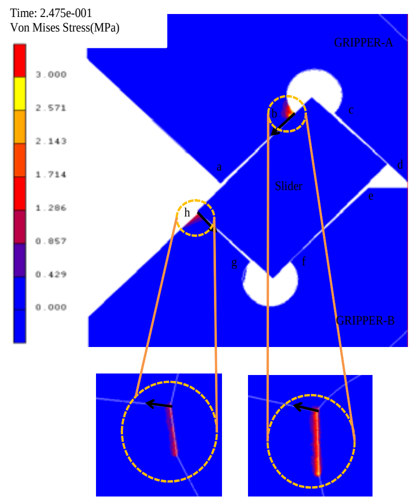
III. FINITE ELEMENT MODELS

A. *Macro scale finite element model*

The macro scale finite element model representing the motion of the grippers in contact with the slider is reported in [2]. Their work analyzed the contact normal stresses on the non-coated grippers for each increment of motion that contact takes place. All slider initial positions were considered. The model does not take into account the influence of coating or surface roughness. The macroscopic stresses reported range from 0.004 MPa to 0.652 MPa. These stresses will be used to calculate the micro scale contact normal stresses as described in Part III (B). Fig. 9 shows the FE model and an example of stresses incurred on grippers when in contact with the slider. In addition, a sliding distance between the slider and grippers while they are in contact is also reported in [2]. It was calculated using nodal displacement in the FE models. Their values will be used to estimate the wear depth of the coated grippers described in Part III (C).



(a)



(b)

Fig. 9. (a) Macro scale FE model; (b) Stress distribution on grippers for the case of slider initially at +6.75°[2]

B. *Micro scale finite element models*

Micro scale finite element models were developed to take into account the influence of coating and surface roughness on micro contact stresses on the coated grippers. Based on the results of roughness measurement, the surface asperities for both TiCN and CrN coatings can be assumed to take a wave profile as seen in Fig. 10 and Fig. 11. The amplitude and the period of the wave representing TiCN surface are 0.0395 µm and 1.25 µm, respectively. The amplitude and the period of the wave representing CrN surface are 0.0347 µm and 1.56 µm, respectively. The slider surface can be assumed flat.

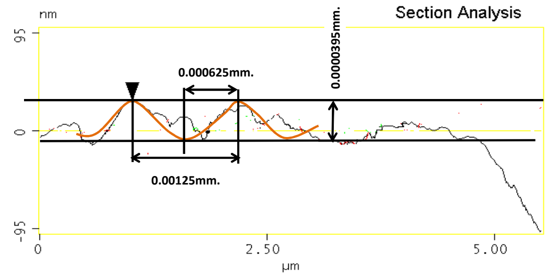


Fig. 10. The assumed wave profile of TiCN surface

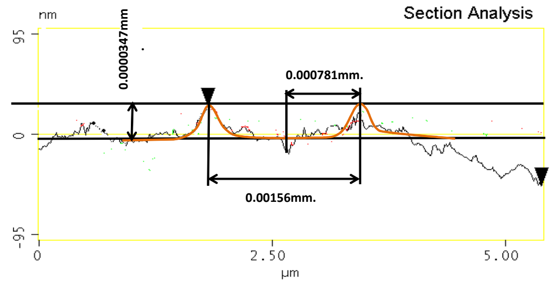


Fig. 11. The assumed wave profile of CrN surface

The micro scale FE model consists of a flat slider, a wave-like coating (either TiCN or CrN) and a substrate. The macroscopic contact normal stresses obtained from [2] were applied to the slider as shown in Fig. 12. For each of the stresses applied, the corresponding micro scale contact normal stress on the TiCN- and CrN- coated grippers was analyzed. The micro scale stress is order of magnitudes higher than their corresponding macroscopic stress. For example, a 0.25 MPa macroscopic stress results in as high as 450.5 MPa micro scale stress, as shown in Fig. 13.

C. *Wear depth estimation*

The wear depth (δ) of various areas of the TiCN- and CrN-coated grippers for each case of slider initial position can be estimated from

$$\delta = k\frac{PS}{H} \qquad \text{(Eq. 2)}$$

where k and H are wear coefficient and hardness of coating obtained experimentally. P is micro scale contact normal stress analyzed from Part III(B) and S is sliding distance obtained from [2]. Since P and S vary with time, the total wear depth at a specific area (node) of the grippers is the sum of the incremental wear depths throughout the time in which the slider and grippers are in contact, i.e

$$\delta_{node} = \left(k\frac{PS}{H}\right)_{t1} + \left(k\frac{PS}{H}\right)_{t2} + \cdots + \left(k\frac{PS}{H}\right)_{tn} \text{(Eq. 3)}$$

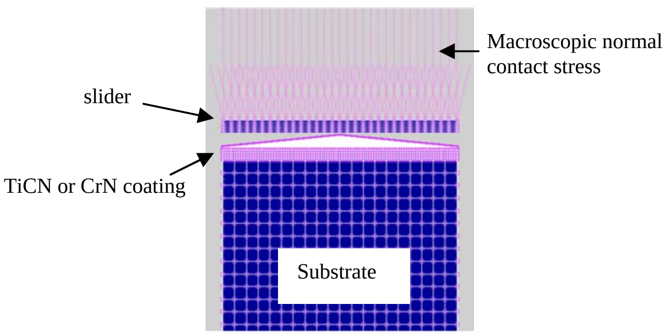


Fig. 12. Micro scale finite element model

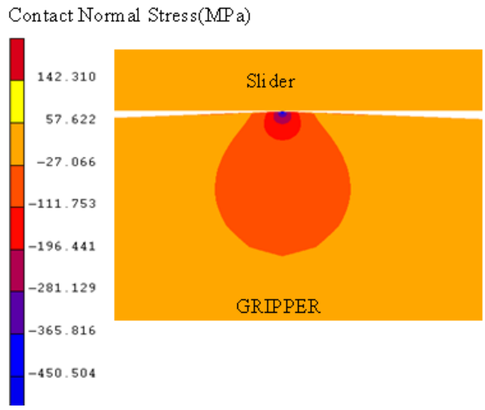


Fig. 13. Micro scale contact normal stress on area 'b' of TiCN-coated gripper (slider initial position is 6.75°)

IV. Results and Discussions

A. *Wear depth estimation of TiCN-coated grippers*

The wear depth along the contact area of the TiCN- and CrN-coated grippers was calculated for each of the slider initial position. For positive angle deviations, contact only takes place at 'b', 'f' and 'h'. On the other hand, for negative angle deviations, contact takes place at 'a' and 'e'. Contact at other areas is also made when the slider has initial translation.

The estimated wear depth for areas around 'a', 'b', 'c', and 'd' are shown in Fig. 14 to Fig. 17, respectively. The cases of 'e', 'f', 'g', and 'h' show very small wear depth and hence are not shown here for brevity. In Fig. 14, no wear incurred for the cases of positive angle without translation i.e. +4°, +5°, +6° and +6.75 because no contact to area 'a' was made. Likewise, no contact was made to area 'b' for the cases of negative angle without translation so no such results appeared in Fig. 15.

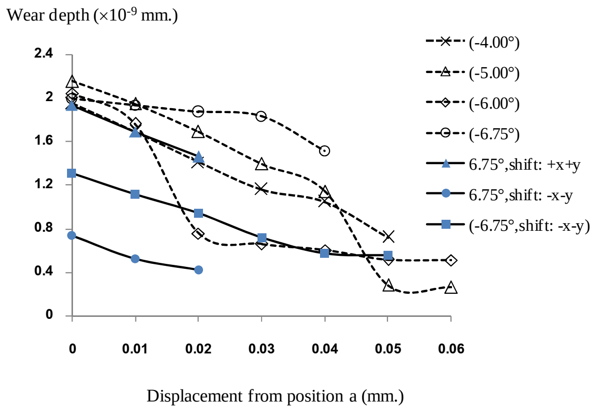


Fig. 14. Wear depth along TiCN-coated gripper area 'a' for different slider initial position.

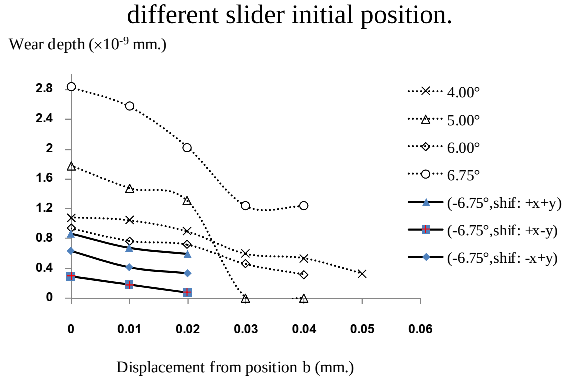


Fig. 15. Wear depth along TiCN-coated gripper area 'b' for different slider initial position

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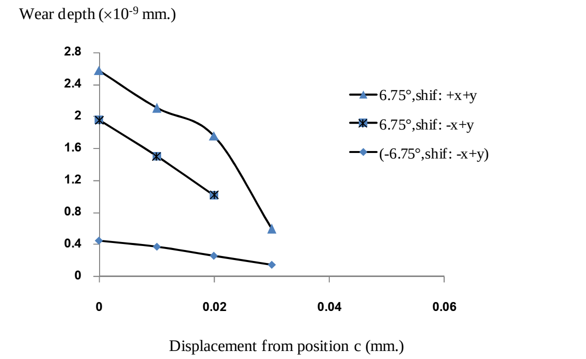

Fig. 16. Wear depth along TiCN-coated gripper area ‘c’ for different slider initial position

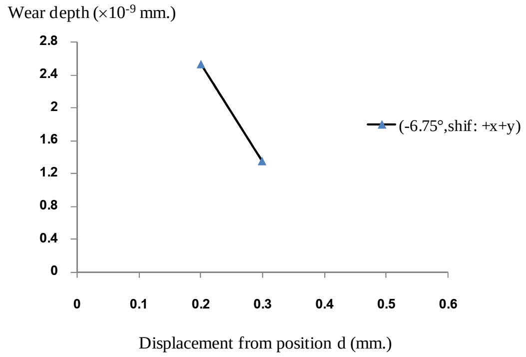

Fig. 17. Wear depth along TiCN-coated gripper area ‘d’ for different slider initial position

B. *Wear depth estimation of CrN-coated grippers*

Similarly, the wear depth on the surface of the CrN-coated grippers was calculated. Although the micro scale contact stress of CrN is generally higher than that of TiCN, the resultant wear is smaller than that of TiCN. This is because the wear depth not only depends on the stress but also on the material properties, i.e. k and H. Fig. 18 to Fig. 21 show the wear depth along the surface of the CrN-coated grippers. The cases of ‘e’, ‘f’, ‘g’, and ‘h’ are not shown here due to their insignificant wear level.

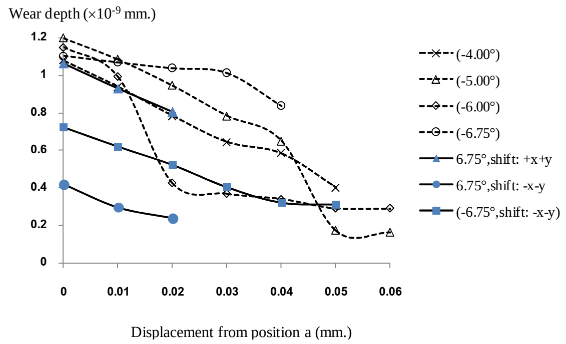

Fig. 18. Wear depth along CrN-coated gripper area ‘a’ for different slider initial position

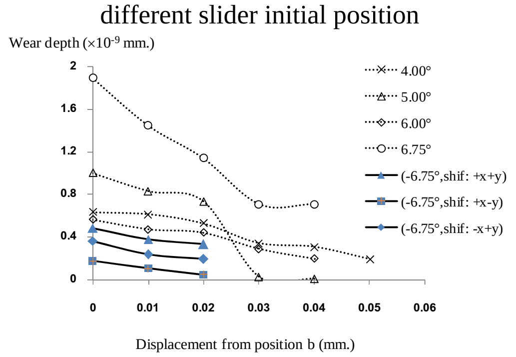

Fig. 19. Wear depth along CrN-coated gripper area ‘b’ for different slider initial position

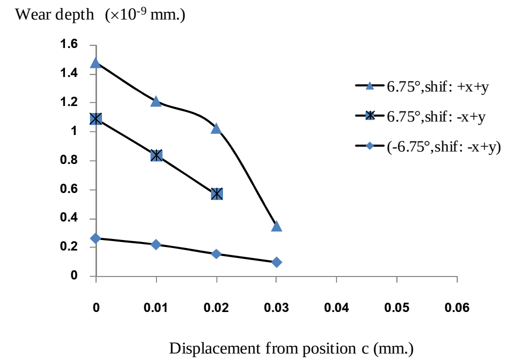

Fig. 20. Wear depth along CrN-coated gripper area ‘c’ for different slider initial position

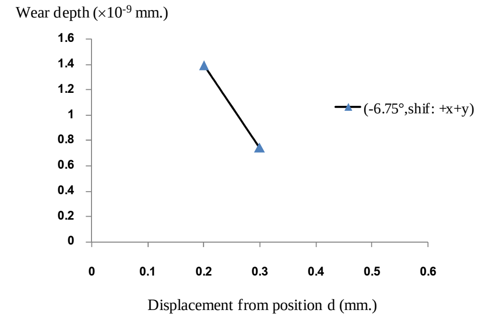

Fig. 21. Wear depth along CrN-coated gripper area ‘d’ for different slider initial position

C. *Lifetime predictions and comparison with non-coated grippers*

From the work of [2] it was concluded that the lifetime of the non-coated grippers is determined by the level of wear at ‘b’. Microscopic examination of damaged grippers revealed 2.5 μm deep wear at ‘b’ [2]. If it is assumed that the coated grippers are also considered ‘damaged’ when wear depth at ‘b’ reaches 2.5 μm, then the cycles to failure for each slider initial position can be calculated. This lifetime estimation is, however, based on the assumption that the slider is repeatedly placed at the same position. Fig. 22 shows estimated lifetime of grippers based on this assumption. It can be seen that for all slider positions, the CrN-coated grippers have the longest lifetime compared to non-coated or TiCN-coated ones.

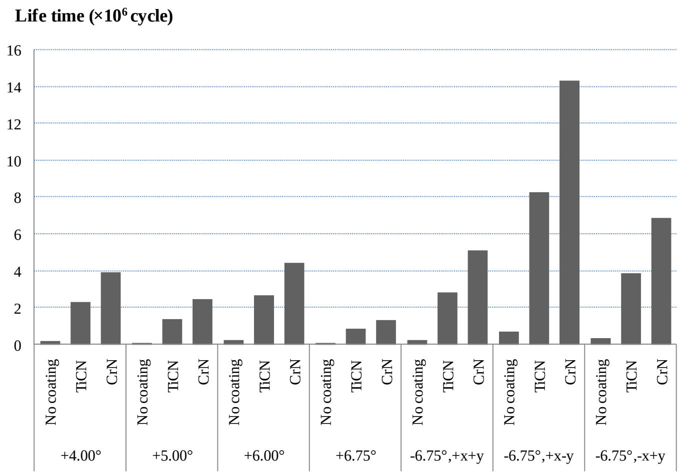

Fig. 22. Estimated lifetime of non coated-, TiCN- and CrN-coated grippers for each slider position

Presently, no information on the actual initial position of the slider in the assembly line is available. If it is assumed that

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the slider initial position is random evenly within the aforementioned range, then the lifetime of the grippers can be estimated from a combination of the lifetime of each position. The estimated lifetime of non-coated grippers, based on this assumption, was in agreement with the actual lifetime and was reported in [2]. Fig. 23 shows the estimated lifetime of the coated grippers compared to non-coated ones. It can be seen that using TiCN coating can increase the lifetime of approximately 10 times. CrN coating can increase the lifetime of around 20 times.

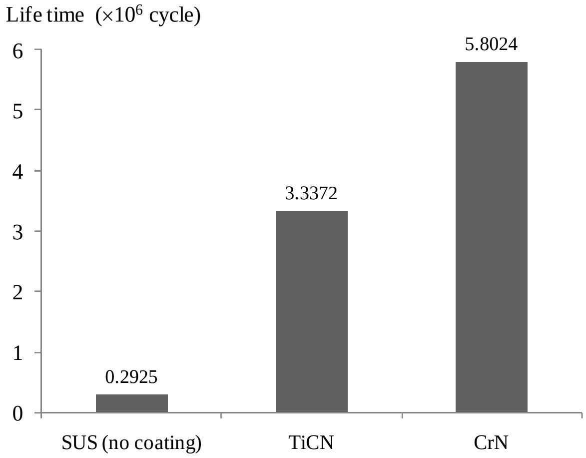

Fig. 23. Estimated lifetime of non coated [2], TiCN- and CrN- coated grippers based on evenly random slider position

In addition, if the slider initial position can be controlled such that the range of deviations narrows down to ±4°, the lifetime can be significantly improved. An approximately 30% increase in life can be achieved. An improvement in lifetime of as much as 50% can be made if the slider is in negative angle deviation only. Fig. 24 shows estimated lifetime for controlled slider initial position, compared to random positions.

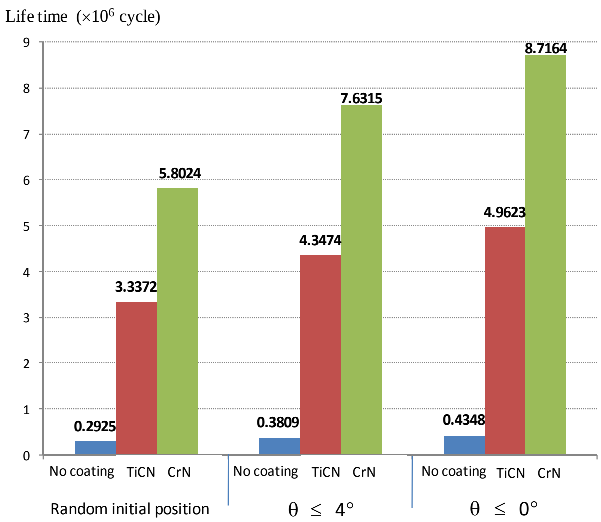

Fig. 24. Estimated lifetime of non coated-, TiCN- and CrN- coated grippers based on controlled slider position

V. CONCLUSIONS

This work studies the use of TiCN and CrN thin film coatings on high precision grippers used for aligning the slider during hard disk drive manufacture. It is found experimentally that both films possess good adhesion strength to the currently stainless steel grippers. The life of the coated grippers is substantially increased, e.g. 10 times for TiCN coating and 20 times for CrN coating. Further lifetime enhancement can be achieved if the slider initial position is controlled such that it only varies in the range of ±4° or negative deviations from the reference position. As in future work, the trial of the coated grippers and the actual lifetime will be compared to the predictions.

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