Patterned Tape Head Air Bearing Surface Development

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Unlike modern hard disk drives, magnetic tape heads operate in continuous contact with the tape media to maintain the low head-to-media spacing required for reliable magnetic recording. This contact, however, generates significant friction forces—on the order of 50 mN—which induce tape vibration and readback signal jitter. To mitigate these effects, a patterned air bearing surface (ABS) design was proposed. Design parameters for the etched steps were derived through modeling that incorporated tape mechanics, surface roughness, and Reynolds lubrication theory. The steps, fabricated via ion milling following photolithography, were placed in non-active regions of the head—areas not containing read/write elements. Experimental results from 1,000 km tape runs demonstrated a 70% reduction in friction.

***Index Terms*—magnetic recording, tape technology, air bearing, friction reduction**

I. INTRODUCTION

In magnetic tape recording systems, a tensioned tape passes at constant velocity over a stationary recording head. A slight tilt, known as the wrap angle, introduces a contact pressure that ensures head-media engagement. Figure 1 illustrates the overall system configuration. Data is written on narrow tracks, and a servo mechanism keeps the head aligned with the target track. The relative motion induces air bearing pressure, influencing contact forces between the head and tape. Friction arises from both contact pressure and viscous shear, leading to vibrations in both longitudinal and transverse directions. These vibrations degrade signal quality and limit storage capacity. In this paper, we present a method to reduce friction by introducing a patterned tape bearing surface (TBS).

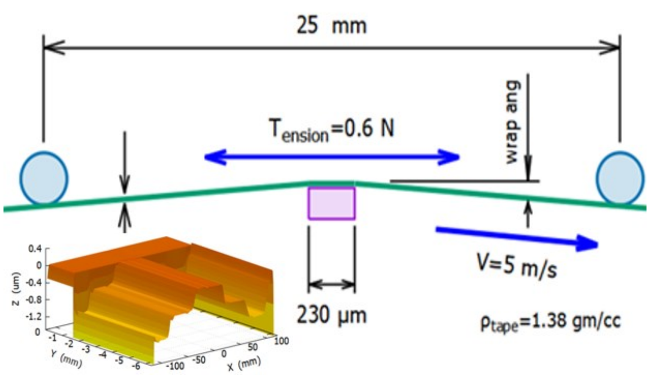

Fig. 1. Overall tape configuration and patterned tape bearing surface

II. BACKGROUND

Previous studies have characterized the tape-head interaction as fundamentally contact-based due to the high surface roughness of magnetic tapes [1]. The tape itself comprises a polymeric substrate with a magnetic coating and a thin lubrication layer, lacking the carbon overcoat typically found in disk media. The magnetic elements on the head are located within a 3 mm wide central "active band" of the 22.5 mm wide head. The surrounding regions are magnetically inactive. To reduce overall friction, we targeted an increase in tape-head clearance in the inactive bands while preserving contact within the active band to ensure recording fidelity. Optimized etched steps were introduced at the leading edges of the inactive bands [2][3]. These steps generate localized air pressure that lifts the tape above the surface roughness, reducing contact. In contrast, the active band maintains contact to support consistent recording. Etched cavities have been tried [9].

III. HEAD FABRICATION

The tape heads were fabricated using an AlTiC substrate, on which magnetic read/write elements were constructed. Each tape row includes a TBS and two arrays comprising 33 read and write transducers, respectively. A closure, also made from AlTiC, is bonded atop the read/write array to protect the transducers.

The TBS pattern was defined through a mask design that generated four photomask patterns. These were transferred onto a photosensitive resist layer using an optical lithography system. A set of rows were assembled and bonded to a stainless steel carrier to maximize process efficiency. The carrier was mounted on a vacuum spindle, and liquid photoresist was dispensed and spin-coated to achieve desired thickness. This process was repeated to obtain a final thickness target. TBS required two layers and eight exposure passes. Ion milling was then used to transfer the pattern into the substrate. Two step etching process were applied to fabricate TBS on figure 1.

IV. SIMULATION

A steady state numerical model was developed to simulate the coupled interaction between the tape, air bearing pressure and surface roughness. The model equations are:

Tape Equation: describes the out-of-plane deformation w of the tape with bending stiffness D, tension T, velocity V, under air bearing pressure P and contact pressure Pc [8].

$$\nabla^4 w + (\rho V^2 - T)\nabla^2 w = P + P_c \quad (1)$$

Reynolds Equation: models the compressible air film pressure P between the tape and head. The clearance is H, the velocity is Λ, and Q denotes pressure flow, derived from the Boltzmann equation at any clearance [4].

$$\nabla(PQH^3\nabla P - \Lambda PH) = 0 \quad (2)$$

Contact Pressure Model: characterizes tape-head interface compliance using a generalized power function with constants c1 and c2, the clearance is h. Alternatively, the classic contact Greenwood-Williamson model [7] can be used.

$$P_c/P_o = (h/c_1)^{1/C_2} \quad (3)$$

The tape and head domains were discretized with a smooth nonuniform Sobolev-norm based finite difference grid [5]. The grid smoothness ensures second order accuracy and low condition number. Detailed feature resolution was attained with 60K variables. The coupling of equations introduced nonlinearity, and the system exhibited bifurcation behavior under certain conditions, leading to multiple stable solutions. A dedicated iterative solver with super-linear convergence was developed to handle the nonlinearity and resolve the hysteresis loops that emerged during parameter sweeps.

The friction force arising from the friction and viscous shear at the tape and head interface was evaluated with the numerical model. The tape deformation, clearance and contact and air bearing pressures were also obtained. The friction results from the product of the contact force and the friction coefficient, assumed 0.5, plus the viscous shear force of the air bearing.

V. EXPERIMENTAL DATA & DISCUSSION

Figure 2 compares friction force versus wrap angle for a step-etched ABS and a standard LTO-9 reader head with no etching. At 0.5° wrap angle—corresponding to normal operating conditions—the reference head exhibited a friction force of approximately 20 mN, while the step-etched head showed a reduced force of 7 mN. Across the full range of wrap angles, the etched head consistently demonstrated lower friction. A localized friction increase at 0.7° may be attributed to the etched edge acting as a skiving surface under high wrap conditions. Low friction and friction jump angle are nicely modeled.

Friction as a function of tape velocity was also measured at a fixed 0.5° wrap angle. (Fig.3) The step-etched ABS maintained low friction from 0.5 to 6 m/s, satisfying operational velocity requirements for LTO systems.

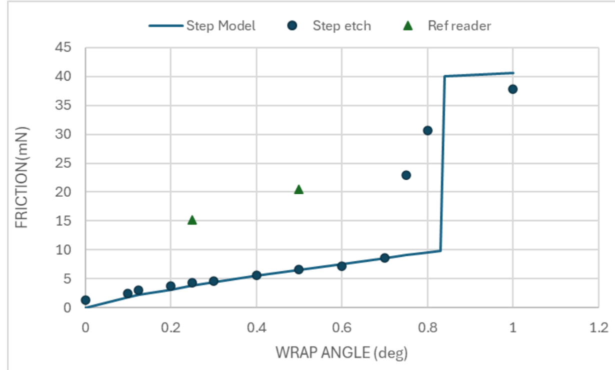

Fig. 2. Friction force as a function of wrap angle, at 5 m/s.

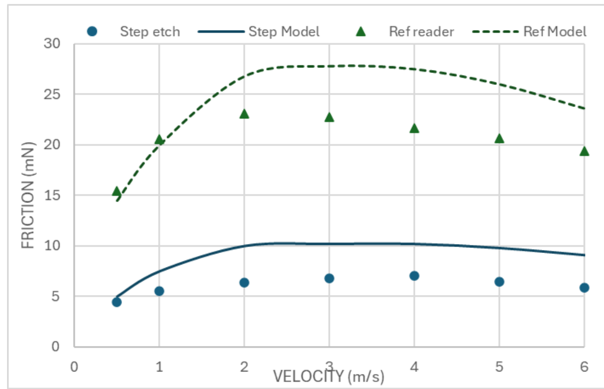

Fig. 3. Friction force as a function of tape velocity, at 0.5 deg wrap angle.

The modeling predicts velocity dependence of friction for step etch head and reference head quantitative well. It will be utilized for further design optimization to reduce friction for future tape heads.

VI. REFERENCES

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