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A MODEL FOR THE MAGNETIC TAPE/GUIDE INTERFACE WITH LASER SURFACE TEXTURING

Bart Raeymaekers [1*], Izhak Etsion[2], Frank E. Talke[1]

[1]Center for Magnetic Recording Research
University of California, San Diego
9500 Gilman Drive, #0401
La Jolla, CA 92093, USA
*bart@talkelab.ucsd.edu

[2]Department of Mechanical Engineering
Technion
Haifa 32000, Israel

ABSTRACT

The spacing between a magnetic tape and a guide in a tape path can be increased by creating dimples on the guide surface. The dimples enhance the formation of an air bearing. A model is presented to maximize the average air bearing pressure.

INTRODUCTION

Lateral tape motion (LTM) is defined as the time-dependent motion of magnetic tape perpendicular to the tape transport direction, and is one of the critical parameters in the design of magnetic tape drives. LTM is influenced by friction between tape and guide surfaces and by the dynamics of the tape and the guides. In a previous investigation [1], laser surface textured guides were studied and it was found that laser texturing reduced the friction coefficient between the magnetic tape and the guide significantly, especially in the low tape speed range.

THEORETICAL MODEL

We have simulated the pressure distribution between the tape and the guide surface for a column of ten dimples. We made the following assumptions:

1. The tape is considered rigid. Local elastic deformations of the tape are neglected. This assumption implies that no elasto-hydrodynamic effects are taken into account.
2. The tape is assumed to be conformal to the guide [2]. This case is identical to a parallel slider bearing. One-dimensional foil bearing simulations [3] show that the tape is indeed conformal to a smooth guide over 95 percent of the interface length.
3. The shape of all dimples is identical and spherical.
4. The gas in the air bearing is compressible and has a constant viscosity.
5. The air bearing is assumed to be infinitely wide, i.e., side flow effects are neglected. Hence, one column of dimples is representative of the whole air bearing surface, when a periodic boundary condition is applied in the direction perpendicular to the flow.
6. The model is only valid for hydrodynamic lubrication.

According to assumption 1, the guide and magnetic tape are separated by a uniform air film of thickness c. It should be noted that in reality the tape is flexible, i.e., simultaneous solution of the Reynolds equation along with the tape elasticity equation is required. However, the assumption of a rigid tape allows a first order approximation of the physical situation without the need for extended numerical solutions.

The effects of the curvature of the cylindrical surface can be neglected in the model, since the minimum tape/guide spacing c is much smaller than the guide radius. Additionally, we assume full fluid film lubrication and therefore require $c \geq 3\sigma_s$ [4]. The dimples are uniformly distributed over the guide surface and each dimple is contained within an imaginary square cell of length $2r_1$. Fig. 1 shows one dimple with radius r_p, positioned at the center of the imaginary cell. We have defined a local Cartesian coordinate system $x^* y^*$ with origin at the center of the imaginary cell.

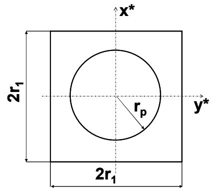

Fig. 1: Single dimple within its imaginary cell

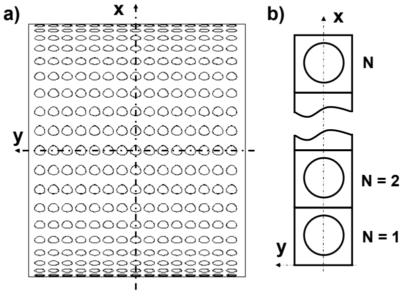

Fig. 2: a) Dimple distribution and b) a single column of dimples (global coordinates)

The cell length r_1 can be expressed as a function of the dimple area density S_p, and the dimple radius r_p, as

$$r_1 = \frac{r_p}{2}\sqrt{\frac{\pi}{S_p}} \qquad (1)$$

Fig. 2 a) shows the distribution of the dimples on the guide surface in a global Cartesian xy coordinate system. Each column of dimples is parallel to the x-axis and can be modeled as shown in Fig. 2 b). Fig. 3 presents a cross section through the center of the dimples. Here, r_p denotes the radius of the dimple, h_p denotes the depth of the dimple, c is the tape/guide minimum spacing and $h(x,y)$ is the clearance between the guide surface and the magnetic tape.

The two dimensional, steady-state compressible Reynolds equation, which relates the pressure distribution to the spacing at the tape/guide interface, is given by

$$\frac{\partial}{\partial x}\left(ph^3\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial y}\left(ph^3\frac{\partial p}{\partial y}\right)=6\mu_a U\frac{\partial(ph)}{\partial x} \qquad (2)$$

where x and y represent coordinates in a global Cartesian coordinate system, $p(x,y)$ is the air bearing pressure, μ_a is the dynamic viscosity of air and $h(x,y)$ is the local clearance between tape and guide. Because the tape/guide spacing is much larger than the mean free path of air, rarefaction effects are neglected.

For the analysis of the textured surface, it is convenient to introduce the following non-dimensional expressions:

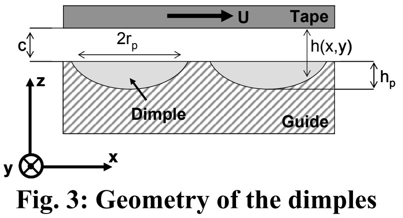

Fig. 3: Geometry of the dimples

$$X = x/r_p,\ Y = y/r_p,\ P(X,Y) = p(x,y)/p_a$$

$$H(X,Y) = h(x,y)/c\ , \qquad (3)$$

where X and Y denote the non-dimensional (global) coordinates, and P and H denote the non-dimensional pressure and spacing, respectively. The normalizing pressure p_a is the atmospheric pressure. The dimensionless local spacing H^* as a function of the dimensionless local coordinates X^*, Y^* for one cell shown in Fig. 3 is given by [5]:

$$H^*\left(X^*,Y^*\right)=1\ \text{, for } X^{*2}+Y^{*2}>1$$

$$H^*\left(X^*,Y^*\right)=1+\sqrt{\left(\frac{\varepsilon}{2\delta}+\frac{1}{8\varepsilon\delta}\right)^2-\left(X^{*2}+Y^{*2}\right)\frac{1}{4\delta^2}}$$

$$-\left(\frac{1}{8\varepsilon\delta}-\frac{\varepsilon}{2\delta}\right)\text{, for } X^{*2}+Y^{*2}\le 1 \qquad (5)$$

where $\varepsilon = h_p/2r_p$ is the aspect ratio of the dimple and $\delta = c/2r_p$ is the dimensionless tape/guide minimum spacing.

To create a column of dimples of identical shape (see Fig. 2 b)), we expand the dimensionless height distribution for a single cell, $H^*\left(X^*,Y^*\right)$, to a column of $N = 10$ cells by repeating the height distribution for a single cell for each cell in the column. The dimensionless Reynolds equation in the global coordinate system can then be expressed as

$$\frac{\partial}{\partial X}\left(PH^3\frac{\partial P}{\partial X}\right)+\frac{\partial}{\partial Y}\left(PH^3\frac{\partial P}{\partial Y}\right)=\frac{\lambda}{\delta^2}\frac{\partial(PH)}{\partial X} \qquad (6)$$

where $\lambda = 3\mu_a U/2r_p p_a$ and $\delta = c/2r_p$.

The following boundary conditions are assumed. The pressure is atmospheric at the inlet and outlet of the tape/guide interface. In addition, the pressure is periodic in the direction perpendicular to the air flow (Y-direction). Multiple columns of dimples next to one another will yield a periodic pressure distribution. The period is defined by the size of the imaginary cell ($2r_1$). The boundary conditions can be expressed as

$$P(X=0,Y)=1$$

$$P(X=N\frac{2r_1}{r_p},Y)=1 \qquad (7)$$

$$\frac{\partial P}{\partial Y}(X,Y=-\frac{r_1}{r_p})=\frac{\partial P}{\partial Y}(X,Y=\frac{r_1}{r_p})=0$$

where N is the number of cells in a column (see Fig. 2 b)). Eq. (6) can be solved for the pressure distribution if the dimensionless spacing $H\left(X,Y\right)$ and the dimensionless parameters λ, δ and ε are specified.

RESULTS AND DISCUSSION

In the following, we use our model to numerically investigate how these parameters can be chosen to yield the highest possible average air bearing pressure between the conformal tape and the guide. A maximized average air bearing pressure will yield the highest load carrying capacity and hence, the highest tape/guide spacing for a given tape tension.

Fig. 4 shows the dimensionless average air bearing pressure p_{avg}/p_a versus the dimple density S_p for different values of the dimple aspect ratio ε and for the reference values $\delta = 0.002$ and $\lambda = 2E-5$. From Fig. 4 we observe that the optimum S_p occurs for values from 0.10 to 0.30 depending on the dimple aspect ratio ε. We note that the optimum dimple density shifts towards lower values for an increasing dimple aspect ratio ε. We also found that the dimensionless tape/guide minimum spacing δ does not affect the optimum dimple density. Simulations of the dimensionless pressure versus the dimple aspect ratio for different values of the parameter λ and δ revealed that the optimum value for the dimple aspect ratio ε is approximately 0.006 regardless of δ or λ. For instance, if the dimple radius $r_p = 50$ µm, we observe that the optimal value of the dimple depth $h_p = 0.6$ µm. We also observed that the dimensionless average air bearing pressure increases for decreasing δ and for increasing tape speed U (increasing λ), as would be expected.

Finally, Fig. 5 shows the optimum combination of dimple density and dimple aspect ratio, for different values of the dimensionless tape/guide minimum spacing and for $\lambda = 2E-5$.

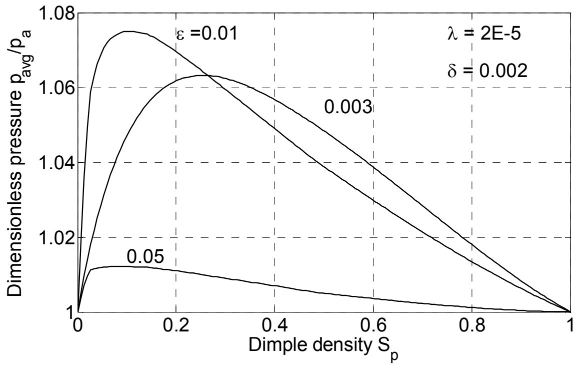

Fig. 4: Dimensionless average air bearing pressure, p_{avg}/p_a versus dimple density S_p

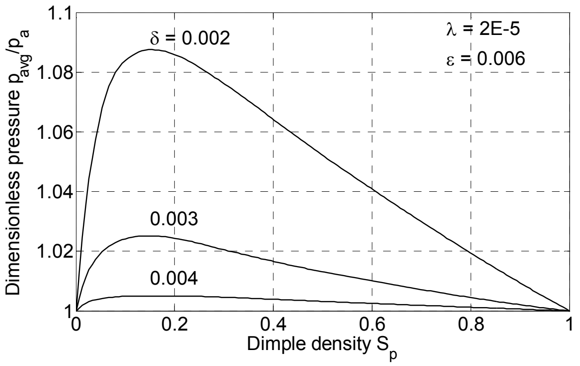

Fig. 5: Dimensionless average air bearing pressure versus dimple density S_p, for the optimum dimple aspect ratio

We observe that for the optimum dimple aspect ratio $\varepsilon = 0.006$ and the optimum dimple density $S_p = 0.15$, the dimensionless pressure reaches a maximum value of approximately 1.09 for $\delta = 0.002$ and $\lambda = 2E-5$. This number represents the maximum dimensionless average pressure that can be obtained, according to our simplified model.

CONCLUSION

- The optimum dimple density with respect to maximum average pressure ranges between 0.1 and 0.3, depending on the dimple aspect ratio. A greater dimple aspect ratio will reduce the optimum dimple density. The tape/guide minimum spacing does not affect the optimum dimple density.
- The optimum dimple aspect ratio for maximum average air bearing pressure was found to be 0.006, almost independent of the dimensionless tape/guide spacing δ and the flow factor λ.

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