ASME Information Storage and Processing Systems Conference, 2005
Santa Clara, CA, June 28-29, 2005

Head-Disk Interface Analysis Using Quadrilateral Adaptive Finite Elements

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ABSTRACT

A finite element solution of the modified Reynolds equation using isoparametric, bilinear quadrilateral elements with an adaptive meshing strategy is presented. The modified hydrodynamic stiffness method (Smith, 1995) was used to obtain a coupled solution of the air bearing equation with the slider equilibrium equations. The vertex label based adaptive meshing algorithm of Cheng et al. (1999) was also implemented. The problem is initially solved with a regular quadrilateral FE mesh. The mesh adaptation (h-refinement) is based on the relative pressure gradients in the initial solution, and on the geometry of the slider. The refinement is implemented on an existing element, if preset criteria on the pressure gradient and/or slider geometry are exceeded.

1. INTRODUCTION

Today, magnetic hard disk drives (HDD’s) constitute a large portion of digital data storage capacity. The overall performance of hard disk drives may appear to depend on simple components; however their design and manufacture require leading-edge capabilities in device modeling, materials science, photolithography, vacuum deposition processes, ion beam etching, reliability testing, mechanical design, machining, air bearing design, tribology, and head/disk interface.

Magnetic recording requires relative motion between the magnetic media and a read-write head. In a computer HDD a shaped slider, attached to a flexible suspension-arm, glides over a rigid cylindrical disk, which rotates at rotational rates reaching 10,000 rpm or more. The trailing edge of the slider contains a built-in magnetic read-write head. Air lubrication between the rotating disk and the slider is critical to maintain a small gap; a delicate balance is established between the suspension preload, air bearing pressure and restoring forces due to small perturbations from the equilibrium flying height.

The numerical modeling of the pivoted slider bearing provides a means to evaluate different configurations without actually having to build them. Different spatial discretization methods have been used for solving the non-linear, compressible RE for the head-disk interface (HDI) problem. These include finite difference (FD) [1], finite volume (FV) [17,18], and finite element (FE) [5,6,13,15] methods. The slider equilibrium position is coupled to the air pressure. The coupling between the two sets of equations can be handled by considering the dynamical effects of the system [11,12,14,16]. Alternatively, the coupled solution can be obtained by formulating the problem entirely for steady state [3,13,15].

One of the challenging problems with numerical analysis is the need to represent a continuous domain with a spatially discretized mesh. The FD method typically requires a structured mesh and is limited in the choice of mesh refinement that it offers. Wu and Bogy presented a three level adaptive meshing strategy based on Delaunay triangulation in a FV based method [17,18]. In this paper a finite element solution of the modified RE using isoparametric, bilinear quadrilateral elements with an adaptive meshing strategy is presented.

2. FORMULATION

The details of the solution method implemented for this work are given in references [7,8]. The problem is initially solved with a regular quadrilateral FE mesh. The mesh adaptation (*h*-refinement) is based on,

a) the relative pressure gradients in the initial solution, and
b) the geometry of the slider.

An existing element is refined, if preset criteria on the pressure gradient and/or slider geometry are exceeded. Such an element is simply divided into smaller ones keeping the original element boundaries intact. The admissible function algorithm, of Cheng et al. [2], is implemented in order to prevent dangling nodes. A typical admissible mesh division is depicted in Fig. 1. A bandwidth reduction algorithm has been applied in order to keep the bandwidth of the system as small as possible for efficient memory management and minimizing computational time [4].

2.1 Slider Mechanics

In this work, the slider mechanics is represented by the simultaneous solution of the 2D, compressible Reynolds Equation (RE), with second order slip flow correction [9], and the rigid body equilibrium equations of the slider. The coupled solution is obtained by the modified hydrodynamic stiffness method [15]. Compressible RE with slip flow corrections is given by:

$$\nabla.\left\{ ph^3 Q_r \nabla p \right\} = 6\mu\left(\vec{V}.\nabla(ph)\right), \qquad (1)$$

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where, p is the air pressure, h is the head-disk clearance, μ is the dynamic viscosity of air $\vec{V}$ is the disk velocity and $Q_r = 1 + 6(\lambda/h) + 6\ (\lambda/h)^2$ is the second order slip flow correction factor, with the molecular mean free path λ. The head-disk clearance is given by:

$$h(x,y) = h_p + \alpha\left(x_p - x\right) + \beta\left(y - y_p\right) + h_0\left(x,y\right) \qquad (3)$$

where h_p is the height and (x_p,y_p) is the planar location of the slider pivot point. The pitch and roll angles are α and β, respectively. The rigid body equilibrium of the slider with respect to its steady state flying height is represented by:

$$\mathbf{K_s}\ \mathbf{du} = \mathbf{f}(p) - \mathbf{f}^{ext} \qquad (4)$$

where $\mathbf{K_s}$ is the stiffness matrix, $\mathbf{du}$ is the degree of freedom vector composed of the incremental changes of $d\alpha$, $d\beta$ *and* dh_p, $\mathbf{f}(p)$ is the vector of normal forces and bending moments acting on the slider due to air lubrication, and $\mathbf{f}^{ext}$ if the vector representing initial spring loads. The *modified hydrodynamic stiffness* method [13,15] was used to obtain a coupled solution of the air bearing equation with the slider equilibrium equations. Details of the implementation are provided in [8].

2.2 Pressure Gradient Based Subdivision Level, $S_1(f)$

The element subdivision assignment S_1 is an integer value based on the pressure gradient of a given element. For *each* element, f, two element subdivision levels indicated by S_{1x} and S_{1y} are calculated in the x- and y-directions as follows:

$$\text{if } R_{low} \le \left\{\frac{dp}{dx}\right\}_{\max}^{\text{elem}} \Big/ \left\{\frac{dp}{dx}\right\}_{\max}^{\text{mesh}} \le R_{high} \quad \text{then } S_{1x}\left(f\right) = I$$

$$\text{if } R_{low} \le \left\{\frac{dp}{dy}\right\}_{\max}^{\text{elem}} \Big/ \left\{\frac{dp}{dy}\right\}_{\max}^{\text{mesh}} \le R_{high} \quad \text{then } S_{1y}\left(f\right) = I$$

where R_{low} and R_{high} are the lower and upper limits of the pressures gradient ratios and $I \in \left(N \cup \{0\}\right)$ is an integer value indicating the level of subdivisions. As the pressure gradient ratio approaches 1 the value of I should be increased to ensure finer refinement. In the implementation, the pressure gradient of each element is checked and an approporiate class number C_i is assigned for each element. The refinement classes C_i used in this work are given in Table 1. The refinement level assignments are typically higher for higher classes. For example, a choice could be $C_1 = C_2 = C_3 = 0$, $C_4 = 1$ and $C_5 = 2$.

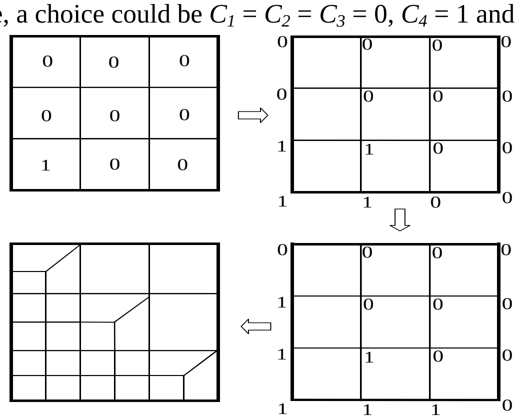

Figure 1. Admissible label assignment

For a given element the maximum of the two refinement levels is used:

$$S_1(f) = \max\left(S_{1x}, S_{1y}\right) \qquad (5)$$

2.3 Step Height Based Subdivision Level, $S_2(f)$

It is important to refine the mesh locally along all of the edges where there is an abrupt change in the height, as this condition causes very large changes in pressure in the vicinity of such edges. The step height based subdivision assignment around the outer periphery of a geometric step is carried out by using the S_2 function:

$$S_2(f) = \max\left(S_1(f)\right) \qquad (6)$$

2.4 Effective Adaptation Criterion, $S(f)$

The effective adaptation criterion is defined as follows:

$$S(f) = \max\left(S_1(f), S_2(f)\right). \qquad (7)$$

Note that this criterion is only used for the elements associated with edges of the geometry. For all other elements the $S_2(f) = 0$.

3. RESULTS

The algorithm is applied to a negative-pressure slider bearing, whose geometric details are reported in reference [7]. The initial mesh consists of regular rectangular four noded elements. Two finite element meshes with different adaptation levels are shown in Fig 2. Part-a of this figure shows a mesh initially with 6516 (81×81) nodes, with a maximum adaptation level of one, resulting in 13505 nodes and 13327 quadrilateral elements. The refinement class assignments for this case were $C_1 = C_2 = C_3 = 0$, $C_4 = 1$ and $C_5 = 1$. Fig. 2b shows a mesh initially with 7569 (87×87) nodes, with a maximum adaptation level of two, resulting in 15519 nodes and 15338 four noded elements. The refinement class assignments for this case were $C_1 = C_2 = C_3 = 0 = C_4 = 1$ and $C_5 = 2$. Observe that the mesh density is high at the trailing edge. Also the mesh is refined at the steps where a large change in slider height exists. The pressure contours predicted by the first and second mesh are presented in Figs 3a and 3b, respectively. This figure shows that the refinement level defined in the second mesh is sufficient to resolve the trailing edge pressure gradient.

4. FUTURE WORK

Improvements to this work in the future should include a) placement of nodes exactly on the recess boundaries, b) implementation of iterative solution scheme, c) implementation of contact pressure between the disk and the slider.

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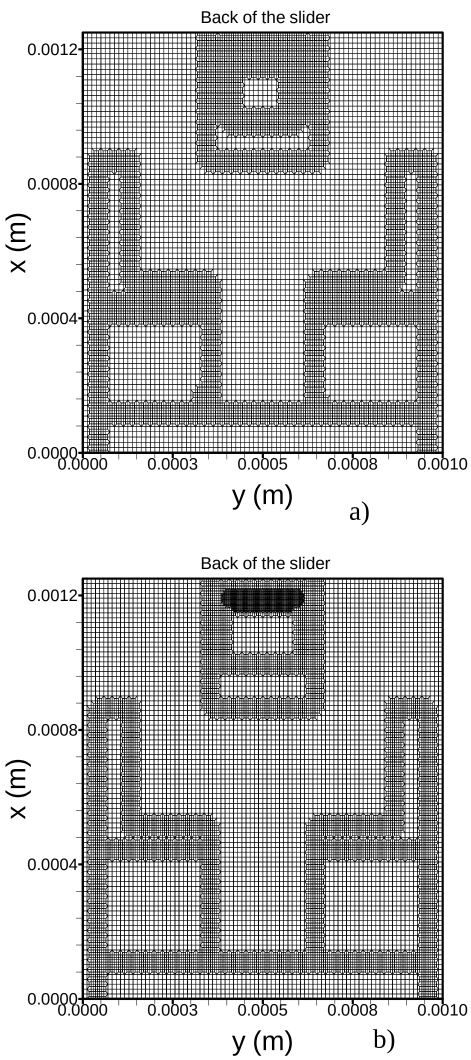

Figure 2. Mesh layout for the negative bearing slider a) with one subdivision level (initial mesh: 81 × 81), b) with two subdivision levels (initial mesh: 87 × 87).

R_{low}	R_{high}	Refinement Class, C_i
1×10^{-4}	5×10^{-4}	1
5×10^{-4}	5×10^{-3}	2
5×10^{-3}	2.5×10^{-1}	3
2.5×10^{-1}	8.5×10^{-1}	4
8.5×10^{-1}	1	5

Table 1 The pressure gradient ratios used to determine refinement levels.

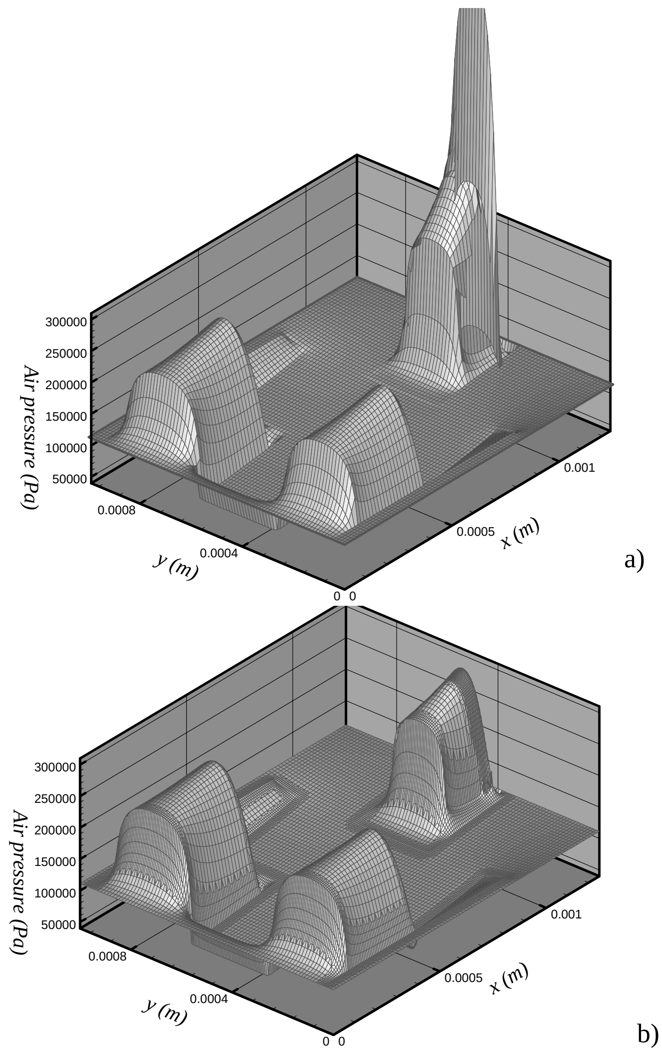

Figure 3. Comparison of the air pressure distributions under the negative bearing slider with a) Uniform 87 × 87 mesh, and b) with the mesh given in Figure 3b.