Optimum Design of a HDD Suspension System

Presented in 1st Data Storage Technology Conference (DST-CON 2008)

Darin Wannapong and Sujin Bureerat**

Abstract

Topology optimisation is one of the most efficient and effective numerical tools for design/optimisation of a hard disk drive (HDD) suspension. In this paper, the application of topology optimisation to the conceptual design of a suspension is presented. The impact of predefined topological design domains on the resulting load beam topologies is investigated. The comparison shows that the predefined design domains of the topological design problem have an impact on the suspension dynamic characteristics.

Introduction

A suspension system is a part that connects an E-block to a sliding head in a HDD. It can be classified according to the start-up options as contact start/stop (CSS) and load/unload (L/UL) suspensions. Suspensions can also be categorized as being 3-piece or 4-piece. The former has three main components i.e. baseplate, load beam and gimbal (flexure) whereas the later has four main parts with a hinge being added to the system. The baseplate is used as an attachment to the E-block part. The hinge is introduced to the system so as to enable pitching and rolling movement of the load beam. The load beam is usually stiffened by adding to its edges a couple of stiffeners, usually called rails (Lee et al., 2006). The sliding head is attached at the tip of the beam by a spherical joint called a dimmer. The dimmer enables the head to move without a severe contact between itself and the platter's flexible shape.

Suspension design is said to be complicated and difficult due to some conflicting design conditions and manufacturing tolerances. It can be thought of as a cantilever beam extended from an E-block. The suspension needs to have sufficiently low vertical stiffness so that the air bearing to suspension stiffness ratio is maintained at the proper range (Yu and Liu , 2005). However, the in-plane dynamic stiffness has to be as high as possible in order to alleviate the off-track phenomenon and enable the servo bandwidth being increased (Bensfe and Sigmund,2003; Yu and Liu,2005). This means that we need to minimise the suspension vertical stiffness and, at the same time, maximise the natural frequencies associated with the sway and torsion modes (Yu and Liu , 2005).

In the past, engineers designed their suspension by the trial-and-error approach. However, it has been found recently that the use of optimisation

---

Department of Mechanical Engineering, Khon Kaen University, Khone Kaen, Thailand, 40002

**corresponding author; e-mail: daringroy@hotmail.com, sujbur@kku.ac.th*

technology to suspension design is the more efficient and effective approach (Yang and Tu , 1996). Some research work on the use of topology optimisation for the design of a HDD suspension has been made (Lee et al.,2006;Yu and Liu,2005;Yang and Tu,1996;Hong et al.,2005;Lau and Du,2004;Pan et al.,2002). The design problems are mostly the maximisation of sway and torsion modes natural frequencies whereas the mass and vertical stiffness are constrained (Yu and Liu, 2005).

In this paper, the use of topology optimisation for the conceptual design of a load beam is studied. Several topological design problems with different design domains are posed to find an initial configuration of the load beam. The design objective is aimed at maximising the first sway mode natural frequency whilst structural mass being constrained. The attain optimum topologies of the load beam are compared and discussed. It is shown that the predefined topological design domain has an impact on the initial topology of the load beam.

Topology Optimisation

A constrained optimisation problem is assigned to find the solution of design variables that optimise the value of design objective while fulfilling predefined constraints. For topological optimisation, since it is commonly operated on the conceptual design stage, some of the design constrains can be removed and the design problem can be simplified as:

$$\min_{\boldsymbol{\rho}} : f(\boldsymbol{\rho}) \tag{1}$$

Subject to

$$m(\mathbf{r}) = r.m(\mathbf{1})$$

$$\mathbf{0} < \mathbf{r}_l \leq \mathbf{r} \leq \mathbf{1}$$

where $\mathbf{r}$ is the vector of topological design variables having lower and upper bounds as $\mathbf{r}_l$ and $\mathbf{1}$ respectively

$f(\mathbf{r})$ is an objective function

$m(\mathbf{r})$ is structural mass

and r is the ratio of structural mass to the maximum mass.

Starting with a predefined structural design domain with boundary conditions and applied loads as shown in Fig 1, the initial structure can have voids and some parts are unchangeable. The design problem can be thought of as how to obtain the best material distribution on the design domain while the objective function value is optimised. The classical design objectives are structural compliance, eigenvalue and buckling factor (Bensfe and Sigmund, 2003).

Topological design is traditionally carried out by employing finite element analysis and optimisation techniques. For a microstructure-based approach, with a predefined structural design domain being assigned, a structure is discretised into a number of finite elements (Figure 2). Topology design variables are element density distribution which implies that locations at which element density is nearly zero form voids on the structure whereas the others represent material solid. The inevitable problem encountered when performing topological design is checkerboard formation due to numerical instability of the finite element method. It has been illustrated that, for the low-order finite element types such as 4-node elements, a topology with checkerboards is artificially stiffer. Such a problem can be alleviated by applying the higher order finite element formulation (Bensfe and Sigmund , 2003) and the use of additional numerical schemes e.g. filtering technique (Sigmund and O, 2001) and checkerboard constraint (Poulsen, 2002) and ground elements filtering (Kunakote and Bureerat , 2006).

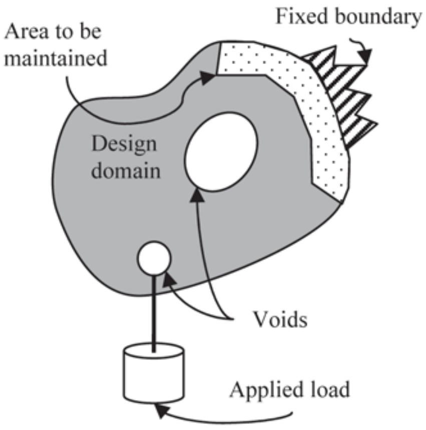

Figure 1. Design domain for topology optimisation

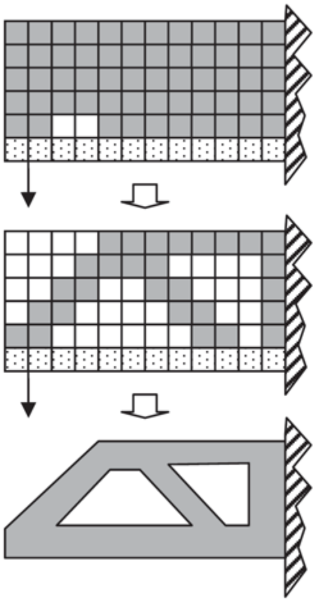

Figure 2. Practical topological design process

Design Problems

The topology optimisation problem in the paper can be written as:

$$\min_{\boldsymbol{\rho}} : f_{1^{st}\, sway} \tag{2}$$

Subject to

$$m(\mathbf{r}) = r.m(\mathbf{1})$$

$$\mathbf{0} < \mathbf{r}_l \leq \mathbf{r} \leq \mathbf{r}_u$$

The structure is made up of stainless steel. The mass reduction ratio is set to be 0.5. Three different design domains are proposed as shown in Figure 3-5. The design domain for eigenvalue or dynamic stiffness maximisation needs some parts to be maintained in order to have a reasonable optimum topology (Bensfe and Sigmund ,2003). Note that only the hinge and load beam are used in this design study. The first design domain termed DM1 has a rectangular design domain. This is a design domain that most of the articles in the literature employ. The second design domain (DM2) has a trapezoidal shape where small strips along the tapered edges are maintained. The third domain (DM3) is a 3D design domain as shown in Figure 5. It is the DM2 design domain with stiffeners being added as shown. The first two domains use membrane elements so as to avoid mode tracking operation while the last domain uses shell elements. The high-order finite element formulations are used so that checkerboard patterns can be suppressed. It should be noted that, in this study, the hinge is not allowed to be changed as it is used to deal with suspension compliance sufficiency.

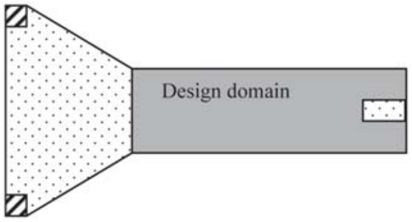

Figure 3. DM1 design domain

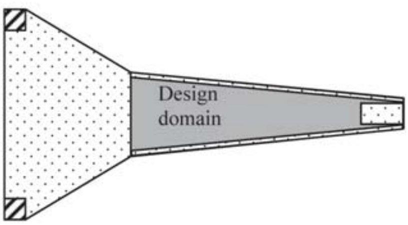

Figure 4. DM2 design domain

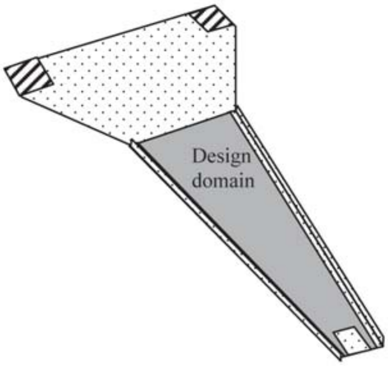

Figure 5. DM3 design domain

Optimum Results

The optimum topologies obtained from using DM1, DM2 and DM3 are displayed in Figure 6, Figure 7 and Figure 8 respectively. The first two topologies are somewhat symmetric while the third topology is not symmetric due to the mode switching effects. All of the topologies are refined and three different shapes of the suspension are obtained as depicted in Figure 9-11. Note that the layout of the DM3 load beam is modified to be symmetric. Three of them have a couple of rails attached to the edges.

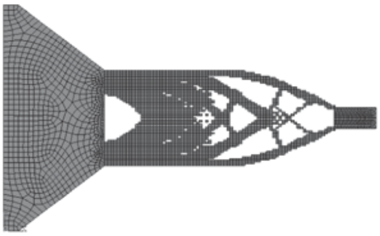

Figure 6. Optimum topology of DM1

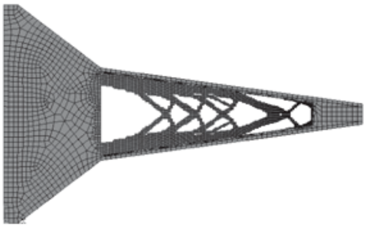

Figure 7. Optimum topology of DM2

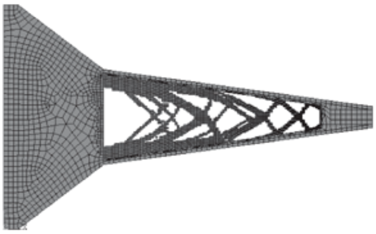

Figure 8. Optimum topology of DM3

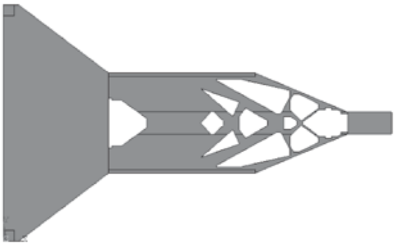

Figure 9. Optimum shape of DM1

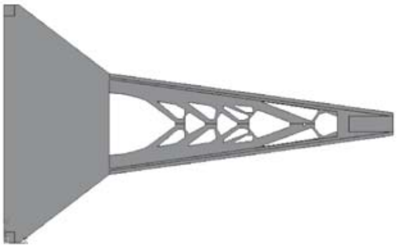

Figure 10. Optimum shape of DM2

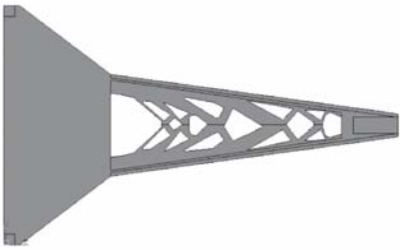

Figure 11. Optimum shape of DM3

The structures in Figure 9-11 are then modelled using shell elements. The first three sway-mode natural frequencies of the structures are given in Table 1. It can be seen that the structure DM1 has the highest first sway mode natural frequency due to its wider design domain. The natural frequencies of DM2 and DM3 structures are said to be indifferent as they are obtained from using the similar design domains. Nevertheless, based upon the FRF magnitude (in-plane (y-direction) point receptance at the tip of the structures) as show in Figure 12, it can be seen that the DM2 structure has superior harmonic response to the others while the DM1 structure is the worst.

Table 1. Sway Mode Natural Frequencies

Modes	DM1	DM2	DM3
1st sway	6093	4876	4884
2nd sway	13124	12640	12288
3rd sway	14034	14029	14220

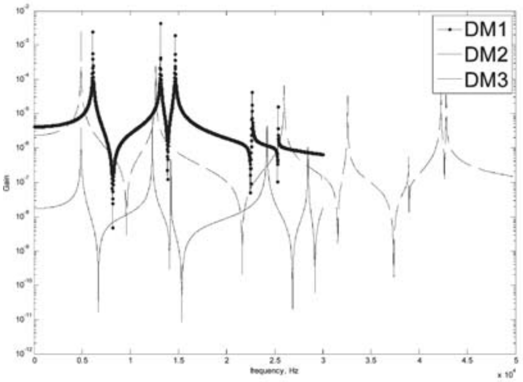

Figure 12. FRF of the suspensions DM1, DM2 and DM3

Conclusion

The present work shows that the predefined design domains affect the resulting load beam topologies and their dynamic characteristics. Both natural frequency and FRF magnitude are some of the most important design criteria for HDD suspension systems. DM1 domain gives the best sway-node natural frequency but has inferior harmonic response compared to the others. The use of membrane elements is advantageous over shell elements when maximising the sway mode frequencies as it has no undesirable mode switching problems.

Acknowledgment

The authors are graceful for the support from NECTEC, I/UCRC KKU, Western Digital (Thailand), and the Faculty of Engineering, KKU.

References

Bensfe, M. P. and Sigmund, O. 2003. *Topology optimization theory, method and applications*, Springer-Verlag, Berlin Heidelberg.

Hong, E. J., Oh, W. S., Park, N. C., Yang, H. S. and Park, Y. P. 2005. "Design of suspension and swing arm for improved shock resistance in the micro optical disk drives," *Microsystem Technologies*, vol. 11, pp. 506-514.

Kunakote, T., and Bureerat, S. 2006. "Topological Design of Structures with Stress Constraints," in *20th Conference of Mechanical Engineering Network of Thailand*, Nakhon Ratchasima, Thailand, pp. 153-157

Lau, G. K. and Du, H.2004. “Topology optimization of head suspension assemblies for suppressing head lift-off”. *Microsystem Technologies*, vol., pp. 671-679.

Lee, H. S., Kim, W. S., and Lee, H. S. 2006 . “Suspension to reduce off-track due to disk vibration and suspension bending,” in Asia-Pacific Magnetic Recording conference, pp. 1-2.

Pan, L., Lau, G. K., Du, H. and Ling, S.-F.2002. “On optimal design of HDD suspension using topology optimization,” *Microsystem Technologies*, vol. 9, pp. 137-146.

Poulsen, A.2002. “A Simple Scheme to Prevent Checkerboard Patterns and One-Node Connected Hinges in Topology Optimization,” *Structural and Multidisciplinary Optimization*, vol. 24, pp. 396 – 399.

Sigmund, O.O. 2001. “A 99 line topology optimization code written in MATLAB,” *Structural and Multidisciplinary Optimization*, vol. 21, pp. 120 – 127.

Yang, Y. P.and Tu, C.C. 1996. “Multiobjective optimization of hard disk Suspension assemblies: partI structure design and sensitivity analysis,” *Computers and Structures*, vol. 59, no. 4, pp. 757-770.

Yu, S. K., and Liu, B.2005. “Topology optimization for femto suspension design,” *Microsystem Technologies*, vol. 11, pp. 851-856.

* * *