Structural Dynamics Modification Using Surface Grooving Technique

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Structural Dynamics Modification (SDM) is a very effective technique to improve structure's dynamic characteristics by adding or removing auxiliary structures, changing material properties and shape of structure. Among those of SDM technique, the method to change structure shape has been mostly relied on engineer's experience and time consuming trial-and-error process. In order to develop a systematic method to change structure shape, surface grooving technique is studied. In this work, the shape of base structure is modified to improve its dynamic characteristics such as natural frequencies via surface grooving technique. Grooving shape is formed by merging the neighboring small embossed elements after analyzing frequency increment sensitivities of all the surrounding emboss elements. All this process is targeted to pack in software to get an optimum grooving shape automatically. In this package, the initial grooving position starts from the element having highest modal strain energy then it expands into neighboring elements. The range of grooving area for checking its frequency sensitivities is restricted to their surrounding elements to reduce its computation effort. The developed algorithm was tested with a hard disk drives (HDD) cover to raise its natural frequency by giving some groove on its surface. Also the grooved HDD cover design was manufactured using rapid prototyping and tested to prove the effectiveness of the surface grooving as SDM techniques.

1. Introduction

Structural Dynamics Modification (SDM) is a very effective technique to improve structure's dynamic characteristics such as natural frequency, mode shape and frequency response function (FRF). This research topic has been widely studied since 1970s and the overall methodology of the technique and issues was summarized by Avitabile [1].

Among those of SDM technique, the rib design problems like adding beam stiffeners have been studied. Yamazaki [2] proposed the stiffener layout optimization technique of plates by introducing a growing and branching tree model. In this technique, a stiffener start from seeds, the positions of which are predetermined in advance, and grows stiffeners around seeds by obeying the growing and branching rules depending on design sensitivity. Lam and Santhikumar [3] developed a methodology for an automatic determination of optimum rib locations within the given set of design constraints such as height, width of ribs and distance between ribs. Utilizing evolution strategies (ESs) and the constraint-handling technique of EVOSLINOC (Evolution Strategies for Scalar Optimization with Linear and Nonlinear Constraints), Lee, Kim and Park [4] proposed a new geometry constraint handling technique which can define both convex and concave feasible regions and measure a degree of geometry constraint violation.

But in the past several decades, there only has been much lot of studies to add or remove the auxiliary structures. Just a few extensive studies have been carried out on changing the shape of structure which is limited to the spatial or light weight constraints condition. So, according to industrial demands increase, necessity of systematic methodology for changing shape is increasing.

Up to now, the method to change shape of structure has been mostly relied on engineer's experience and trial-and-error process. For that reason, process is very time-consuming and inaccurate. So for improving the computational efficiency and accuracy, Yang, Chen and Lee [5] proposed bead pattern optimization technique. This method can roughly categorize into two parts. At first, topology optimization is carried out adding the beam elements to calculate the changes of moment of inertia in a plane cross-section. According to the result of this topology optimization, the optimal beam deployment is obtained. Then, based on this beam deployment, a bead pattern is generated. Although this bead pattern optimization is systematic, it still depends on a engineer’s experience when a bead pattern is formed.

So, this research is targeted on developing the systematic algorithm which is called Surface Grooving Technique for improving targeted frequency of structure and offer a guideline for creating arbitrary shape and deployment.

In this work, the shape of base structure is modified to improve its dynamic characteristics such as natural frequencies by surface grooving technique. Grooving shape was formed by merging the neighboring small embossed elements after analyzing frequency increment sensitivities of all the surrounding emboss elements.

The initial grooving position starts from the element having highest modal strain energy and the grooving expands into neighboring elements. The range of targeting grooving area for checking its frequency sensitivities is restricted to their surrounding elements to reduce its computation effort. The developed algorithm was tested with a hard disk drives (HDD) cover to raise its natural frequency by giving some groove on its surface. Also the grooved HDD cover design was manufactured using rapid prototyping and tested to prove the effectiveness of the surface grooving as SDM techniques.

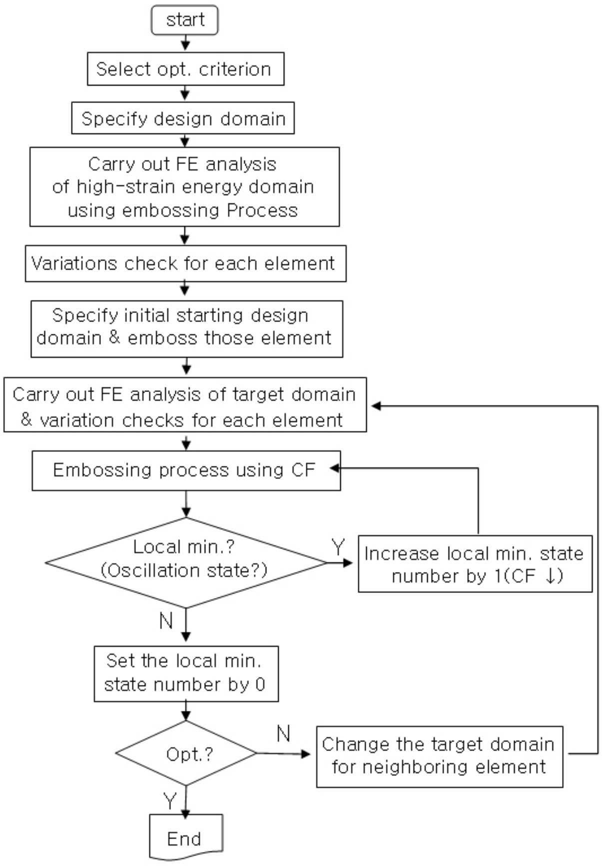


Fig 1. Flowchart of Surface Grooving Technique

2. SURFACE GROOVING TECHNIQUE

2.1 Algorithm

Groove means arbitrary shaped bead pattern which gathered each embossed element. It is formed by merging the neighboring small embossed elements and expands into arbitrary shape and also can be divided into arbitrary numbers.

Surface grooving technique can be described by the following steps.

Step 1 : Select optimization criteria and specify design domain. Calculate modal strain energy at each element within design domain. Modal strain energy (MSE) [6] is defined as

$$MSE_{ij} = \frac{1}{2}\{\phi_{ij}\}^T \left[K_j\right]\{\phi_{ij}\} \tag{1}$$

MSE_{ij} is modal strain energy of *j*th element stiffness matrix in the *i*th mode shape. $\left[K_j\right]$ is the stiffness matrix of the *j*th element, and $\{\phi_{ij}\}$ is a collection matrix conformal with, $\left[K_j\right]$ containing the *i*th mode shape components associated with the degrees of freedom of element *j*.

Step 2 : Carry out finite element analysis using embossing process for searching the high-modal strain energy domain which was calculated in the previous Step.

Step 3 : Check frequency variation for the case of each selected element in the previous step. Then, specify initial starting region and emboss those elements.

Step 4 : Carry out embossing process using selected Criterion Factor. If optimum value falls into the local minimum, reduce the criterion factor for expanding the candidate elements and repeat this step until escaping the local minimum.

Step 5 : Change the target domain for neighboring element and repeat the steps 4~5. Target domain consists of embossed elements and their neighboring elements.

Following the algorithm, grooving shape was formed by merging the neighboring small embossing elements after analyzing frequency increment variation for all the neighboring emboss elements. The flowchart of this iteration is shown in Fig 1.

2.2 Criterion Factor (CF)

Criterion Factor is defined as below :

$$\alpha_e \geq CF \cdot \alpha_{Max} \tag{2}$$

$$\alpha_e : Embossing \quad Variation$$

$$\alpha_{Max} : Max.\, Variation$$

$$0 < CF < 1$$

The elements which have bigger variation than the maximum variation multiplied by criterion factor will be selected for embossing elements. Usually, criterion factor is set as 0.98.

3. NUMERICAL EXAMPLE

This surface grooving technique was applied to a hard disk drives (HDD) cover model intended to raise its 1st natural frequency by giving some groove on its surface.

Fig 2 shows HDD cover and Fig 3. shows its finite element model. Fig. 4 shows modal strain energy which is calculated using Eq. (1) of the cover model. Fig. 5 is the top-view of HDD cover FE model. White region indicates design domain and grayed region indicates the elements which have high-modal strain energy. Among the elements having high-modal strain energy, initial starting elements are selected through steps 2~3. Figs 8-(a) and 9-(a) show the initial starting elements.

The HDD cover FE model is in free-free condition and its dimensions are about: length 145mm, width 100mm, height 10mm. Aluminum is used for this HDD model and the 1st natural frequency of this FEmodel is 249.64Hz (twisting mode). Height of embossed element is set 1mm.

Fig 2. HDD Cover

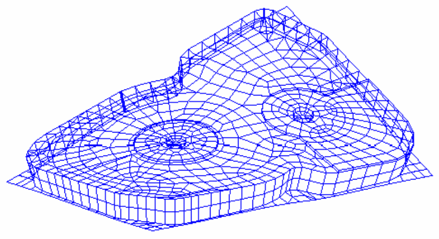


Fig 3. HDD Cover FE Model

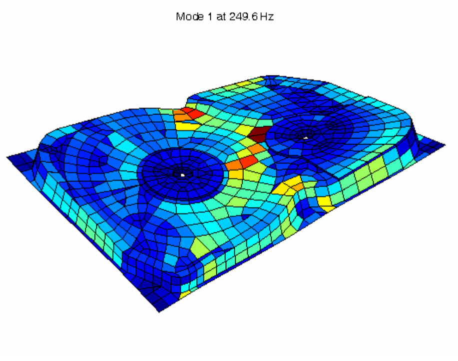


Fig 4. Modal strain energy

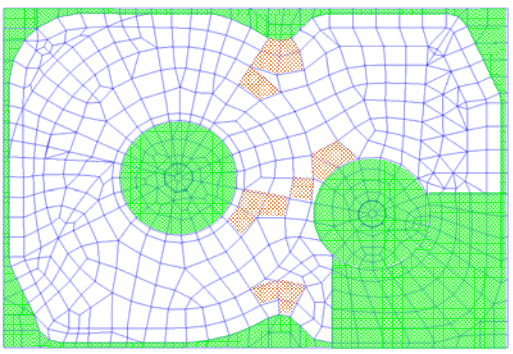


Fig 5. Design Domain
and high-modal strain energy domain

Fig 6. shows the variation of the 1st natural frequency and Fig 7 shows the computing times (min.)
To verify the efficiency of the surface grooving technique, simulations were carried out for three cases.

'whole' indicates the whole design domain was calculated at each iteration to find global maximum natural frequency and its grooving shape. 'range' indicates only the neighboring elements tested at each iteration but doesn't used the high-modal strain energy domain to find initial grooving element. 'strain' indicates only the neighboring element are tested at each iteration and the high-modal strain energy domain is used to find initial grooving element.

Figs 6 and 7 show that the 1st natural frequency raise looks similar for all the cases but its very different. Case 'strain' can effectively reduce its computing efforts drastically.

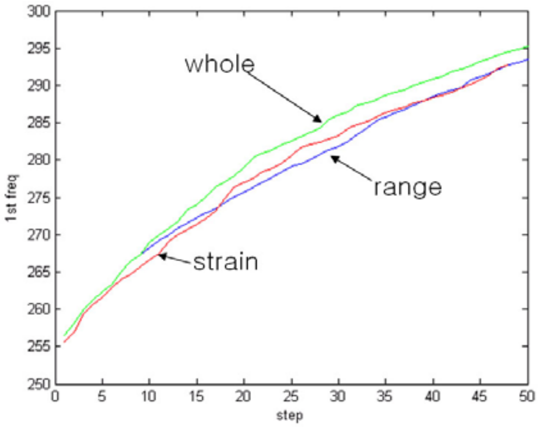


Fig 6. 1st natural Frequency

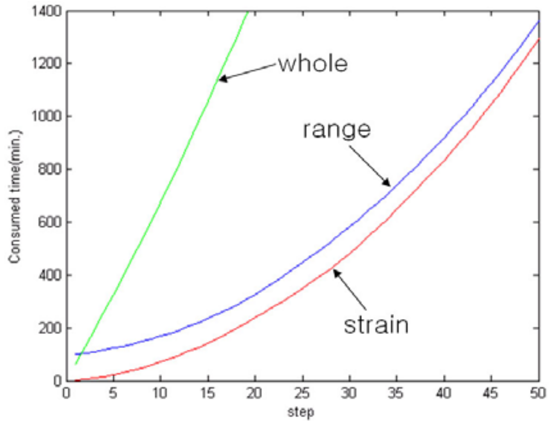
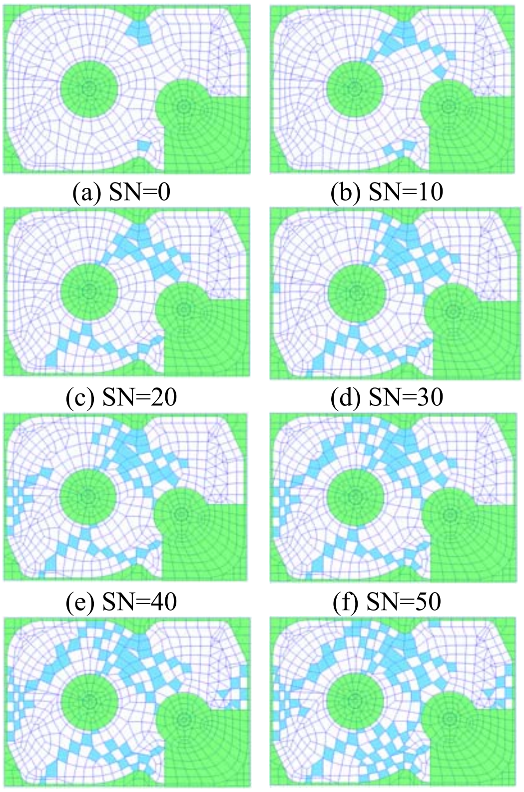
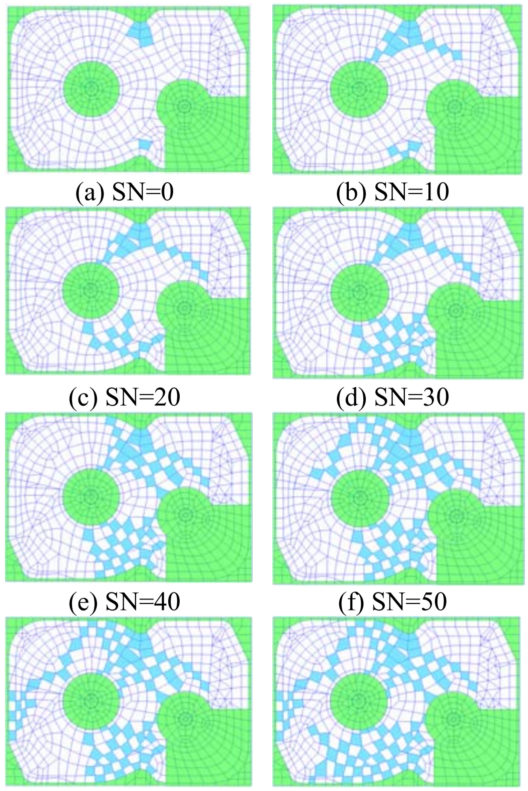


Fig 7. Computing Times(min.)

Figs 8, 9 show the shape of grooved pattern in each Step Number (SN). Those patterns are very similar to each other. There occurs checker-board pattern in the middle of model and diagonal-bead patterned groove is observed in up to left region.

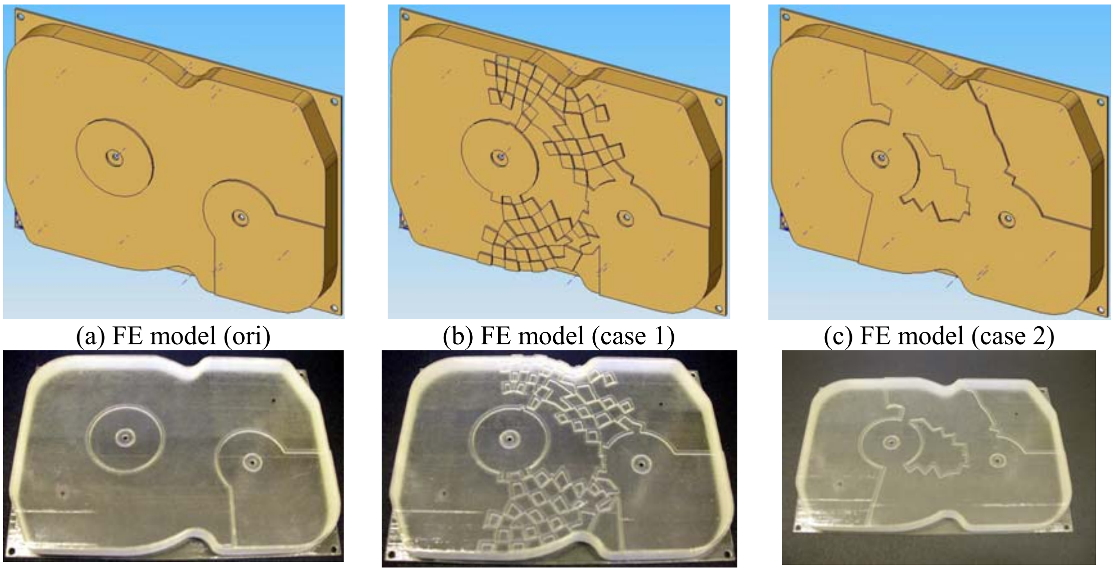

(a) SN=0 (b) SN=10
(c) SN=20 (d) SN=30
(e) SN=40 (f) SN=50
(g) SN=60 (h) SN=70
Fig 8. Grooving Shape of Each Step (‘whole')


(a) SN=0 (b) SN=10
(c) SN=20 (d) SN=30
(e) SN=40 (f) SN=50
(g) SN=60 (h) SN=70
Fig 9. Grooving Shape of Each Step (‘strain’)

4. Experiments

The grooved HDD cover design was manufactured using Rapid Prototyping (RP) and tested to prove the effectiveness of the surface grooving idea. Especially, to check the efficiency of the simulation result, changing the pattern in the checker-board pattern which seems to do most important role to determine natural frequencies, three different models were manufactured. Fig 10. shows FE model and manufactured RP HDD cover. FE model was built by commercial software Solid Works.

'Ori' indicates the original HDD cover model. 'Case 1' indicates the checker-board patterned groove model and 'Case 2' indicates the model where whole-region is embossed for all checker-board patterned region.



(a) FE model (ori) (b) FE model (case 1) (c) FE model (case 2)

(d) RP HDD cover (ori) (e) RP HDD cover (case 1) (f) RP HDD cover (case 2)

Fig 10. FE model and manufactured RP HDD cover

Fig 11 and Table 1 show the experimental result of modal testing. 1^{st} Frequency of checker-board patterned groove model is increased 13.85% which is almost 3 times higher than the other cases. It says that the surface grooving technique, especially checker-board patterned groove is very effective to raise its natural frequencies.

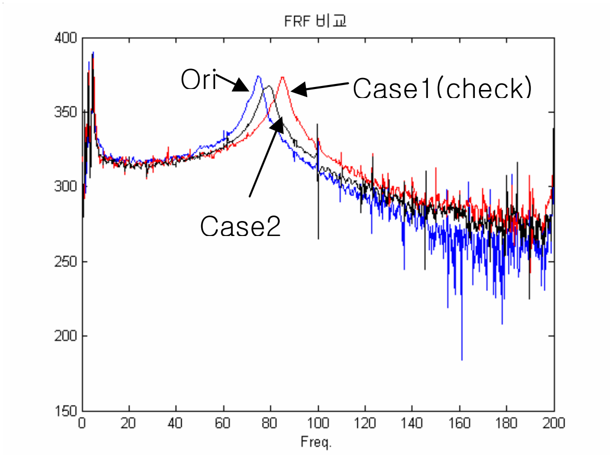


Fig 11. measured frequency response functions

Table.1

1^{st} natural frequency and its increment (%)

Ori	74.8 Hz
Case2	78.32 Hz (4.78%↑)
Case1(check)	85.16Hz (13.85%↑)

5. Conclusion

In order to improve structure’s dynamic characteristics, Surface Grooving Technique which is a systematic tool to derive structure shape is proposed. To reduce the computational effort, the target domain is restricted to their neighboring area of embossed elements and initial grooving position was started from among the elements having high-modal strain energy. This technique successfully applied HDD cover finite element model to raise its 1st natural frequency by giving some groove on its surface. The grooved HDD cover design was manufactured using rapid prototyping method and tested to verify the effectiveness of the suggesting surface grooving method.

6. References

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Acknowledgments

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