COUPLING MESH MORPHING AND PARAMETRIC SHAPE OPTIMIZATION USING SIMUOPTI

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KEYWORDS –optimization, morphing, shape basis vectors, RSM

ABSTRACT –As the complexity of the analysis task increases the computational volume and requires many hours, the optimization method contribute significantly in optimization design. Simuopti is a powerful optimization software which completely independent of any pre-processor and solver. It's easy to define optimization parameters in pre-processor software, and provide shape basis vectors. A existing FE models, which already have boundary conditions and load, can directly be used for the optimization, using mesh morphing techniques in ANSA brings a lot of convenience , It's easy to define optimization parameters, and provide shape basis vectors.

This paper demonstrates the process of design improvement on rear bracket of front leaf spring. The objective is to reduce the mass of the rear bracket, using Simuopti and ABAQUS. Different new shapes of the structure were created by mesh morphing of ANSA.

TECHNICAL PAPER -

1. INTRODUCTION

In traditional mechanical design methods, the engineer must apply knowledge of engineering, mechanics, mathematical and material science including the statistical data of products performance in the process of developing or re-creating; including analog design. Since this design method finds out the parameters to meet design requirements by trial method, the level of the product design depends largely on designer's experience and it's not easy to find out the optimal parameters. This approach has been used from the beginning of the last century to now. With the advent of the energy crisis, raw materials should be saved in mechanical design. It's essential to look for a design which meet all requests and cost the minimum material. However, as the complexity of mechanical design computing capacity and labor costs largely increased, structural design is very difficult to meet all requirements. At present, the optimization method is playing an increasingly important role in the mechanical design.

2. THEORY

Structural shape optimization method base on finite element theory has been commonly adopted in the field of industrial production, this method has a wide application range,good stability and high reliability. Since shape optimization use finite element method require parametric modeling and automatic mesh generation, a lot of time is cost to re-mesh and resulted in few applications of shape optimization in large-scale structures. A new method was introduced in shape optimization, parametric modeling and auto-meshing is not necessary. New shape of a structure is described by a set of shape basis vectors in the reduced basis method. These shape basis vectors can be generated from the finite element model of the initial structure. Differences between the structure's shape transition and its initial shape can be considered as the shape basis vector and its production process as shown in Figure 1.

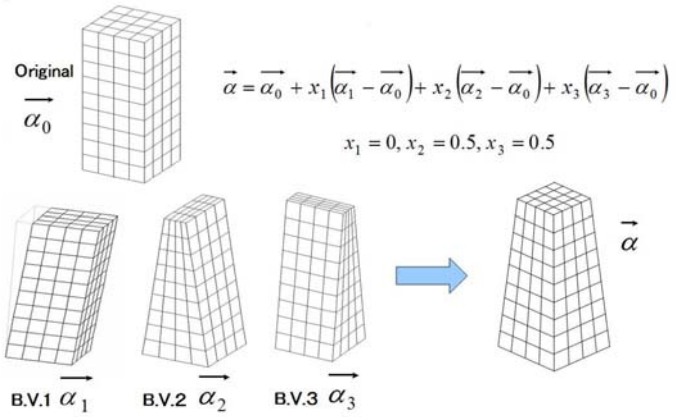

Figure 1 –Production process of shape basis vector

Mesh morphing techniques in ANSA can be used to reshape shell and solid mesh in finite element model, without having to return to the geometry model for modifications and re-mesh the model. This technique makes structure shape optimization analysis much easy. Application of morphing can be found in many disciplines: Durability, Crash, NVH, CFD etc. ANSA mesh morphing can be applied by two methods: using Morphing Boxes, or using Direct Morphing. Reshape ways are shown in Figure 2.

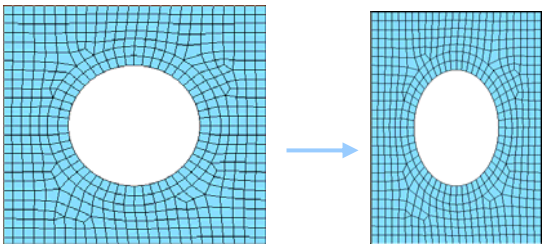

Figure 2 –Reshape ways

SimuOpti is a multi-objective optimization software that developed by our company. Response Surface Method-RSM was adopted in this software to reduce the number of the iteration. RSM was introduced by G. E. P. Box and K. B. Wilson in 1951. It explores the relationships between several explanatory variables and one or more response variables. The main idea of RSM is to use a set of experimental value or computational value to obtain an optimal response, then the response value will instead of experiment value for optimize (maximize, minimize, or attain a specific target) .
RSM researches the optimization problem under some constraint conditions, but the exact expression of the objective function is unknown. In the process of experiments and analysis with RSM, the independent variables that impact the response value are supposed as $X_1, X_2, \ldots\ldots X_k$, the unknown function is: $\ldots\ldots X_k) + \varepsilon$, where ε is deviation of the response variable.
In general we suppose that ε follows normal distribution and independent each other, its expectation is 0. If $\ldots\ldots X_k) = \eta$ is used as the expression of expectation of response variable, then the surface that represented by $\ldots\ldots X_k)$ is the response surface.
We often use the least squares estimation with first-order regression model to find a suitable approximation of the function, the first-order regression model is expressed as $\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 X_1 + \hat{\beta}_2 X_2 + \ldots\ldots + \hat{\beta}_k X_k$, where X is the independent variable and Y is the response variable. Then the significant test of regression analysis is adopted to find the relationship between independent variables and response variables is strong or weak, and test the appropriateness of the regression model. When test region close to the best response value, the curvature of real response surface will increase, and the curvature mode should be match with response surface. Between the first-order mode and the second-order

mode, the lack of test should be used to test whether the appropriateness and curvature of the first-order mode is significant or not. If significant curvature was found, then the second order or so-called quadratic model should be taken into account, it's mathematical expression is: $Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum\sum_{i<j} \beta_{ij} X_i X_j + \varepsilon$, The variation of deviation is supposed as constant and expressed as σ^2, we use test data to estimate unknown parameters at least square estimation. At the same time, we need to test the appropriateness of the second-order model. When the second-order model is well matched with the response surface, we can obtain the optimal operating conditions and the optimal response level with the second-order model, and get the maximum value or the minimum value according to actual needs, as shown in Figure 3.

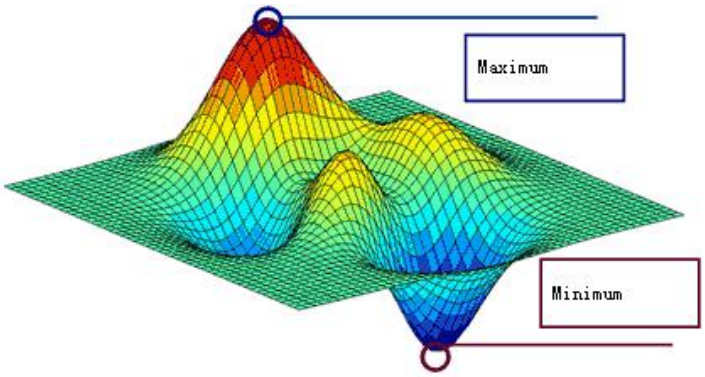

Figure 3 –Objective function surface.

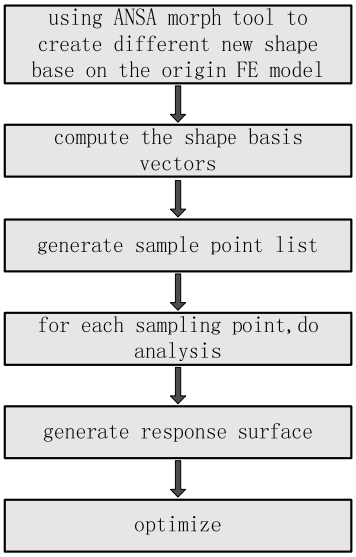

Figure 4 –workflow

RSM can effectively reduce the number of experiments in dealing with the situation of unknown function surface, and get an approximate function between several independent variables and one response variable to obtain the optimal response value, its advantages are: (1) The principle of economy: RSM can use fractional factorial design or special response surface design (such as hybrid design) to get effective information with less labor and time costs. (2) It can explore the impact of interaction among factors deeply: RSM researches interaction among factors and then examine the extent of the impact of multi-factors to the response variable. (3) The optimal experiment condition could be obtained: It can obtain the optimal experiment condition base on mathematical theory, and draw three-dimensional surface with the contour map using the matched mode, thus the optimal operating condition can be obtained.

The SimuOpti software used in this paper coupling ANSA mesh morphing and RSM shape optimization methodology, Simuopti is a powerful optimization software which completely

independent from any pre-processor. It's essential to define the optimization parameters easily and flexibility in pre-processor software to provide shape basis vectors. As existing CAE models, which are already validated such as most of boundary and loading conditions, may directly be used for the optimization。

3. EXAMPLE

This example demonstrates the process of design improvement on rear bracket of front leaf spring. The objective of the project was to reduce the weight of the rear bracket with the use of Simuopti 、morph of ANSA and ABAQUS .

Material and mesh

The bracket and spring model is linear elastic. A Young's modulus of E= 156 GPa and a Poisson's ratio of ν= 0.27, The initial yield stress is $\sigma|_0$= 370 MPa.
The 3D element was used for analysis in this model. The surface element use S3R and S4R of ABAQUS. The solid element use C3D10M of ABAQUS. Bolt is replaced by MPCs.
The mesh model shown in Figue 5.The sum of element number is 17814.

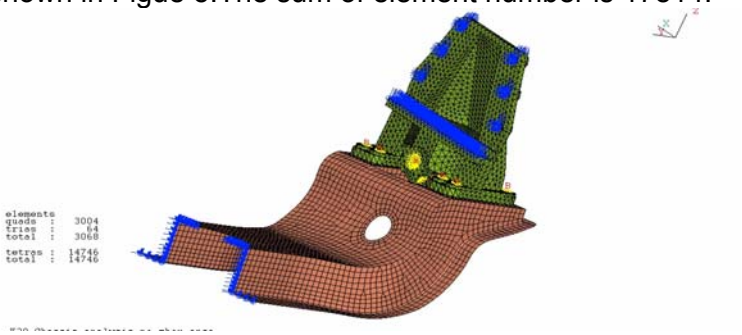

Figure 5 –Finite element model

Load and boundary conditions

The load on the brackets of a truck is equal to 13*9.81*1000=127530(N).Each cracket's load is 31882.5N in Z-axis direction, and -11360N in X-axis direction.
Result:
The cracket analysis is a single-step standard procedure. Figure6 shows the contour of Mise stress of the cracket. Max. Mise stress is equal 91.58MPa.

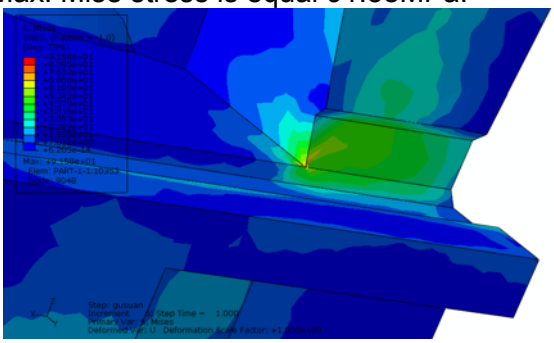

Figure 6 –Von-mises stress contour

Optimization
First step: We can select the dimension of the structure to determine the design variables. We found the value of stress in the area as Figue6 shown is very small.

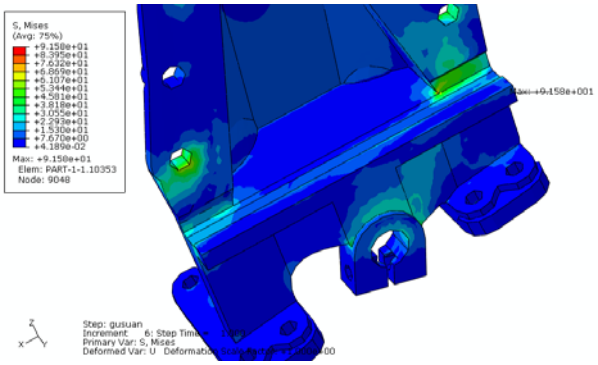

Figure 7 –Von-mises stress contour

We remove this area from the cracket model and re-computing. The contour of Mises stress is shown as Figue7.

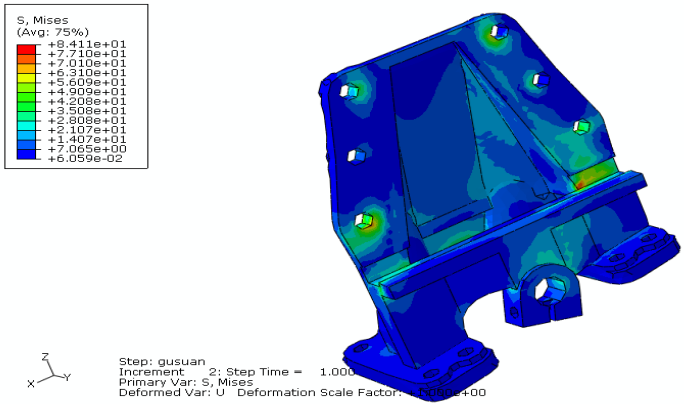

Figure 8 –Von-mises stress contour

As Figue 8 shows, the value of Mise stress in cracket is equal 84.11MPa, is less than the Figue6 shows. So we make sure that the modification is feasible.

Optimization parameter:

1. Dedign variable: We select three wall's thickness for design variable.These are shown in Figue5: t1、t2、t3.
2. Object function: minimize the weight of bracket.
3. Constrain: Max(Mise stress)≤$[\sigma_s]/3$=123.3 MPa

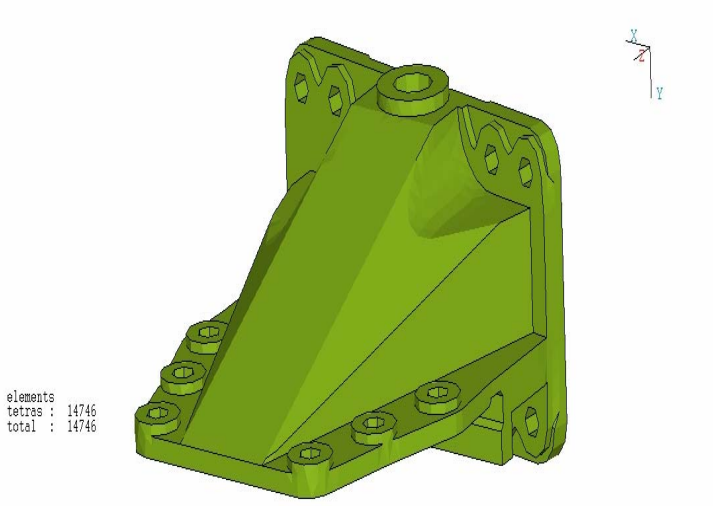

Figure 9 –Optimizaed structure model

TABLE I.

Design variable	Name	Min. (mm)	Init. (mm)	Max. (mm)
	t1	16	20	20
	t2	6	10	10
	t3	6	10	10
Constrain	Max{Mise}<[σ]/3			
Object function	Min{Mass}			

Sample space
We list sample space by using Simuopti as Table□ shows.

TABLE II.

analysis table			
analysis No.	**t1**(mm)	**t2**(mm)	**t3**(mm)
1	16	6	6
2	16	8	8
3	16	10	10
4	18	6	8
5	18	8	10
6	18	10	6
7	20	6	10
8	20	8	6
9	20	10	8

After getting Table□,we use morph of ansa to generate FEA sample model. We obtain the result value of each FEA sample model.It is showm in Table□.

TABLE III.

analysis table					
analysis No.	**t1** (mm)	**t2** (mm)	**t3** (mm)	**Max mise stress（MPa）**	**Mass（Kg）**
1	16	6	6	134	9.57952
2	16	8	8	122.2	10.6927
3	16	10	10	91.21	11.7859
4	18	6	8	121	10.7436
5	18	8	10	89.16	11.8462
6	18	10	6	111.4	10.1916
7	20	6	10	92.78	11.9094
8	20	8	6	92.69	10.0798
9	20	10	8	117.4	11.332

Result:
We obtain the result value which show in Table□ using Simuopt. When t1=16mm、t2=6.495mm、t3=6mm, the mass of bracket has min. value 9.589Kg, and max. Mises stress:123MPa.

TABLE IV.

design variable			
variable	Lower(mm)	Value(mm)	Upper(mm)
t1	16	16	20
t2	6	6.495172	10
t3	6	6	10

4. CONCLUSIONS

Morphing techniques in ANSA can be used to generate the samples for shape optimization. Sample space would be decreased by using Simuopti software, for reason of RSM was used in Simuopti which would reduce the number of iteration and increase the computational efficiency.
Accoding to the example, the weight of bracket decreased near 30% by optimization, which prove that combining the morph in ANSA and Simuopti software structure optimization is feasible and efficiency.

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