CAE-based Optimization Using Response Surface Methods

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ABSTRACT

Conduct practices of mechanical design optimization by using Abaqus[1] along with Design Expert[2] to conclude the CAE-based Optimization which is a spreadsheet allowing the mechanical engineers to try out the response(s) by her/his own combinations of design factors, and thus, optimize the design at the very beginning of the product development.

Keywords: risk assessment, design of experiment, analysis of variance, responses surface method, optimization, statistics

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1、Introduction

It is an exciting and yet exhausting journey for every electronic manufacturing service providers when there rings the bell of request for quotation, or RDF for short, particularly the customers aggressively push the technology implementation to the cutting edge. The stochastic process may be justified someday by the emerging Industry 4.0[3]. However, the RFQ task force cannot sit and wait for the ideal promising solution to save their lives since it is still distant from most engineers' sight. For example, in early design phase the notebook DOM's design engineers have to provide customers the variant risk assessments of their design proposal out of rare mechanical details in mind. Thus, the simulation-base evaluation have become the acceptable protocol to iterate and communicate among several working groups such as engineering team, engineers and program manager, and the task force and the customers[4]. Although the simulation manifests itself as a practical useful tool in the very period of product development, notebook ODM's CAE forces are expected to deliver efficiently and effectively to fulfill the demands from every individual. However, there is limited information to deliver quality simulation result in the stage. Simulation is barely instructive but sort of newspaper dispatch day in and day out. "Garbage in and garbage out", like said the simulation guru analysts.[5] [6] [7] [8] The conventional workflow has to be changed to improve productivity and working atmosphere. This cannot be done without precautious scheme and predictable metric to assess the risk level at an affordable cost of simulation work. The CAE team at LCFC [9] has been developing and practicing so-called CAE-based Optimization for the past few years to refine the workflow. A case study is conducted to demonstrate the workflow and its impressive prediction capability of the outcome.

2、Methodology

- Apply Design Expert to create 3-factor DOE [10] to analyze the impact of three design parameters on the specific response(s). Consider numerically ordering factors exclusively.
- Apply Abaqus to conduct simulations following DOE matrix aforementioned to get the responses such as deformation and stress.
- Apply Design Expert to conduct ANOVA, or analysis of variance, to validate the significance of statistical model. Move back to the previous step if the model is statistically invalid to provide meaningful information.
- Apply Design Expert to conclude the regression equation(s) of response(s)

concerning the factors by Response Surface Method.

- Create the spreadsheet to allow authorized staffs to specify their trial of design factors to calculate the response(s) by that particular RSM [11] equation(s).

3、Case study of optimization of 2 in 1 folded stand

- Statement of issue

  Consider optimizing the folded stand of a detachable 2 in 1 device. Changing recession is mechanically meaningful but might interfere with capacity intentionally reserved for battery, shown as Figure 1. The alternative is to unite additional ribs on the opposite side for reinforcement of whole folded stand, shown as Figure 2. By careful engineering arrangement one can provide what-if scenario in an interactive manner to an amount of requests on demand.

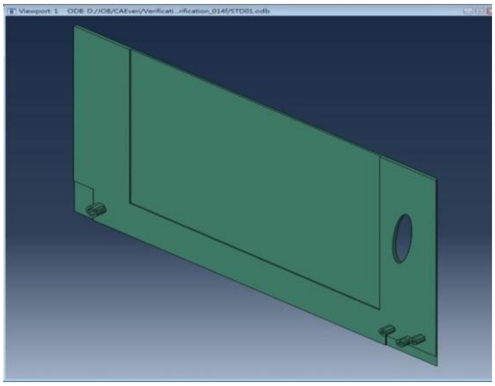

Figure1, The inner view of the folded stand with recession

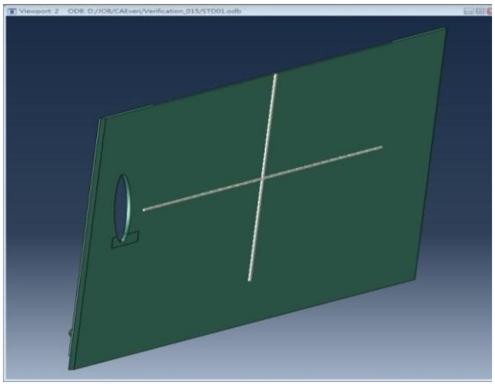

Figure 2, The outer view of the folded stand with certain reinforced ribs

- Procedure
  - Figure 3 shows the workflow of CAE-based Optimization developed at LCFC. Followed by the detailed descriptions in next section.

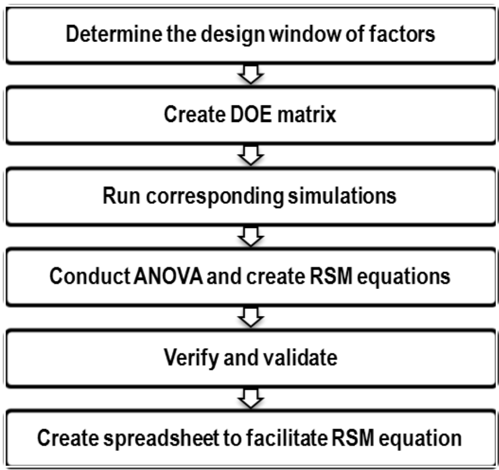

Figure 3, CAE-based Optimization workflow

- Result and discussion
  - Determine three major design factors of reinforced rib formation as follows and shown as Figure 3,
    - ✓ THK- thickness of ribs (height and length of ribs are taking as constant for simplification)
    - ✓ NoH- count of horizontal rib(s)
    - ✓ NoV- count of vertical rib(s)

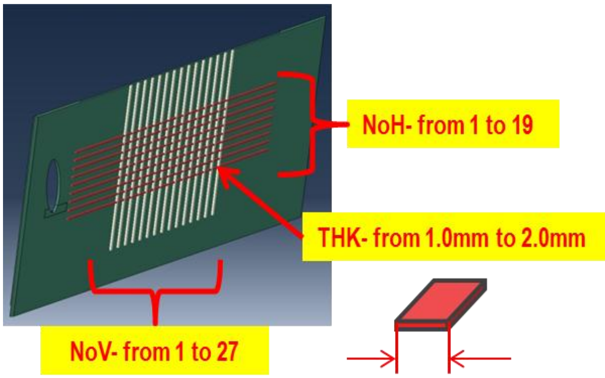

Figure 3, Three design factors in optimizing the folded stand

  - Determine the design window of every factor, i.e., the low and high bounds of THK, NoH and NoV, respectively as shown in Table 1.

Table 1, design window of factors

Factor	Unit	Low	High
THK	mm	1.0	2.0
NoH	N/A	1	19
NoV	N/A	1	27

- Create DOE by Central Composite Design [12] by Design Expert and create the DOE matrix DOE matrix as Table 2.

Table 2, DOE matrix

Std	Run	Factor 1 A:THK mm	Factor 2 B:NoH	Factor 3 C:NoV
1	1	1	1	1
2	2	2	1	1
3	3	1	19	1
4	4	2	19	1
5	5	1	1	27
6	6	2	1	27
7	7	1	19	27
8	8	2	19	27
9	9	1	9	15
10	10	2	9	15
11	11	1.5	1	15
12	12	1.5	19	15
13	13	1.5	9	1
14	14	1.5	9	27
15	15	1.5	9	15

- Build up the fifteen CAE models corresponding to DOE matrix, i.e., model 1 has rib thickness of 1 mm, one horizontal rib and one vertical rib, and so forth. Schematic representation is shown as Figure 4.

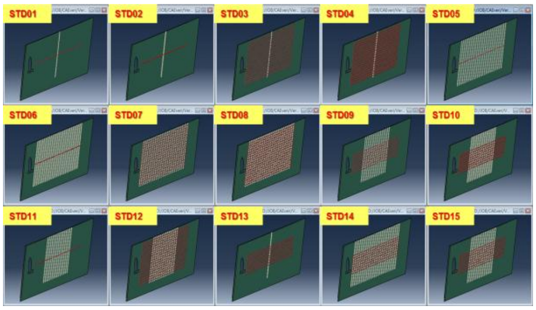

Figure 4, fifteen CAE models corresponding to the DOE matrix

- Apply specified load and boundary conditions to all the fifteen CAE models. Figure 5 shows the representative scheme as setting plunger load in the vicinity of dashed circle and being fixed at ends of four bolts.

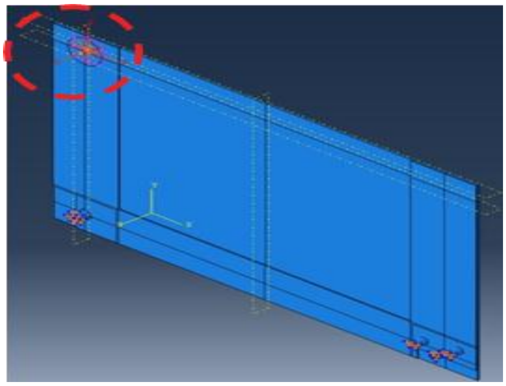

Figure 5, Load and B.C.'s for all fifteen CAE models

- Solve extract responses, maximal deformation and maximal von Mises stress, being used as indices of risk assessment of the folded stand, referred to Figure 6, Figure 7 and Table 3.

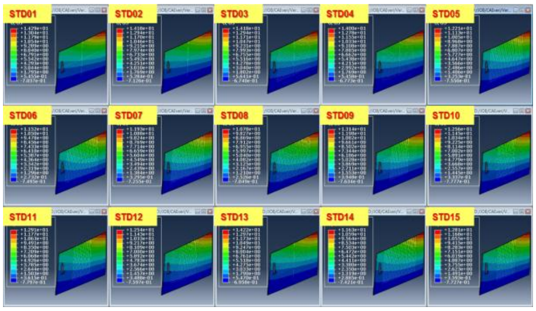

Figure 6, Deformation contour plots

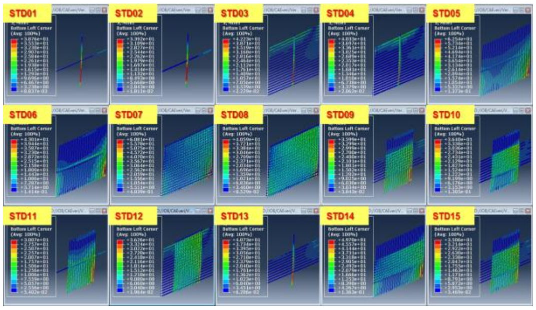

Figure 7, von Mises stress contour plots

Table 3, DOE result of maximal deformation and von Mises stress

Std	Run	Factor 1 A:THK mm	Factor 2 B:NoH	Factor 3 C:NoV	Response 1 U_50N mm	Response 2 SE_50N MPa
1	1	1	1	1	12.17	20.90
2	2	2	1	1	12.08	20.94
3	3	1	19	1	12.12	21.70
4	4	2	19	1	11.95	22.60
5	5	1	1	27	11.28	21.34
6	6	2	1	27	10.19	21.95
7	7	1	19	27	11.13	22.04
8	8	2	19	27	9.82	23.02
9	9	1	9	15	11.70	20.95
10	10	2	9	15	10.96	21.23
11	11	1.5	1	15	11.42	20.98
12	12	1.5	19	15	11.22	22.19
13	13	1.5	9	1	12.12	21.02
14	14	1.5	9	27	10.65	21.64
15	15	1.5	9	15	11.36	21.08

- Conduct ANOVA to test the hypothesis of statistical model regarding responses and design factors [13], i.e., the impact or contribution by varying each individual factor and therefore their interactions to the response(s).

- Conclude the regression equations for responses, maximal deformation and von Mises stress, by Response Surface Method. Verify the predicted and actual values to ensure the errors of equations for deformation and stress, shown as Figure 8 and 9, respectively, are within acceptable range, said +/- 5% likewise.

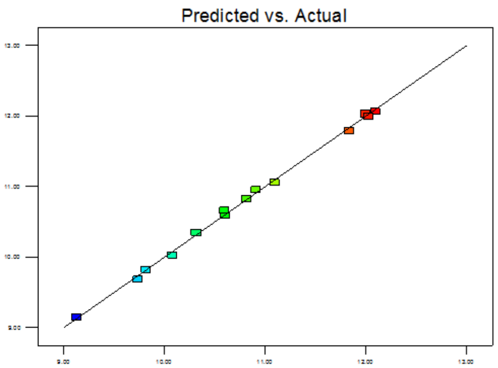

Figure 8, Validation of deformation equation

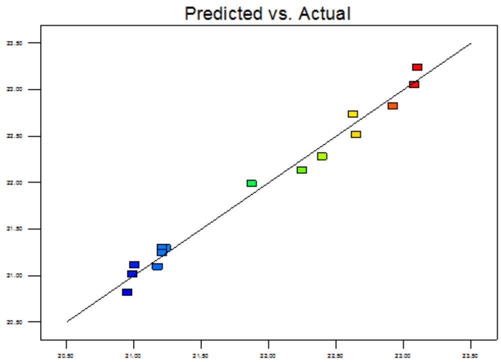

Figure 9, Validation of stress equation

- Randomly pick up additional six design nodes as listed in Table 4 other than DOE matrix to double check the difference between predicted and actual values for both maximal deformation and von Mises stress. Table 5 shows the differences of deformation and stress are less than 0.6% and 1.2%, respectively which is very impressive for any regression equation.

Table 4, Additional six verification runs

Verification	VER01	VER02	VER03	VER04	VER05	VER06
A - THK	1.2	1.8	1.5	1.6	1.1	1.65
B - NoH	11	3	7	5	7	13
C - NoV	7	1	23	15	7	25

Table 5, Maximal deformation validation of additional six runs

Verification	VER01	VER02	VER03	VER04	VER05	VER06
A - THK	1.2	1.8	1.5	1.6	1.1	1.65
B - NoH	11	3	7	5	7	13
C - NoV	7	1	23	15	7	25
CAE	11.49	12.01	10.23	10.82	11.56	9.81
RSM eq.	11.55	12.02	10.20	10.85	11.61	9.79
Difference	0.5%	0.1%	-0.2%	0.2%	0.4%	-0.2%

Table 6, Maximal von Mises stress validation of additional six runs

Verification	VER01	VER02	VER03	VER04	VER05	VER06
A - THK	1.2	1.8	1.5	1.6	1.1	1.65
B - NoH	11	3	7	5	7	13
C - NoV	7	1	23	15	7	25
CAE	21.32	21.03	21.66	21.08	21.12	22.30
RSM eq.	21.25	21.01	21.67	21.10	20.89	22.25
Difference	-0.3%	-0.1%	0.0%	0.1%	-1.1%	-0.3%

4、Conclusion

Several observations can be drew from the case study or any other live practices being conducted at LCFC as follows

－ At certain simplified level, it is doable to conduct mechanical design optimization by Design Experts and Abaqus. However, we should take into account the affordability based on the routines with considerably limited force and resource in hand. Also the complexity of the problem should be prescreened or roughly assessed to certain acknowledge of RSM methodology.

- To practice optimization in the early phase of product development, CAE should have more experienced engineers to facilitate the mechanical-design innovations.
- Under certain circumstances either topology or reinforced structure can be correlated precisely with CAE-based Response Surface Method to realize instant risk assessment of design change.
- The policy 3-Factor*15-Run is affordable and sufficient to deliver CAE-base Optimization in concept design phase particularly the relationship among design factors and responses cab be correlated no larger than third order polynomial equations.

5、Acknowledgement

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6、Reference

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