Multiobjective Optimization of Automotive Vehicle Gage Panel

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Abstract

Automotive vehicle gage panels must meet many requirements starting with appropriate styling and precisely measurable functional characteristics such as stiffnesses, stress levels under loads, weight, accuracy, eigenfrequencies etc. and last but not least – minimal environmental pollution. Gage panel styling is a less easily measured concept and frequently is handled informally. The method of imprecision is used to allow for a formal approach to the incorporation of this imprecise information. Geometrical models of the gage panel are elaborated using SolidWorks (SW) and style is designed by SW PhotoView360. Static and dynamic responses of the gage panel are calculated by SW Simulation and impacts to environment are evaluated by SW Sustainability. Due to the complexity of FEM models, appropriate metamodels have been developed based on design of experiments. These metamodels are used for multiobjective optimization. Partial objectives are aggregated in complex objective function for optimization purposes.

Keywords

Gage panel, metamodel, multiobjective shape optimization.

1 Introduction

Developing safe and environmentally friendly engineering objects with excellent functional properties, attractive visual appearance and competitive price is a pressing problem. This work discusses designing the mechanical part of an automotive vehicle gage panel (GP). We try to take into account not only precisely measurable functional indices, but also such a difficult-to-define index as styling of GP.

The Industrial Designer Society of America defines industrial design as the professional service of creating and developing concepts and specifications that optimize the function, value, and appearance of products and systems for the mutual benefit of both users and manufacturer. In fact, industrial designers focus their attention upon the form and user interaction of products. There are five critical goals [1]: 1) Utility: The product's human interfaces should be

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safe, easy to use, and intuitive. Each feature should be shaped so that it communicates its function to the user. 2) Appearance: Form, line, proportion, and color are used to integrate the product into a pleasing whole. 3) Easy maintenance: Product must also be designed to communicate how they are to be maintained and repaired. 4) Low costs: Form and features have a large impact on tooling and production costs, so these must be considered jointly by the team. 5) Communication: Product design should communicate the corporate design philosophy and mission through the visual qualities of the products. The practical concept selection methods [1] vary in their effectiveness and include the following: 1) External decision: Concepts are turned over to the customer, client, or some other external entity for selection. 2) Product champion: An influential member of the product development team chooses a concept based on personal preference. 3) Intuition: The concept is chosen by its feel. Explicit criteria or trade-offs are not used. The concept just seems better. 4) Multivoting: Each member of the team votes for several concepts. The concept with the most votes is selected. 5) Pros and cons: The team lists the strengths and weaknesses of each concept and makes a choice based upon group opinion. 6) Prototype and test: The organization builds and tests prototypes of each concept, making a selection based upon test data. 7) Decision matrices: The team rates each concept against prespecified selection criteria, which may be weighted. The concept selection method is build around the use of decision matrices for evaluating each concept with respect to a set of selection criteria. At the same time such formalized methods are elaborated as method of imprecision [2] with non-compensating aggregation and compensating aggregation as well as a fuzzy design method with different level interval algorithms.

GP styles of different cars significantly differ and should be evaluated in context of specific vehicle. At the same time styling determines an arrangement of particular components (distances between gage axes etc.). In Fig. 1 we can see the initial style and models of GP designed for a new AmoPlant [3] vehicle.

Fig. 1. Frontal view of the initial GP styling, geometrical model and meshed model of GP.

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2 Shape Optimization

For topology and shape optimization of structures, the different realizations of homogenization method are widely used [4, 5]. This method is highly effective for shell constructions. However, it is a very time consuming procedure because the number of design parameters can reach a million and more. In the case of solid bodies it frequently produces shapes that are difficult to manufacture. As shown in work [6], the Hybrid Cellular Automata method does not allow parallelization of computations and PBS queuing system has been used. At the same time the following approach [7] can be used for shape optimization: 1) Planning of position of control points of NURBS for obtaining a smooth shape. 2) Building of geometrical models by CAD software in conformity with design of experiment. 3) Calculation of responses for a complete FEM model using CAE software. 4) Building of metamodels for responses obtained in the previous step. 5) Using metamodels for shape optimization. 6) Validating the optimal design using CAE software for the complete FEM model.

2.1 Test problem

Let us demonstrate this approach on a simple test problem. A clamped square plate is considered under a concentrated load of 500 N applied at the centre in a direction orthogonal to its main surface. The isotropic material properties are: the Young's modulus E = 200 GPa, the Poisson's ratio μ = 0.3 and dimensions are 400×400×4.2118 mm. The shape optimization of the plate with constant thickness is carried out to minimize its volume in the case of a single displacement constraint δ=0.5 mm. The cutout shape of the plate is defined by the following techniques shown in Fig. 2: 1) with the points that are connected with straight lines; 2) with the NURBS knot points; 3) with the control points of NURBS polygon. Due to symmetry, only ⅛ of the plate is considered for cutout definition and ¼ of the plate for problem solution by FEM.

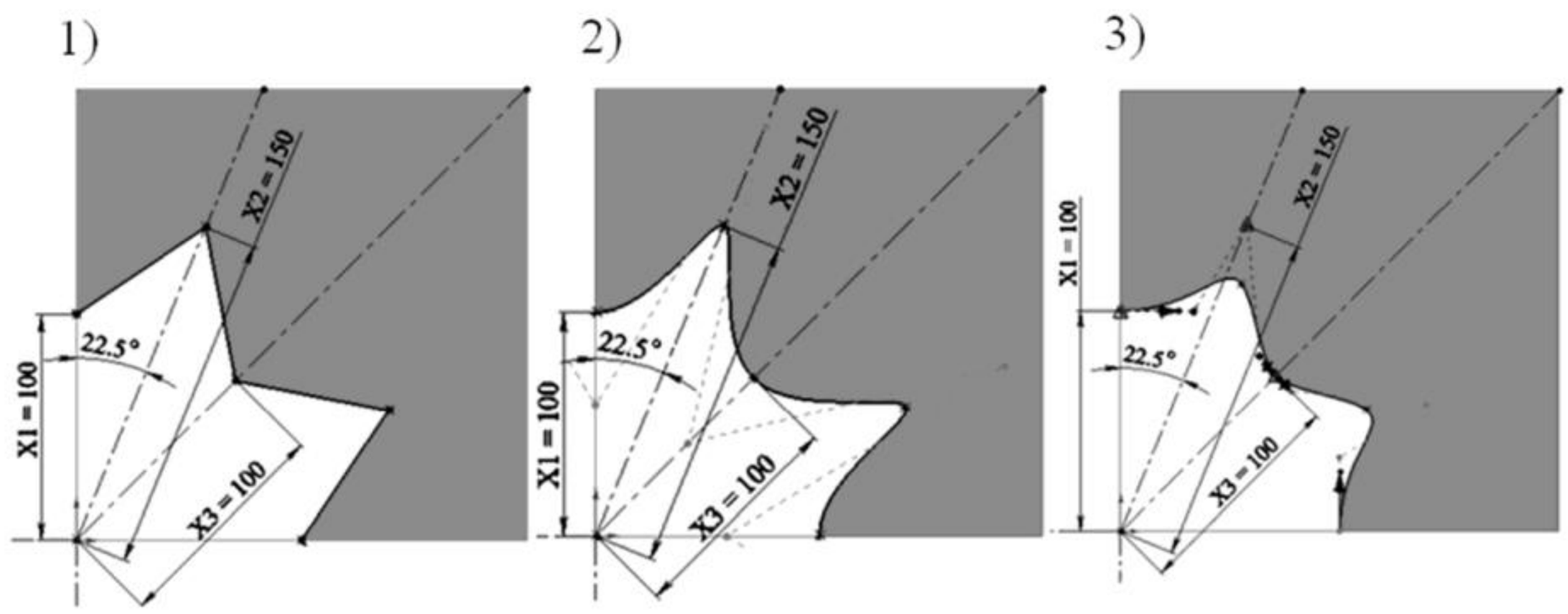

Fig. 2. Techniques for definition of cutout.

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Three parameters are stated to define location of points. Parameters are varied in the following ranges: $100 < X1 < 170$; $100 < X2 < 210$; $100 < X3 < 230$ mm for the first two variants and $100<X1<180$; $100 < X2 < 235$; $100 < X3 < 230$ mm for third variant of definition. In the last case, additionally at both end points two continuity vectors with fixed length of 19 and 3 mm are defined in directions perpendicular to the corresponding side and to symmetry axis of the plate. The design of experiment for 3 factors and 40 trial points is calculated with the mean-square error criterion (MSE) [8] value 0.4262 by EDAOpt [9] (software for design of experiments, approximation and optimization developed in the Riga Technical University). This design of experiment is also available at http://www.mmd.rtu.lv. The geometrical models are developed using SolidWorks (SW) for all variants. The shapes for the third variant of definition are shown in Fig. 3.

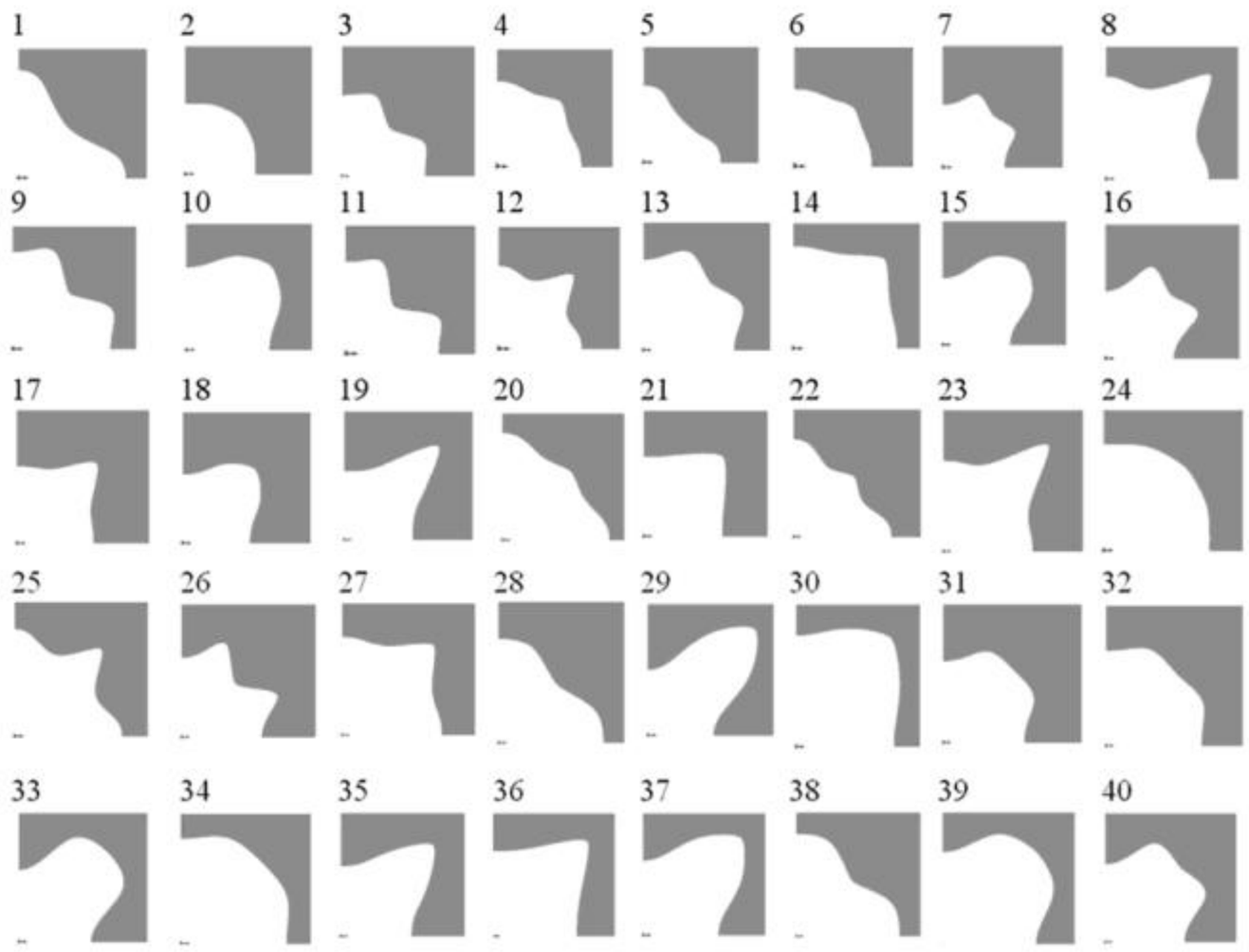

Fig. 3. Shapes of cutout in compliance with design of experiment.

In the next step, responses of these models are calculated by SW Simulation, using elements with global size 4 mm and total number of DoF ~100000. Then these responses are used for approximation by EDAOpt. Using the obtained locally weighted polynomial approximations, by the global search procedure [10], implemented in EDAOpt, the optimal cutout shape is obtained (see Fig. 4) for the different aforementioned techniques. In Table 1, the results are summarized and compared with the volume obtained in the work [11] using the homogenization method (60 iterations). Variants correspond to shapes shown in Fig. 4. The value of Gaussian kernel parameter α of the local quadratic polynomial approximation is chosen to minimize the relative leave-one-out crossvalidation error σ_{err} of approximations of appropriate responses, i.e., deflection δ and volume v of plate. v_p is the predicted volume, calculated using

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approximations, and v_a is actual volume, calculated using the geometrical model. v_p and v_a in % show comparison of appropriate volume in respect to the volume obtained in [11]. Best results are achieved with the technique using the control points of NURBS polygon. This allows reducing volume of plate by 1.38 % (Fig. 4 e) in comparison with the homogenization method.

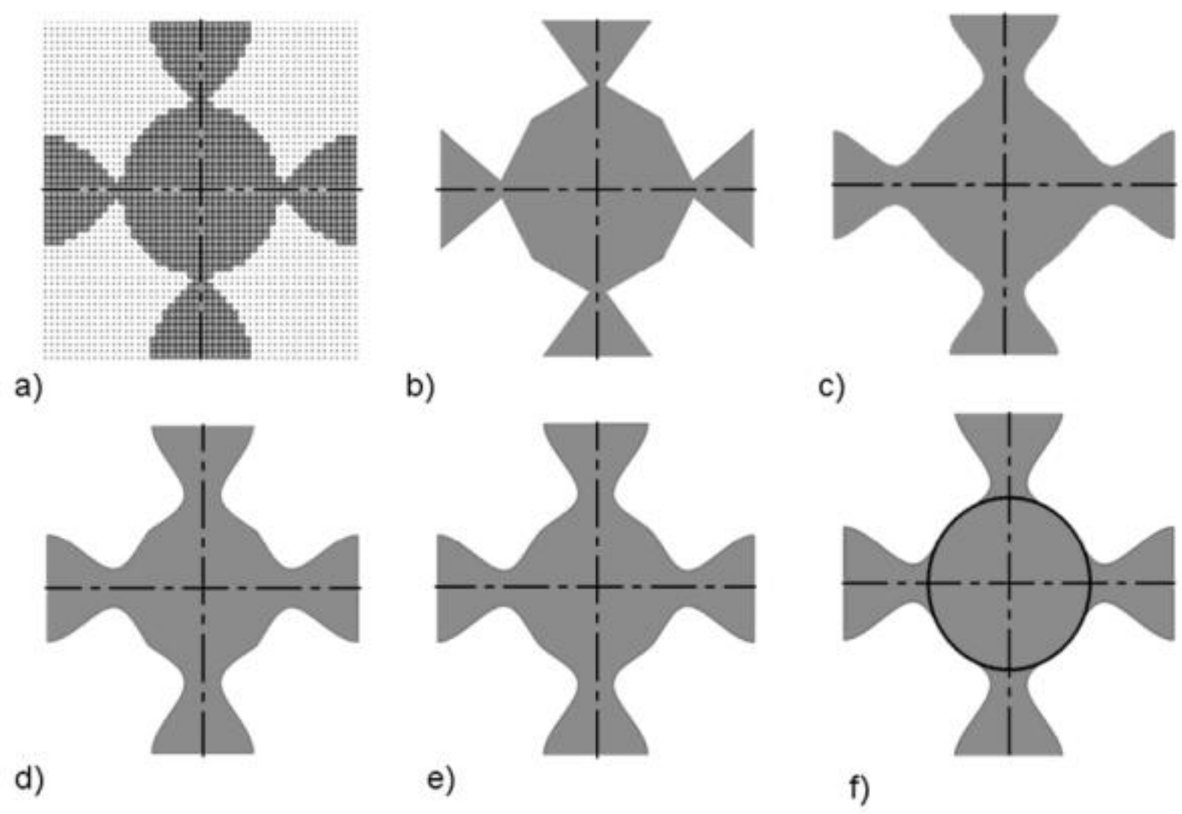

Fig. 4. Shapes of plate obtained by a) homogenization method [11]; and by the current approach using different techniques: b) the points that are connected with straight lines; c) with the NURBS knot points; d) with the control points of NURBS polygon; e) same as "d", but with additionally optimized tangent weighting at the spline endpoints; f) same as "e", but with circle added.

Table 1. Quantitative indices of the shape optimization of the plate cutout.

Variant	α	$\sigma_{err\ \delta}$ %	$\sigma_{err\ v}$ %	v_p mm^3	v_a mm^3	v_p %	v_a %
a	–	–	–	–	68750.00	–	–
b	17	9.81	0.03	69414.78	69331.58	1	0.84
c	17	9.81	0.03	68988.67	68815.88	0.4	0.096
d	15.6	9.81	0.03	68862.32	68721.98	0.16	−0.04
e	3.2	0.79	0.16	67797.524	67800.975	−1.385	−1.38

2.2 Automotive vehicle GP problem

The previously described metamodeling approach was used for multiobjective shape optimization of the GP. Following indices were considered: maximal von Mises stress in material of GP from impact loading and from harmonic vibrational excitations calculated by SW Simulation; styling of GP using the α-cut method [2], the carbon footprint and other environmental impacts of GP throughout its entire lifecycle calculated by SW Sustainability. Fig. 5 shows the definition of design variables and the obtained shape of the GP frame bracket.

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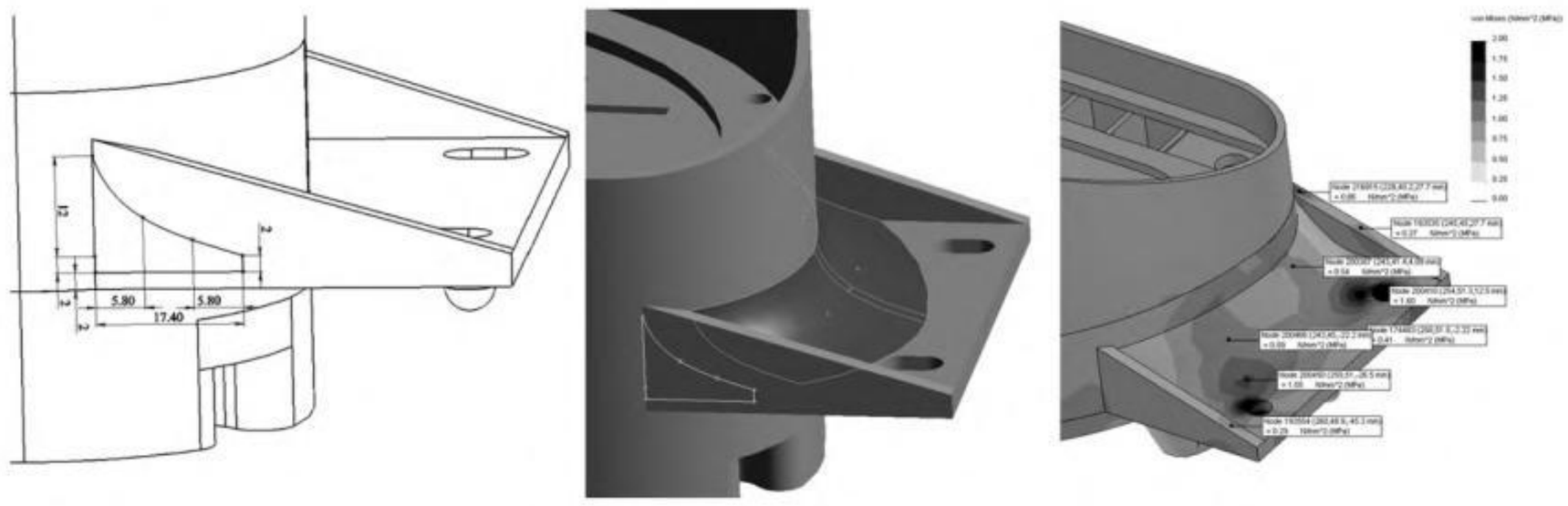

Fig. 5. Shape definition, optimal shape and stress levels in the frame bracket of GP.

3 Conclusions

The first results of multiobjective optimization of the automotive vehicle GP are presented. The described approach allows obtaining smooth shapes that are easy to implement technologically. The jagged forms are excluded from optimization process and there's no need for excessive computational resources. The most time consuming step of the current approach is FEM analysis of GP variants defined by design of experiments, the results of which are used for building metamodels of GP responses. Then the solution of various single objective problems and the realizations of different aggregation strategies for multiobjective optimization are relatively easy in order to obtain an acceptable final solution.

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Vibration Problems ICOVP 2011 : Supplement : The 10th International Conference on Vibration. Liberec : Technical University of Liberec, 2011. ISBN 978-80-7372-759-8.

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