SIMULATION OF BEHAVIOR OF VEHICLE GAGE PANEL

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Abstract. Automotive vehicle and tractor gage panels must meet many requirements – such functional characteristics as appropriate stress levels under loads, eigenfrequencies, stiffnesses, weight, accuracy etc. and last but not least they must be with minimal environmental pollution during life time. The 3D geometrical models of the gage panel are elaborated by SolidWorks (SW). Static and dynamic responses of the gage panel are calculated by SW Simulation and impacts to environment are evaluated by SW Sustainability that include such indices as the total energy consumed, carbon footprint, air acidification and water eutrophication. The stationary and transient behaviors of the gage panel under dynamic excitation as well as stress distribution under static loading are investigated. Due to complexity of the gage panel FEM models the appropriate metamodels are elaborated based on the design of experiments. These metamodels are used for multiobjective optimization by global search procedure. Partial objectives are aggregated in the complex objective function for optimization purposes. Dynamic behavior of the gage panel is then verified by solution of the full FEM models in case of random vibrations.

Keywords: gage panel, simulation, shape optimization, metamodel.

Introduction

Always an actual problem is developing of safe and environmentally friendly engineering objects with high functional properties, attractive style and competitive price. In this work designing of the mechanical part of automotive vehicle and tractor gage panel (GP) is discussed. We try to take into account not only precisely measurable functional indices, but also such hardly formalized index as the style of GP.

Fig. 1. **Frontal view of GP of the initial styles and 3D geometrical model 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 manufacturers. 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 human interfaces should be safe, easy to use, and intuitive. Each feature should be shaped so that it communicates its function to the user. 2) Appearance: The form, line, proportion, and color are used to integrate the product into a pleasing whole. 3) Easy to maintenance: The product must also be designed to communicate how they are to be maintained and repair. 4) Low costs: The form and features have a large impact on tooling and production costs, so these must be considered jointly by the team. 5) Communication: The 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: The 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 the test data. 7) Decision matrices: The team rates each concept against pre specified selection criteria, which may be weighted. The concept selection method is built 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 the method of imprecision [2] with non-compensating aggregation and compensating aggregation as well as the fuzzy design method with different level interval algorithms.

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

Vehicle GP optimization problem

Now we try to use the previously proposed [4; 5] metamodeling approach for multiobjective shape optimization of the GP. The problem is stated as follows:

$$\min_{x} F(x) = [F_1(x), F_2(x), ..., F_k(x)]^T \tag{1}$$

subject to $g_j(x) \leq 0$, j=1, 2,…, m, and $h_l(x) = 0$, l=1, 2, …, e;

where k – the number of objective functions F_i;
m – the number of inequality constraints;
e – the number of equality constraints;
$x \in E^n$ – a vector of n design variables.

Firstly let us discuss briefly the obtaining of every particular objective.

Strength calculation of GP design

Generally the strength of the GP design is checked on special vibrostands. The GP is subjected to different dynamic loads. Vibrostability and vibration strength of the GP are checked on excitations in the frequency domain from 10 to 250 Hz. One of the main natural experiments is a test of shock resistance of the GP design under the acceleration level a=10 g. Such experiments require significant material and time expenses and for optimization purposes the computer based design check must be used. The 3D geometrical model (Fig. 1) of the GP is created by means of SW and it consists of 18 parts: 6 deformable bodies and 12 rigid bodies that take into account the inertial characteristics of the internal devices. The deformable parts are made of the ABC 2020 plastic, but for the internal device bodies are assumed alloy steel. The initial volume of the GP assembly is v_0=764 674 cm³ and mass m_0=1.02 kg. The 3D model of the GP assembly is used for FEM analysis by SW Simulation to evaluate different responses of the GP. The FE mesh (Fig. 2) is generated with curvature based mesh (max elements size = 9 mm, min element size = 1.8 mm, element size growth ratio = 1.5), that allows accurately mesh the complex shape bodies of the GP. The FE mesh consists of ~210 000 nodes, ~147 000 elements, ~640 000 DOF.

In the initial design of the GP von Mises stresses from impact loading are shown in Fig. 2. We can see that maximal stresses are concentrated on the bracket cross-section and it reaches 4 MPa. Other parts of the GP design are loaded considerably less. This implies that the bracket design should be improved.

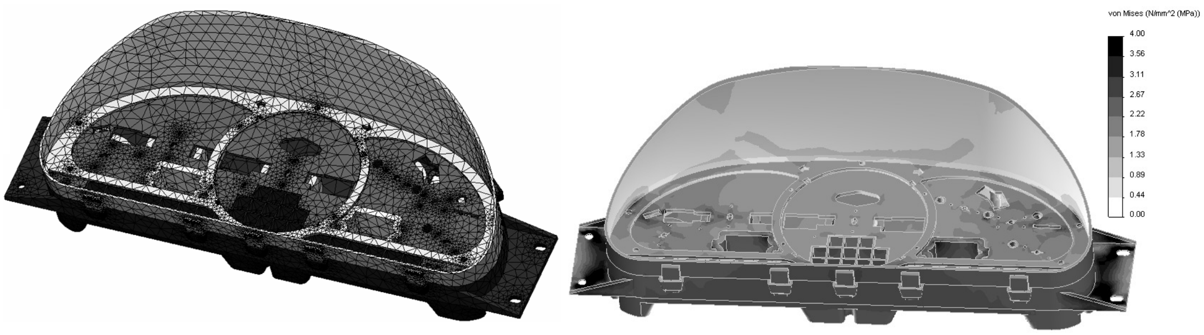


Fig. 2. **Meshed 3D model and von Mises stresses distribution in initial design of GP**

Frequency analysis of GP

The frequency analysis is made to find natural frequencies of the GP model and evaluate the possible resonance in the case external excitation. The same FE mesh for the model as considered before is used. The contacts between the assembly parts are defined as bonded. The numerical solver FFEPlus of SW is used for calculations.

The obtained results show that the fundamental frequency of the GP is sufficiently high f_1=170.47 Hz. The obtained mode shapes for the GP natural frequencies (f_2=201.35 Hz, f_3=264 Hz, f_4=331.85 Hz) are shown in Fig. 3.

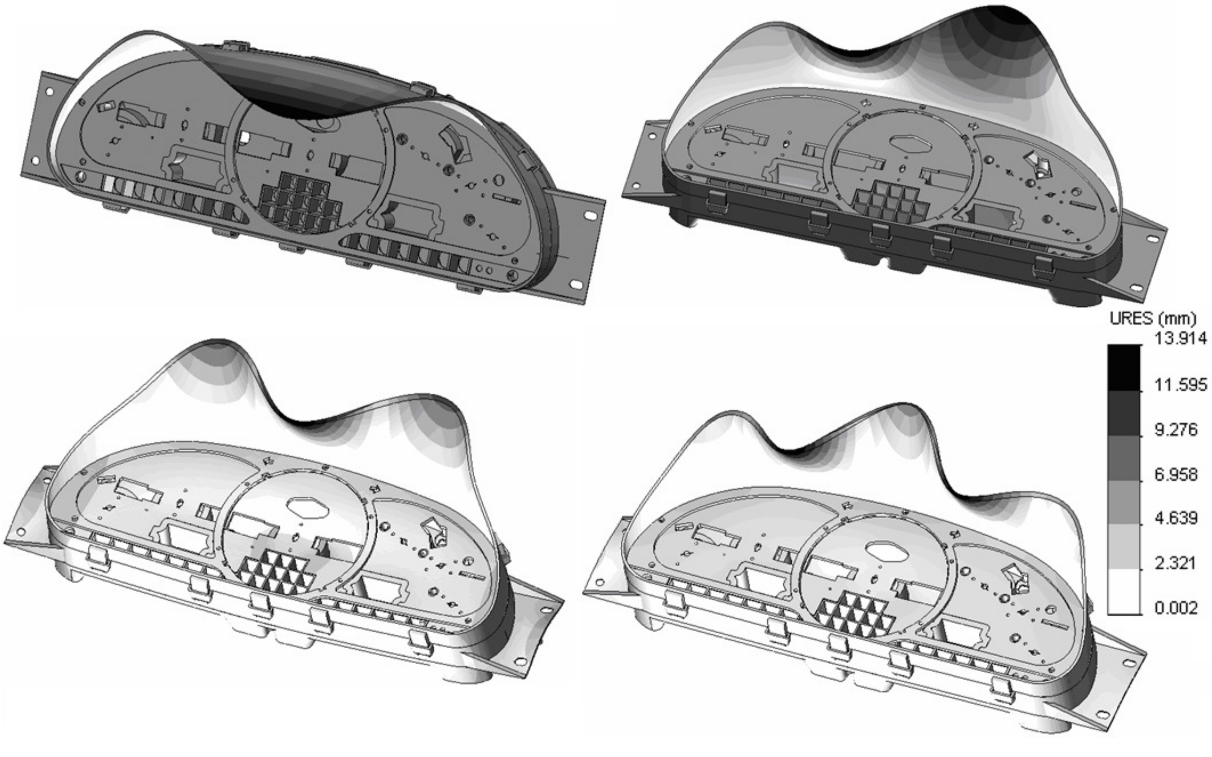
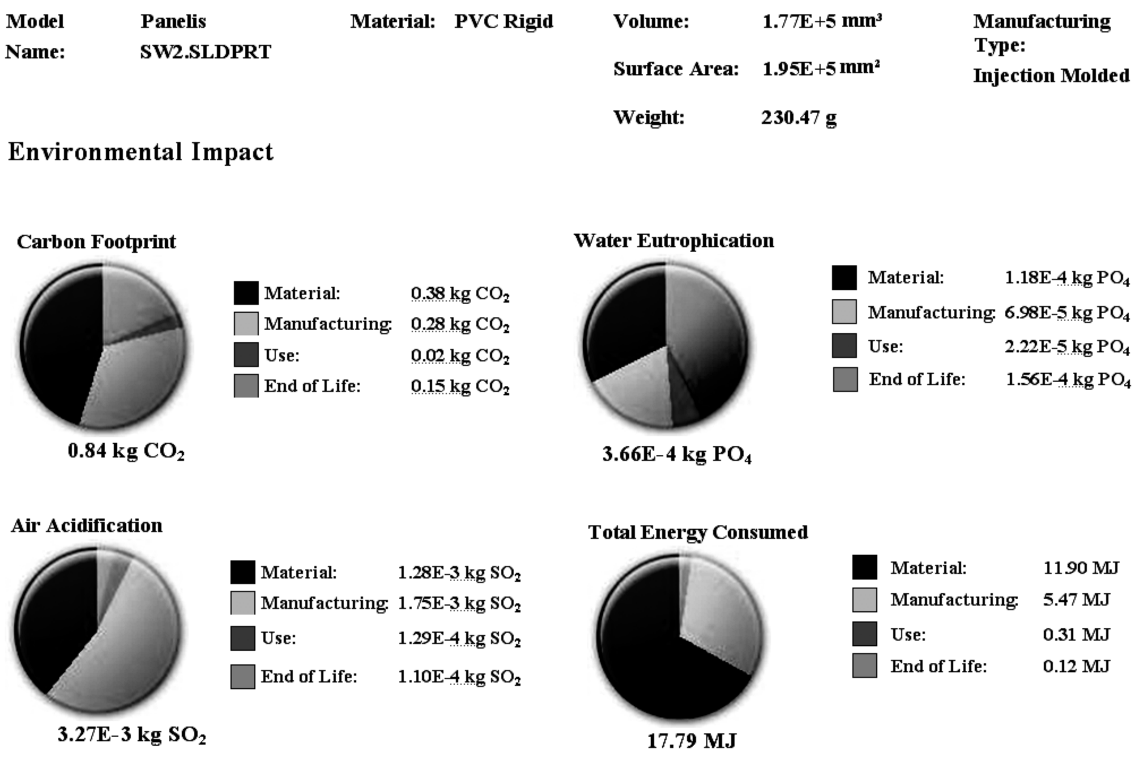


Fig. 3. **Mode shapes of four lower natural frequencies of GP**

Sustainability analysis of GP

SW Sustainability allows to get immediate feedback on the carbon footprint and other environmental impacts of the GP throughout its entire lifecycle, including material selection, production, transportation, use and end of life (Fig. 4).



Model Name:	**Panelis SW2.SLDPRT**	**Material:**	**PVC Rigid**	**Volume:**	**1.77E+5 mm³**	**Manufacturing Type:**
				Surface Area:	**1.95E+5 mm²**	**Injection Molded**
				Weight:	**230.47 g**	

Environmental Impact

Carbon Footprint

■	Material:	0.38 kg CO_2
□	Manufacturing:	0.28 kg CO_2
■	Use:	0.02 kg CO_2
▨	End of Life:	0.15 kg CO_2

0.84 kg CO_2

Water Eutrophication

■	Material:	1.18E-4 kg PO_4
□	Manufacturing:	6.98E-5 kg PO_4
■	Use:	2.22E-5 kg PO_4
▨	End of Life:	1.56E-4 kg PO_4

3.66E-4 kg PO_4

Air Acidification

■	Material:	1.28E-3 kg SO_2
□	Manufacturing:	1.75E-3 kg SO_2
■	Use:	1.29E-4 kg SO_2
▨	End of Life:	1.10E-4 kg SO_2

3.27E-3 kg SO_2

Total Energy Consumed

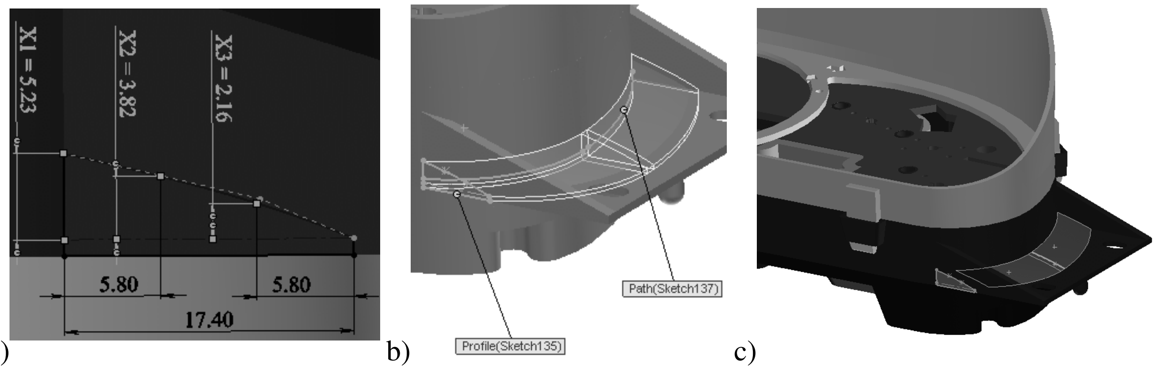
■	Material:	11.90 MJ
□	Manufacturing:	5.47 MJ
■	Use:	0.31 MJ
▨	End of Life:	0.12 MJ

17.79 MJ

Fig. 4. **Environmental impact of frame component of GP calculated by SW Sustainability**

Shape optimization of GP

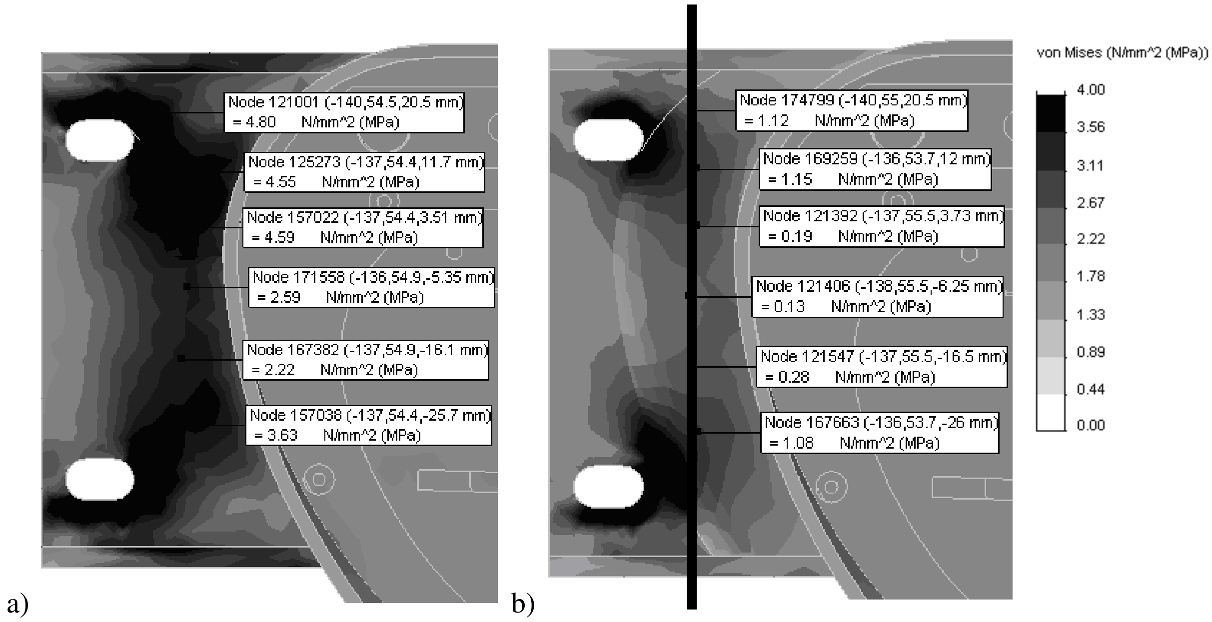
The shape optimization approach based on metamodeling [5; 6] is used to reduce the necessary time and other resources. It includes the following: 1) Planning of position of knot points of non-uniform rational B-splines (NURBS) for smooth shape obtaining. 2) Building of geometrical models by CAD software in conformity with the design of the experiment [7; 8]. 3) Calculation of responses for complete FEM model by CAE software. 4) Building of metamodels for responses obtained in the previous step. 5) Using of metamodels for shape optimization by global search procedure [9]. 6) Validation of optimal design by CAE software for complete FEM model. In this specific situation one of the solutions could be increasing of the GP bracket cross-section thickness and changing the shape at the most loaded place. The cross-section shape for bracket strengthening is defined by the 3 knot points (Fig. 5, a) of NURBS. The design parameters are coordinates of the knot points varied in the following ranges: $3 \leq X1 \leq 6$; $2 \leq X2 \leq 5$; $0 \leq X3 \leq 3$. As a cross-section profile is defined, the 3D-shape is created using the path curve (Fig. 5, b). The same shape for strengthening is created on the second bracket of the GP frame component. The maximal von Mises stress in the bracket was minimized with constraint on the GP volume (v<770500 cm^3).



a) b) c)

Fig. 5. **Shape definition of bracket:**
a – cross-section shape; b – 3D shape creation through path curve; c – shape optimization result

Von Mises stresses are compared in the design of the obtained shape and the initial shape (Fig. 6). There are 6 check points that show von Mises stresses distribution in the most loaded bracket cross-section. The volume of the obtained design is v=770430 cm^3. The change of the assembly volume is insignificant, but the maximal von Mises stress level is reduced by ~82.4 %. Von Mises stress level changes in the cross-section of the GP bracket for initial and optimized variants are presented in Fig. 7.



a) b)

Fig. 6. **Von Mises stress distribution in considered cross-section of:**
a – initial design of GP; b – optimized design of GP

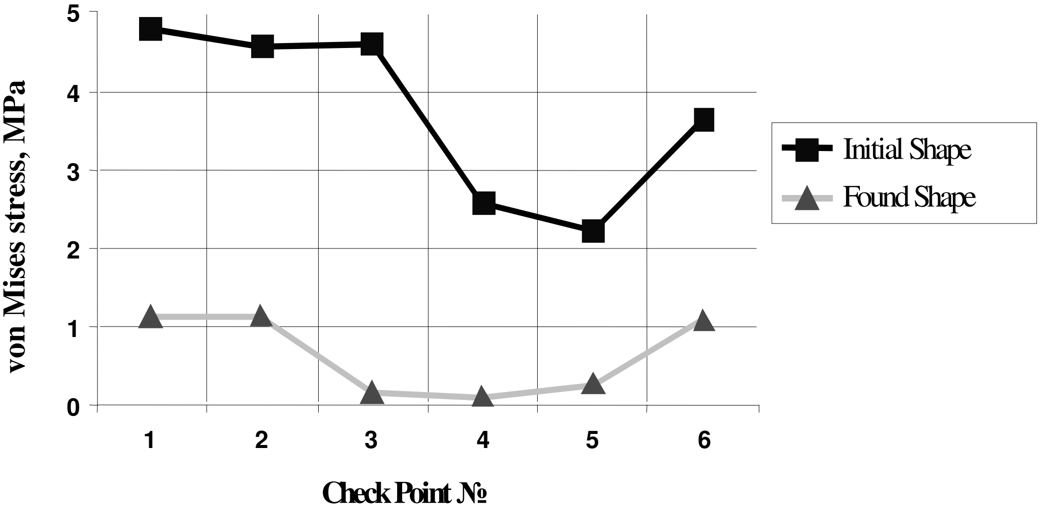
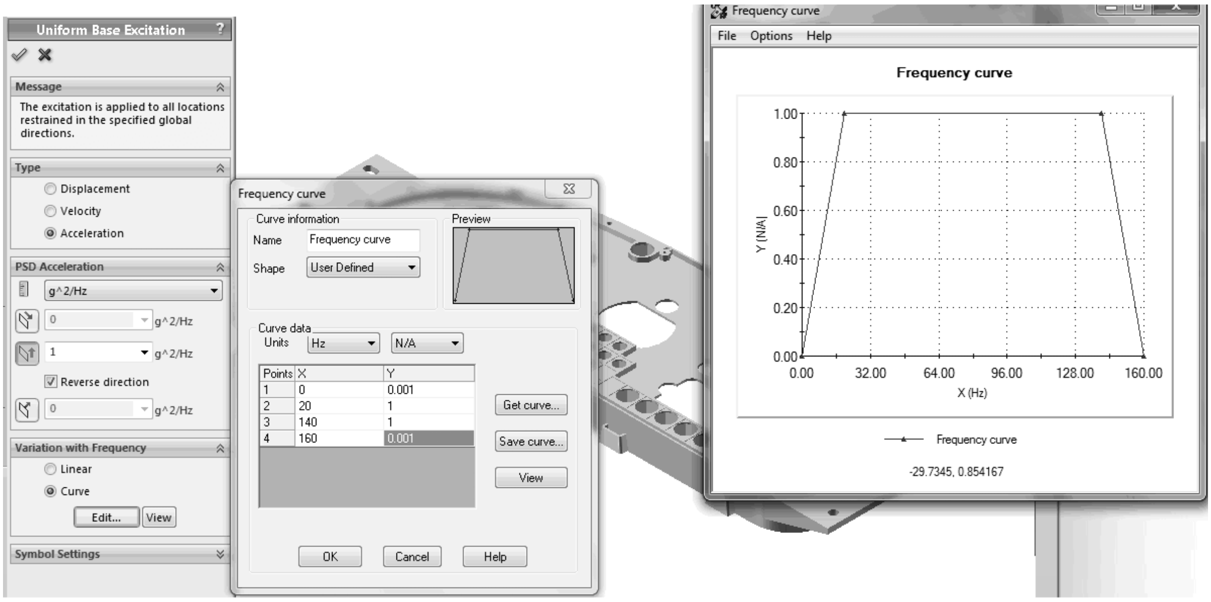


Fig. 7. **Von Mises stress distribution in bracket check points**

These are preliminary results because there are possibilities of further optimization of the path curve shape (Fig. 5, b) and taking into account simultaneously the additional particular objectives such as the maximal von Mises stress in the material of the GP from impact loading and from harmonic vibration excitations calculated by SW Simulation; styling of the GP using α-cut method [2], the carbon footprint and other environmental impacts of the GP throughout its entire lifecycle calculated by SW Sustainability, as well as natural frequencies of the GP. Our investigations are continued intensively for designing of the GP.

For the obtained optimal solution the dynamic behavior of the GP must be verified in case of the uniform base random excitations (see Fig. 8) by analysis of the full FEM model.



The excitation is applied to all locations restrained in the specified global directions.

○ Displacement
○ Velocity
● Acceleration

g^2/Hz
0 g^2/Hz
1 g^2/Hz
☑ Reverse direction
0 g^2/Hz

○ Linear
● Curve

Name: Frequency curve
Shape: User Defined
Units: Hz N/A

Points	X	Y
1	0	0.001
2	20	1
3	140	1
4	160	0.001

Fig. 8. **Definition of random excitations of the GP**

Conclusions

The first results of simulation and optimization of the vehicle GP are presented. The smooth easy technologically realizable shapes are obtained by the current approach. The jagged forms are excluded from the optimization process and there is no need for excessive computational resources. The most time consuming step of the current approach is implementation of computer experiments with FEM analysis for building of metamodels of the GP responses. Then solution of several single objective problems and realization of different aggregation strategies for multiobjective optimization are relatively easy to obtain an acceptable final solution.

Acknowledgments

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