The Euromech Colloquium 650 – Addressing Challenges in Applied Mechanics through Artificial Intelligence Applications, 27 – 29 August 2025, Belgrade, Serbia

Artificial Intelligence-Supported Shape Optimization of an Automotive Rubber Bumper

Dávid Huri[1], Natasa Trisovic[2], Tamás Mankovits[1]

[1] Department of Mechanical Engineering, Faculty of Engineering, University of Debrecen, Debrecen, Hungary

[2] Department of Mechanics, Faculty of Mechanical Engineering, University of Belgrade, Belgrade, Serbia

Corresponding Author: huri.david@eng.unideb.hu

I. INTRODUCTION

In rubber bumper design, the most important mechanical property of the product is the force-displacement curve under compression and its fulfillment requires an iterative design method. Design engineers can handle this task with the modification of the product shape, while the axisymmetric finite element model of the rubber product is an efficient way to evaluate the working characteristics. Using an optimization process in place of a trial-and-error-based mechanical engineering design method can help a company stay competitive in the market if the iteration process can be automated.

II. METHODS

This research examines the sequence of steps in the engineering simulation-based design optimisation process at which automation can be increased using artificial intelligence (AI) tools. Fig. 1 identifies two areas of integration. One possibility is to replace time-consuming simulations with machine learning methods, such as neural networks or support vector regression. Additionally, a task-independent process can be achieved using metaheuristic optimisation algorithms, such as simulated annealing, particle swarm optimisation or genetic algorithms, to approach the global optimum. Further development of deep learning algorithms could enable a method to trigger the entire process without human interaction.

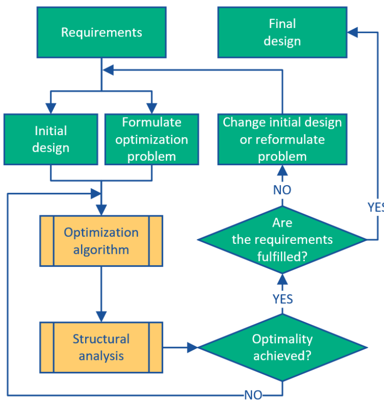

Fig. 2. Design optimization process and the identified sequence of steps for the integration of artificial intelligence methods

The integrability of AI methods was investigated through a two-variable shape optimization problem of a rubber bumper. Given that the geometry, boundary conditions and material behaviour can be considered axisymmetric, it is possible to simplify the problem and perform the discretisation with axisymmetric elements. Thus, the calculation of the simulation-based objective function takes less than a minute using any commercial finite element software. The objective function is calculated as the difference between the initial and optimal spring characteristics shown in Fig. 2.

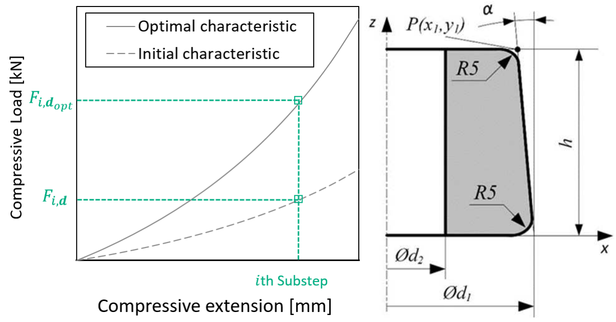

Fig. 1. The working characteristics and section of the rubber bumper

During optimization, the aim is to minimise the objective function by varying the outer and bore diameters of the rubber bumper

$$E(\boldsymbol{d}_{opt})_{FEA} = \min_{\boldsymbol{d}\in\Omega} E(\boldsymbol{d})_{FEA}, \quad (1)$$

where the objective function is given by the sum of squared differences

$$E(\boldsymbol{d})_{FEA} = \sum_{i=10}^{100} \left(F_{i,d_{opt}} - F_{i,d}\right)^2, i \in \{10:10:100\}. \quad (2)$$

Regardless of how the objective function behaves, metaheuristic search techniques can be used to approach the optimal solution; however, task-specific hyperparameter selection is required. The computational cost of the simulation-based objective function evaluation makes it impossible to solve the tuning process in time. The solution devised was to implement a procedure that utilised a support vector regression surrogate model. This procedure was employed for testing and task-specific tuning of the hyperparameters of the simulated annealing algorithm [1]. The novel method has been demonstrated to be capable of solving the optimisation task of the rubber bumper with high accuracy, in a planned timeframe and with high automation.

IV CONCLUSIONS

The utilisation of artificial intelligence tools has the potential to enhance automation and reduce the time required for engineering optimisation tasks. The developed procedure has the potential to reduce uncertainty and increase the efficiency of the design cycle, thereby accelerating innovation.

IV ACKNOWLEDGEMENT

The publication was implemented with the support of the National Research, Development and Innovation Fund (NKFIH) within the framework of the Bilateral Scientific and Technological (TÉT) Cooperation Application No. 2023-1.2.4-TÉT-2023-00114.

V REFERENCES

[1] D. Huri and T. Mankovits, "Surrogate Model-Based Parameter Tuning of Simulated Annealing Algorithm for the Shape Optimization of Automotive Rubber Bumpers" Applied Science, 2022. https://doi.org/10.3390/app12115451