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Optimization of the structure of the micro electric vehicle deck

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ABSTRACT: Urban mobility has a substantial impact on the air quality of urban areas with high population density and, together with the problems related to traffic congestion, parking and noise pollution, has a relevant effect on the quality of life. Electric vehicles in the form of traditional cars do not resolve all these problems, especially in the urban areas. Therefore, new kind of personal transport devices are gaining popularity: the so-called microvehicles. The most popular electric microvehicles also have some disadvantages. European Commission granted funds for the project aiming to develop microvehicle in which some of the most noticeable shortcomings of microvehicles will be addressed. Demanding functional parameters of the new microvehicle raised the need to use advanced engineering tools in the design process. In the paper, optimization of main deck of the microvehicle is presented. The deck has sandwich-like structure with core made from lightweight material reinforced by skin made from fiber reinforced composites. Advanced genetic optimization algorithms allowed the authors to find optimal structure of the deck, especially in terms of stiffness. As a result, the deck can withstand operational loads and also can act as a replacement for a standard suspension.

SŁOWA KLUCZOWE: micromobility, optimization, numerical analysis

1. Introduction

Land transport contributes significantly to the emissions of sulphur dioxide and nitrogen oxides as well as to the concentration and deposit of air pollutants [1]. Urban mobility has a substantial impact on the air quality of urban areas, with high population density and, together with the problems related to traffic congestion, parking and noise pollution, has a relevant effect on the quality of life [2].

Pollution and energy problems led to the development of electric vehicles, mainly traditional cars with hybrid engines [3] and, less common, fully electric cars (2.2% of total circulating in EU [?]). The diffusion of these vehicles is progressively increasing, but the main problems that limit their mass diffusion to date are: (i) limited autonomy of fully electric vehicles; (ii) vehicles high cost; (iii) expensive infrastructure at moment limited recharging points and long charging times; (iv) need for parking with charging stations and consequent footprint in the cities.

Analysing the most common types of microvehicles, there are significant differences in terms of charging times, range, power, handling and ergonomics and price as evidenced by tests carried out by the Swiss Touring Club [4]. The most popular microvehicles are e-bikes, e-scooters (as well as monowheels), but all these best candidates to micromobility have some weakness. E-bikes is suitable for long distance, is easy to use but is bulky (also the foldable models) and not easy to integrate with Public Transport. Their costs could be easily over 1,000 €. E-scooter, that is now very popular, is easy to use for everyone, foldable and very practical for transport by Public Transport. Unfortunately, it is not very suitable for long distances and has little ability to deal with steep slopes and rough roads. Even in terms of braking, they do not work well at all. Monowheel compensate most of the weakness of e-scooter with a competitive price, but we can certainly say that, now, it is not the vehicle for everyone since it is difficult to ride. Probably the next generation could use these vehicles as being special shoes, but it does not seem an immediate solution.

In short, all the best solutions suitable for daily use as a means of transport in urban and suburban areas have some weakness.

In 2020 European Commission accepted the project LEONARDO that aims to develop an affordable, safe, easy to manage and cheap to maintain electric micro-vehicle, which does not require parking and is not left on the road or on the sidewalk and that overcomes the limitations of currently available microvehicles [5]. Among number of engineering activities undertaken in order to develop the new vehicle was the task of optimization of the main deck of the vehicle. In this paper, optimization process is described in detail.

2. Conceptual design

In the course of the project, conceptual design was developed. At the same time, key requirements of the technical design were defined: construction materials, permissible loads, expected vehicle weight, etc. The design is shown in Fig. 1. One of the important decisions was to abandon the suspension. Its role is to be played by the vehicle board, which in this case must have a strictly defined stiffness.

3. Optimization of the main board.

One of the biggest challenges of the design was to keep weight of the entire vehicle at the lowest possible level. Therefore, it was decided that main deck must be made from lightweight materials. Considering previous experience and mechanical characteristics, the choice was made to develop sandwich structure, with outer layers made from fiber reinforced glass composite and core made from PVC.

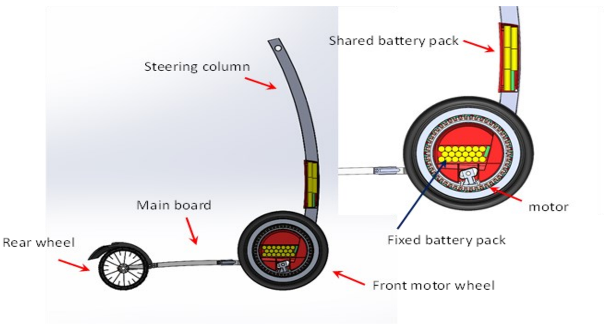

Fig. 1. Concept of the microvehicle.

The main goal of the optimization is to find composite sequence with the smallest number of layers (and in effect generating the lowest mass and cost) maintaining predefined strength and stiffness. The problem can be described in the following form:

$$\min n_{layer}\,(\alpha_1, \alpha_2, \alpha_3, \alpha_4) \text{ subjected to } d \le d_{desired} \quad (1)$$

where n_{layer} – number of layers $n_{layer} =< 4, 6, 8, 10, 12 >$; $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ – reinforcement orientation angles in 4-layers sequence, $d, d_{desired} = 11.5\ mm$ – deflection (maximum of vertical displacement) of the analysed board and reference bamboo board. Orientation angles depends on two parameters, α_{base} (base orientation angle) and α_{rotate} (angle of rotation between layers):

$$\begin{aligned} \alpha_1 &= \alpha_{base} \\ \alpha_2 &= \alpha_{base} + \alpha_{rotate} \\ \alpha_3 &= \alpha_{base} + 2\alpha_{rotate} \\ \alpha_4 &= \alpha_{base} + 3\alpha_{rotate} \end{aligned} \quad (2)$$

where $\alpha_{base} =< 0°, 45°, 90° >$ is orientation angle of whole composite lay-up and $\alpha_{rotate} =< 0°, 45°, 90° >$ is angle between subsequent unidirectional layers. As a results for $\alpha_{rotate} = 0°$ we have unidirectional composite, for $\alpha_{rotate} = 90°$ biaxial and for $\alpha_{rotate} = 45°$ quadaxial composite. The $\alpha = 0°$ is longitudinal direction and $\alpha = 90°$ is perpendicular direction of the deck.

The developed parametric FE model allows to generate several numerical models with variable number of layers and reinforcement orientation angle. Combination of α_{base}, α_{rotate} and n defined as above resulted in 45 sampling points, i.e., different FRC layouts.

Sampling points located in parametric space defined by base direction, number of FRC layers and layers directions is presented in Fig. 2. Each sampling point represents different layout of composite skin of scooter board. The points marked in green meet the defined requirements.

4. Optimization results

Overall results show that a deck made of 6 layers of FRC (Fig. 3) withstands loads and offers desired stiffness. Results show that bidirectional composite with base angle of 45° performs better than the others. Moreover, the maximum value of stresses in fiber direction (85 MPa) is much lower than the tensile strength.

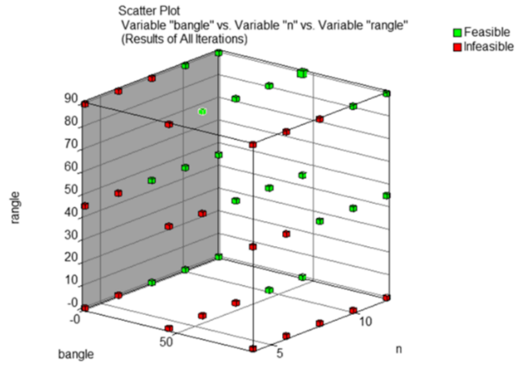

Fig. 2. Sampling points

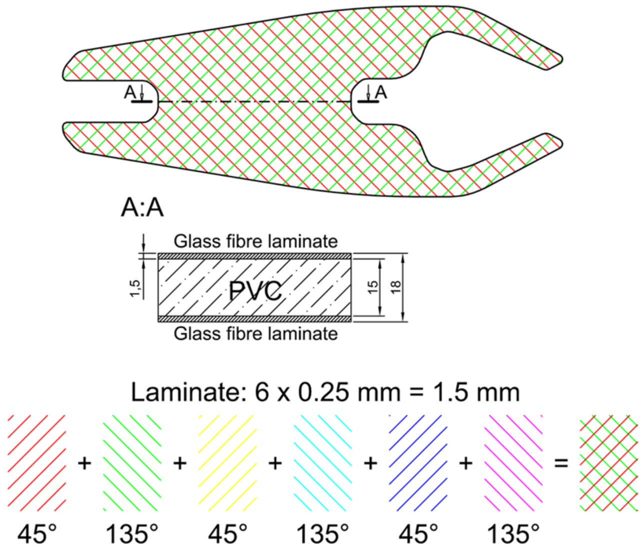

Fig. 3. Sampling points

5. Conclusions

In the article, optimization of sandwich structure of e- cooter is presented. Advanced optimization tools led to the development of a deck that can replace suspension systems and therefore simplify scooter design, minimize its weight and price.

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[1] (European Environment Agency, State Of the Environment Report – SOER 2020: https://www.eea.europa.eu/publications/soer-2020/at_download/file)

[2] (WHO, Air Quality Guidelines - global updates 2005: http://www.euro.who.int/__data/assets/pdf_file/0005/78638/E90038.pdf?ua=1).

[3] registrations in EU / EFTA January-September 2019 equal to 6.7%, plug-in hybrids and hybrids, source ANFIA: 092019_UE-EFTA_Focus Vehicle Market Alternative Power Supply-1.pdf.

[4] https://www.tcs.ch/mam/Digital-Media/PDF/Booklets/test-tcs-dei-veicoli-di-tendenza.pdf

[5] https://leonardoproject.eu/