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Original Article

IMPROVING THE EFFICIENCY OF USING AN ELECTRIC SCOOTER IN URBAN ELECTROMOBILITY

Jacek CABAN[1]✉, Aleksander NIEOCZYM[2],
Edgar SOKOLOVSKIJ[3]☻, Kazimierz DROZD[4]

[1] *Dept of Automation, Faculty of Mechanical Engineering, Lublin University of Technology, Lublin, Poland*
[2] *Dept of Machine Design and Mechatronics, Faculty of Mechanical Engineering, Lublin University of Technology, Lublin, Poland*
[3] *Dept of Automobile Engineering, Faculty of Transport Engineering, Vilnius Gediminas Technical University, Vilnius, Lithuania*
[4] *Dept of Materials Engineering, Faculty of Mechanical Engineering, Lublin University of Technology, Lublin, Poland*

Highlights:
- electric scooters have gained huge popularity as a convenient, ecological and economical means of urban transport;
- FEM strength analysis confirms the correctness of the optimized structure;
- the modernization improved the functionality, driving comfort and safety of the scooter.

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Abstract. The popularity of electric scooters as an individual means of transport results from their availability in the urban sharing system, ease of movement in the city and reduction of driving time compared to other means of passenger transport. The user can choose from a whole range of vehicles with different driving range and equipment with elements increasing the functionality of using the scooter. The article presents a proposal for changes to the design of a typical electric scooter. The main objective of the work is the engineering design of suspension and braking systems, in particular the swing arm suspension of the front and rear wheels and an additional disc brake. Increasing the diameter of the wheels and equipping it with a front and rear suspension system allowed for the reduction of vibrations and shocks transferred to the vehicle when driving on uneven surfaces. The results of analytical calculations confirming the positive effects of the introduced modifications were included. Adding a disc brake allowed for shortening the braking distance from 13.7 to 8.9 m, which has a positive effect on driving safety. A Finite Element Method (FEM) strength analysis was also performed, the results of which confirm the correctness of the new design. The modernized design improved the ride comfort and safety of using the electric scooter.

Keywords: brake system, design, electric scooter, FEM, solid model, suspension system, urban transport.

✉ Corresponding author. E-mail: *j.caban@pollub.pl*

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Notations

a_h – braking acceleration (deceleration) [m/s^2];
$|AB|$ – horizontal dimension of unevenness [m];
c – spring stiffness [N/mm];
d – scooter wheel diameter [mm];
d_1 – wheel diameters 11″ [mm];
d_2 – wheel diameters 8″ [mm];
D – average diameter of the braking force applied [mm];
D_m – spring pitch diameter [mm];
E – elastic modulus [GPa];
F_d – brake pads pressure force on the disc [N];
F_h – braking force [N];
F_n – user's pressure on the brake lever [N];
g – gravitational acceleration [m/s^2];
h – the depth to which the wheel sinks when driving over uneven surfaces [mm];
h_1 – the depth to which the wheel 11″ sinks when driving over uneven surfaces [mm];
h_2 – the depth to which the wheel 8″ sinks when driving over uneven surfaces [mm];

i_d – brake system ratio;
k – dynamic load factor during driving;
L_0 – spring length in free state [mm];
L_n – spring length in compressed state [mm];
m – scooter mass with driver [kg],
M_h – braking torque [N·m];
n – number of brake pads;
N – dynamic force loading the scooter [N];
N_1 – the force acting on the front and rear suspension, resulting from the total load distribution [N];
P – power of the scooter drive engine [W];
q_s – correction factor;
r – wheel radius [m];
R_e – yield strength [MPa];
R_m – tensile strength [MPa];
s – minimum braking distance [mm];
T – torque of the scooter drive motor [N·m];
v – scooter speed [m/s];
τ_{max} – maximum torsional stress [MPa];
μ – coefficient of friction between brake pad and disc;
ξ – coefficient determining the spring shape;
Δ_{Obw} – percentage increase in wheel circumference [%];
Δ_h – percentage change in wheel depth [%].

1. Introduction

Nowadays, electric scooters have gained huge popularity as a convenient, ecological and economical means of urban transport (Setiyo 2023; Yang *et al.* 2020). This is due to the need for fast and efficient movement over short distances, especially in crowded cities. Despite the wide availability of models diversified in terms of construction, scooters often do not meet all the user's expectations in terms of comfort and safety (Moosavi *et al.* 2022). For this reason, in this work, an analysis of the design of an electric scooter model was carried out in terms of its comfort of use and safe design.

The main goal was to modify the design in terms of improving its functionality, driving comfort and safety. The presented work aims to design the engineering suspension and braking systems, in particular the swing arm suspension of the front and rear wheels and the additional disc brake. The presented research shows the loads acting on the structure of the scooter suspension system, introduces boundary conditions defined for Finite Element Method (FEM) calculations, which is confirmed by the results of the simulation.

The suspension system and the scooter braking system were modified, calculated analytically, modelled and simulated. A new swing arm design and springs used in the suspension system connected in parallel the shock absorbers with different damping characteristics. In the case of the braking system, an additional mechanical disc brake system was introduced with a disc diameter of 120 mm. In addition, the diameter of the road wheels was increased by 3''. For this purpose, strength analyses using the FEM of the appropriate structural elements were carried out at allowable values of stresses and deformations.

2. Literature review

The efficiency of urban transport is an important issue not only for transport companies providing transport services, but above all for residents of congested cities. The problem is not only the availability of means of transport but above all the infrastructure (Świtała 2023), which in many cities is not adapted to the existing traffic intensity. The problem of transport congestion is very noticeable in large cities, especially in their centers. Much attention to the issues of monitoring road traffic was presented in reserarches by Bartuska & Hanzl (2019), Paľo & Stopka (2021). Ľupták *et al.* (2018), raised the issue of the quality of the transport network and traffic planning, and similar studies were also conducted by Mikusova *et al.* (2021) and Kalašová *et al.* (2024). Increased traffic in cities forces residents to look for other forms of movement, as mentioned in researches by Bartuska *et al.* (2022) and Bulkova & Gašparik (2024). In many countries, including Poland, city bikes have become very popular (Kubalák *et al.* 2021; Rathouský, Mervart 2023; Turoń, Sierpiński 2018) and then electric scooters available in the sharing system (Hamerska *et al.* 2022; Turoń *et al.* 2023). Detailed information on the operation of the city bike system in a selected Slovak city was provided by Kubalák *et al.* (2021), while Rathouský & Mervart (2023) presented such a system operating in Prague, and Dudziak & Caban (2022) showed the impact of the COVID-19 pandemic on the operation of the city bike system in the city of Lublin, located in south-eastern Poland. Recently, an increasing number of users have their own scooters, including electric scooters (Dižo *et al.* 2025; Szemere, Nemeslaki 2023).

Electric scooters are characterized by high available torque on the drive wheel, they are quiet and do not emit exhaust fumes, like similar designs but with a combustion engine. The drive through the combustion engine, in turn, eliminates the basic disadvantages of electric scooters, which are long charging times and a range limited by the battery capacity (Campisi *et al.* 2023), unfortunately often shorter than that available in the combustion drive system. As rightly noted by researchers Gechev & Punov (2020), and Kozłowski *et al.* (2024), energy consumption in transport depends on the driving strategy and road conditions such as: surface technical condition (Timokhovets *et al.* 2025), road profile (Virin *et al.* 2025), etc. Micromobility not only improves traffic capacity in the city but also does not emit exhaust fumes. Exhaust emissions in the city are an issue widely discussed in the literature (Dziewiątkowski & Szpica 2021; Hunicz & Kordos 2009; Šarkan *et al.* 2021; Zimakowska-Laskowska, & Laskowski 2024) and by the authorities, which is reflected in various types of restrictions and increasingly stringent exhaust emission standards for motor vehicles (Stopka *et al.* 2016). In addition to exhaust emissions, noise emitted from means of transport is a major nuisance in the urban area (Šarkan *et al*. 2017; Skrúcaný *et al.* 2017). For these reasons, a sustainable approach to urban transport is so important (Sendek-Matysiak *et al.* 2020; Shekhovtsov *et al.* 2022).

Progress in the field of engineering materials allows the use of increasingly new materials (Estrada *et al.* 2019; Firlej *et al.* 2021; Pashechko *et al.* 2020; Rumianek *et al.* 2019) and manufacturing techniques including additive techniques (Caban *et al.* 2019; Coutiño-Moreno *et al.* 2021; Sawa *et al.* 2021; Van *et al.* 2023) and obtaining high quality of the product (Bogucki *et al.* 2020; Kowalik *et al.* 2016; Matuš *et al.* 2023; Mazur *et al.* 2023), thanks to which the design of scooters is characterized by low weight and attractive appearance.

A scooter is a means of personal transport, which is characterized by a platform placed low above the ground on which the user stands, and the basic drive is achieved by bouncing the foot off the ground. Scooters can be powered by human muscle power by pushing off the ground, but as already mentioned, also by mechanical drive – a combustion engine or, increasingly often, an electric motor. Due to the fact that they can achieve relatively high driving speeds, they are equipped with brakes, most often disc brakes, but also friction brakes and an emergency brake. Analysing the construction of frames, scooters can have a rigid or foldable frame (Dižo *et al.* 2025). Variants with a foldable frame are intended rather for lighter and smaller scooters and much smaller loads. However, the rigid frame ensures sufficient stiffness and stability of the structure and carries larger loads, which is perfectly compatible with its own electric and combustion drive. The suspension system structures can also take different forms, from simple structures without shock absorption, through a swing arm system on one or 2 wheels and with shock absorption and energy recovery systems during braking. As you can see, there are a number of types and solutions that need to be considered when designing this type of personal transport.

There are no uniform regulations governing the use of electric scooters in the EU. In Poland and Germany, the maximum speed of a scooter can be 20 km/h, and the scooter must be equipped with lights, brakes and a bell. The minimum age of a person using a scooter is 15 years. It is strictly forbidden to ride a scooter on cycle paths or, in the absence thereof, on the road, because riding on pavements is prohibited. In France, the maximum speed of a scooter can be as much as 25 km/h. Electric scooters in the UK are very strictly regulated – they can only be used on private property, unless they are part of an official electric scooter rental program. Users should have at least a provisional driving license and be at least 16 years old (Road Traffic Act 1988).

Electric scooters used in Europe must have a CE (in French: *Conformité Européenne*) certificate and meet the following standards:

- PN-EN 15194+A1:2024-01 – the standard covers all significant hazards, dangerous situations and possible incidents of electric bicycles and scooters when used as intended;
- ISO 4210-2:2023 – the standard specifies terms and definitions related to safety and performance requirements during the design, assembly and testing of bicycles and scooters.

These standards specify requirements and test methods for the engine power management system, electrical system and electrical components at a rated voltage of a DC electric motor of up to 48V. The standards define the method of maintenance of electric vehicles and guidelines for user instructions. Compliance with such standards is a condition for permitting scooters to be used on public roads.

The aspect that determines the performance of an electric scooter, energy efficiency and range is the type of drive. Brushless DC (BLDC) motors are synchronous motors powered by direct current, using an electronic controller to change direct currents in the motor winding (Hanselman 2006; Nadolski *et al.* 2012). Thanks to this type of solution, the torque, voltage and engine speed are linearly related. This type of drive does not require a gear, the engine can be attached directly to the wheel.

The engine controller is used to start and stop the engine, regulate engine speed, provide protection against electrical overloads, and interface with the Battery Management System (BMS) (Małek, Taccani 2021; Pistoia 2009). Advanced BMS solutions provide monitoring of the charge state and temperature, which is crucial for the safety of lithium-ion batteries.

3. Characteristics of the scooter that underwent modernization

In order to conduct a comparative analysis of the effectiveness of the changes, a description of a commonly used electric scooter has been included (Figure 1a).

The vehicle is powered by a BLDC motor with a power of P = 350 W, which allows for a maximum torque of T = 17 N·m. The scooter has a built-in lithium-ion battery with a capacity of 7.5 A·h, which nominally allows for a range of up to 30 km (KugooEU Scooter 2025). The vehicle is equipped with 8″ wheels with a solid honeycomb tire, which are also intended to partially dampen vibrations.

There are 2 ways to brake a scooter: using an electronic brake and a rear brake. The electronic brake is activated by the lever on the left side of the handlebars and braking

Figure 1. 3D model of scooter:
(a) – original; (b) – after modernization

is performed by an electric motor. Another way to stop is to hold the rear mudguard with your foot, which causes the mudguard body to be pressed against the tire using a friction brake.

The front suspension of the basic scooter consists of 2 coaxial sleeves with a compression spring inside, Figure 2a. The outer sleeve is stationary, while the inner one connects the upper part of the handlebars and rests on 2 angular contact ball bearings. The rear suspension (Figure 2b) consists of a tensioner mounted to the base on a rotating axle and a compression spring. The rotating axle is connected to the swingarm. The swingarm, by rotating in a vertical plane, compresses the spring. The front and rear suspension springs have adjustable lengths. Changing the length changes the stiffness of the spring.

4. Scooter modernization

The design changes described below are intended to increase safety and ride comfort. These analyses were conducted based on the authors' experience and literature reports in the field of construction and analysis of various alternative vehicles (Blatnicky *et al.* 2023; Caban *et al.* 2024; Dąbrowska *et al.* 2022; Jenis *et al.* 2023; Jilek, Cerman 2020; Pompáš *et al.* 2023) their comfort of use (Blatnicky *et al.* 2022) and safety (Jilek *et al.* 2022; Karpenko *et al.* 2024). Increasing the diameter of the road wheels reduces vibrations transferred to the steering column when driving over uneven surfaces (Gogola 2020; Jilek 2023; Lukac *et al.* 2016). It also reduces the likelihood of tipping over during a collision with a vertical obstacle. Increased ride comfort is also provided by the suspension with an integrated coaxially placed shock absorber and coil spring. An important part of the scooter modification is the elimination of the rear pressure brake and the installation of a disc brake. Such action will reduce the braking distance and directly affect ride safety.

4.1. Wheel diameter change

Increasing the wheel diameter allows for reducing the vibration amplitude of the wheel that hits the road surface irregularities. Figure 3 shows a comparison of the wheel diameter with its displacement in the vertical axis when driving over road surface irregularities.

The amplitude of vibrations can be defined by the depth h to which the wheel sinks when passing over uneven surfaces (Figure 3b), and is calculated from the formula:

$$h = r - \sqrt{4 \cdot r^2 - \left|AB\right|^2}; \quad (1)$$

$$\Delta_h = \frac{h_1 - h_2}{h_1} \cdot 100\%. \quad (2)$$

The scooter wheel vibration amplitude will decrease by 37% after installing 11″ wheels. The advantage of this modification is improved ride comfort, increased component durability, better traction and ride stability.

Changing wheel circumference:

$$\Delta_{Obw} = \frac{\pi \cdot d_2 - \pi \cdot d_1}{\pi \cdot d_1} \cdot 100\%. \quad (3)$$

In the original scooter, the wheels installed by the manufacturer have a diameter of 8″. During the scooter modernization, it is planned to install wheels with a diameter of 11″. For the example of a horizontal unevenness $|AB|$ = 30 mm, the change in the wheel vibration amplitude achieves the values shown in Table 1.

The increased tire circumference by 37% theoretically increases its maximum speed, range and lower rolling resistance. Additional cushioning is provided by a modified tire type compared to the original. The original tire is a solid tire whose advantage is greater durability when hitting uneven surfaces. The 11″ tire with an inner tube is characterized by better damping of vibrations transferred to the handlebar.

Figure 2. Original scooter suspension: (a) – front; (b) – rear

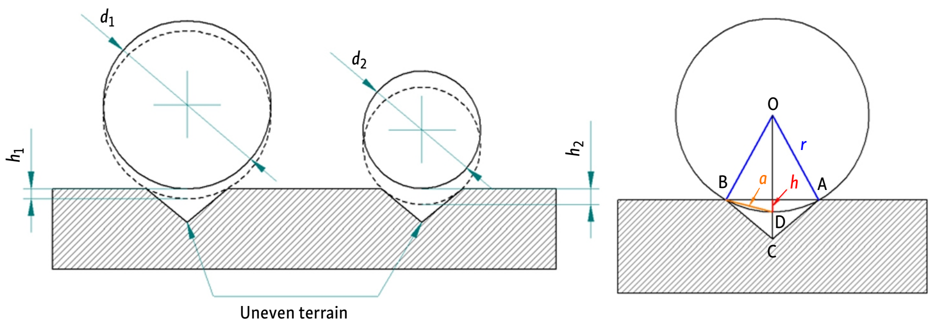

Figure 3. Graphic illustration of differences in overcoming road surface unevenness

Based on other tests of prototype wheeled vehicles (Bąkowski, Czech 2014; Kukla *et al.* 2021; Wieczorek *et al.* 2020), modernizations were carried out in the field of electric scooter suspension.

The key element influencing ride comfort and the ability to dampen and absorb shocks while riding is the scooter suspension. As part of the scooter modernization, a new front and rear suspension based on gas springs and compression springs was designed.

Improved vibration damping in a wide frequency range was obtained by coaxially mounting the shock absorber and the compression spring. The shock absorber is designed to damp vibrations of small amplitude but high frequency. The spring reduces vehicle displacements when riding on uneven surfaces. Adjusting the suspension hardness to the individual needs of the user is achieved by adjusting the length of the compression spring. This allows you to change the suspension characteristics depending on the variety of surfaces and user preferences.

The technical data of the suspension springs are presented in Table 2.

The d and D_m dimensions (Table 2) were adopted because springs with these dimensions are commercially available. Using springs with the same geometry but different lengths L_0 in the suspensions of both wheels results in different stiffnesses, but the force adjustment range remains the same.

The main elements of the new rear suspension (Figure 4b) are a system consisting of a compression spring and a gas shock absorber, as well as 2 swing arms encompassing the wheel. Moving the rear suspension above the upper surface of the scooter base allowed for increasing its main dimensions. Thanks to this, the adjustment range and the shock absorber's operating arm are much larger.

Table 1. Results of calculated parameters

Parameter	Wheel diameter	
	8′′	11′′
h_1	$5.54 \cdot 10^{-4}$	–
h_2	–	$4.03 \cdot 10^{-4}$
Δ_h	37.0%	
Δ_{Obw}	37.5%	

Table 2. Properties of the new suspension compression springs

Property	Shock absorber	
	front	rear
d – scooter wheel diameter [mm]	8	8
D_m – spring pitch diameter [mm]	35.5	35.5
L_0 – spring length in free state [mm]	100	80
L_n – spring length in compressed state [mm]	52.5	45
c – spring stiffness [N/mm]	194.55	243.18
n – number of active coils	5	4

The front suspension (Figure 4a) uses an identical system as the rear suspension. It is attached to the fixed steering column sleeve using supports. The front wheel forks have been replaced with 2 arms on the sides mounted on the lever. The lower part of the shock absorber is mounted on a shaft attached to the arms and one of the ends of the lower levers. The upper part of the shock absorber is mounted on the upper support.

The springs in the front and rear suspension differ in the number of active coils n and the spring free length L_0. These geometric values directly affect the spring stiffness. After modifying the design, the scooter user can smoothly adjust the spring stiffness of the front and rear suspension (Table 2). Changing the spring tension depending on the user's weight and preferences translates into subjective sensations of soft or stiff suspension. Some users adjust the suspension stiffer for smooth road surfaces, i.e., compress the spring more. On roads with a highly uneven profile, they prefer a softer suspension (the spring clamp is loosened). Such adjustments are primarily made for the front suspension because the road surface reactions are more intensely transferred from the scooter handle to the user's hands than from the platform to the legs and body. The rear suspension is rarely adjusted because the reaction forces transferred to the platform do not cause such negative sensations related to ride comfort. The center of the scooter deck always moves less than the rear wheel (and the front wheel) as the rear wheel goes over the bump. These considerations were made assuming that only one scooter wheel is going over the bump at a time.

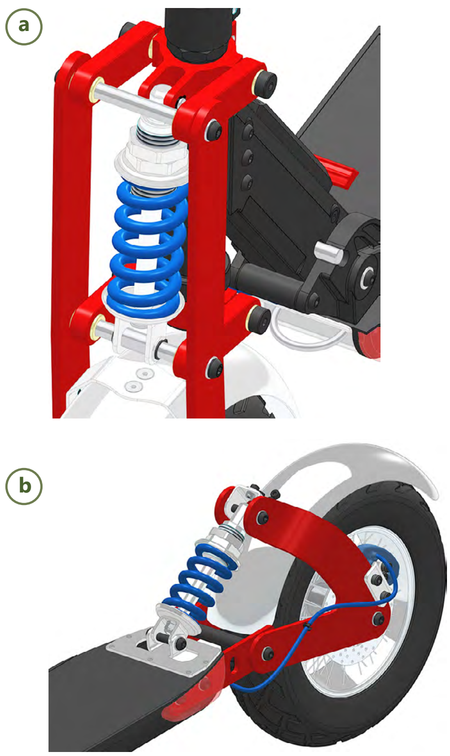

Figure 4. Solid model of the modernized suspension: (a) – front; (b) – rear

In order to verify the correctness of the new suspension, a strength analysis was carried out, which aims to show whether the permissible stresses were not exceeded in any node. The load applied to the scooter base is equal to the maximum permissible weight of the driver, i.e., m = 120 kg. Dynamic force N loading the scooter were obtained by introducing a dynamic load factor during driving k = 1.4:

$$N = m \cdot g \cdot k = 120\ \text{kg} \cdot 9.81\,\text{m}/\text{s}^2 \cdot 1.4 = 1648.08\ \text{N}. \quad (4)$$

The CTETRA 10 tetragonal mesh element made in Abaqus (*https://www.3ds.com/products/simulia/abaqus*) was used for the calculations, each one with ten integration nodes (Figures 5–7). The whole model was meshed automatically and consists of 498472 elements and 881662 nodes. The subjective mesh size was set to 7 mm. The restraints were modelled at the locations where the front and rear wheel axles are mounted.

The properties of the materials used in the scooter construction are given in Table 3.

The simulation was performed separately for the front and rear wheel suspension. It was assumed that the user riding the scooter affects the front and rear suspension equally, so each of them was loaded with a force of N_1 = 0.5·N = 825 N. The force was applied at the rear axle and front wheel mounting points in a direction perpendicular to the ground (black arrows in Figure 5).

The reduced stress distribution maps are shown in Figure 6 and Figure 7. The highest reduced stresses at the maximum load of the scooter suspension are located on the inner diameter of the springs and have a value of approximately 160 MPa. In the swingarms and rear suspension mounting elements, the reduced stresses do not exceed 20 MPa. In the case of the support and levers associated with the front suspension, the stresses also do not exceed 20 MPa.

The correctness of the stress results was checked by analytical calculations. Maximum spring stresses caused by the torsional moment and shear force, assuming a symmetrical load distribution on the front and rear wheels of the scooter:

$$\tau_{\max} = \frac{8 \cdot N_1 \cdot \xi}{\pi \cdot d^2} \cdot q_s; \quad (5)$$

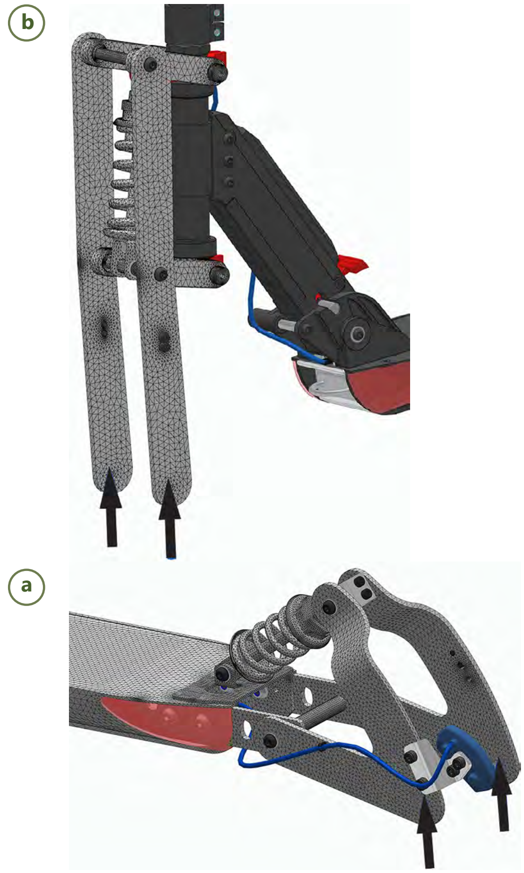

Figure 5. Distributed mesh and the load (black arrows) introduced in the suspension model:
(a) – front; (b) – rear

$$q_s = \frac{4 \cdot \xi - 1}{4 \cdot \xi - 4} + \frac{0.615}{\xi}; \quad (6)$$

$$\xi = \frac{D}{d}.$$

By substituting the geometric dimensions of the spring (Table 3), the maximum stress values were obtained – $\tau_{\max} = 195.8$ MPa. The calculated value of the maximum shear stress in the spring is close to the stress values obtained during the FEM strength analysis (Figure 6 and Figure 7).

Based on the FEM analysis, the correctness of the design of the modernized front and rear wheel suspension was confirmed.

Table 3. Strength parameters of materials

Parameter	Material		
	Suspension components	Suspension springs	Scooter base, rear swing arm, handlebar body handlebar
	Structural steel S235JR	Carbon non-alloy spring steel C55S	Aluminium alloy
Tensile strength R_m	360...510 MPa	650...850 MPa	90...300 MPa
Elastic modulus E	210 GPa	200 GPa	70 GPa
Yield strength R_e	235...350 MPa	550...700 MPa	115...125 MPa

4.2. Disc brake

The project includes the modernization of the braking system. This is due to 2 main reasons. Braking with the engine is often very sudden due to the frequent uncontrolled rotation of the throttle by the driver. In some scooter models, the throttle only works in the on and off positions, it does not have any intermediate state thanks to which the braking force can be adjusted (KugooEU Scooter 2025). For this reason, braking is only performed with maximum force. The front wheel is braked, because the electric motor is mounted on it. During the braking process, the user must remember that the scooter loses speed rapidly, which is why there is a risk of falling over the handlebars.

Braking with the rear mudguard is much safer due to the lower risk of the driver losing balance. Nevertheless, this solution is not without its drawbacks. In emergency situations, the driver must react quickly and transfer the balance to one of the legs and direct the other to the mudguard and press it against the wheel enough to brake effectively. When riding in different weather conditions, there is a risk of dirt on the inner surface of the mudguard and the tire. Mud and water cause longer braking distances. It is necessary to use more force on the fender to achieve the same braking distance as on a dry surface and with a clean rear fender brake.

The rear wheel of the modernized scooter uses a mechanical disc brake system with a disc diameter of D = 120 mm. The model of the brake system is shown in Figure 8.

For the calculation of the braking force (Table 4), the user's pressure on the brake lever was assumed, it has a value of F_n = 100 N, the brake system ratio i_d = 10, the coefficient of friction between the pads and the disc μ = 0.5 and the scooter mass together with the user totalling m = 132.5 kg.

The force of the brake pads pressing on the disc:

$$F_d = F_n \cdot i_d. \tag{7}$$

The disc brake is equipped with n = 2 brake pads:

$$M_h = n \cdot F_d \cdot \mu \cdot \frac{D}{2}, \tag{8}$$

Braking force F_h applied at the contact between the surface and the road wheel:

$$F_h = \frac{M_h}{0.5 \cdot d}. \tag{9}$$

Braking deceleration a_h:

$$a_h = \frac{F_h}{m}. \tag{10}$$

Braking distance s from a maximum scooter speed of v = 6.94 m/s (25 km/h):

$$s = \frac{v^2}{2 \cdot a_h}. \tag{11}$$

At a scooter speed v of 25 km/h, the braking distance is approximately s = 8.9 m and is close to the value given in the technical data of electric scooters (Barslund 2025; Proszek 2026).

The introduction of a disc brake allows the braking distance using a pressure brake to be shortened from s = 13.72 m to s = 8.9 m. For comparison, using electric brakes allows braking on a distance of approximately 12 m. The location of the brake handle on the handlebars reduces

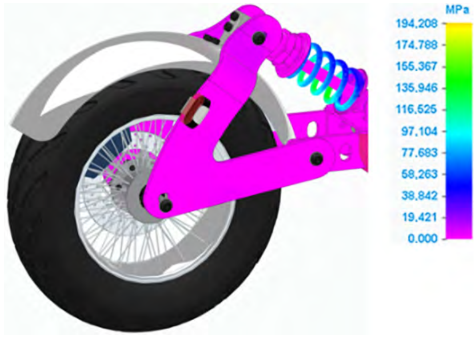

Figure 6. Analysis of the static load of the rear suspension

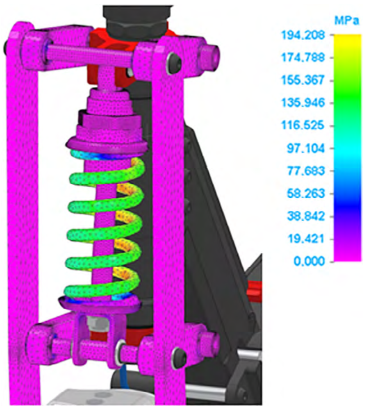

Figure 7. Reduced stress map of the static load of the front suspension

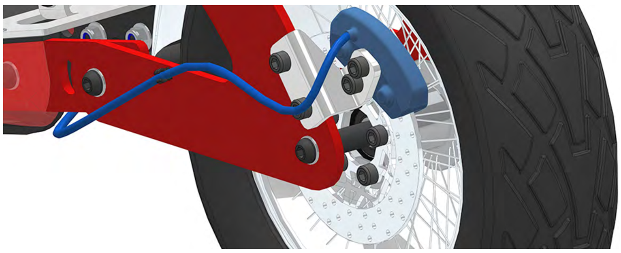

Figure 8. The disc brake mechanism installed in the scooter

Table 4. Results of calculated parameters of brake system

Parameter	Results value	Unit
Scooter wheel diameter d	11	"
Braking force of the brake pads pressing on the disc F_d	1000	N
Braking torque M_h	25	N·m
Braking force F_h	500	N
Braking deceleration a_h	2.7	m/s^2
Minimum braking distance s	8.9	m

the reaction time in the event of a sudden event. This does not force the user to brake suddenly as in the case of engine braking and to lift one foot off the platform to use the rear pressure brake, which may result in loss of balance.

Simulation calculations of both systems have proven that the designed suspension and braking system meets the considered loads during scooter operation. These systems are important from the point of view of safety and travel comfort. The increased wheel diameter provides better damping and overcoming unevenness, which translates into a more comfortable and stable ride of the scooter. An efficient braking system allows for a shorter braking distance, which affects the safe movement of this means of transport. In general, it can be stated that the changes made to the engineering design of the scooter did not deteriorate its durability and driving properties, but rather improved the level of safety and travel comfort. Moreover, as other researchers have noted (Dižo *et al.* 2025), the choice of powering the scooter with an electric motor is more advantageous than with an internal combustion engine. Similar to the design of the scooter presented by Dižo *et al.* (2025), the modernized scooter can be used by people of different ages.

The results regarding ride comfort presented by Cao (2025), show that users prefer to choose e-scooters when their average experience includes smoother road surface, denser street infrastructure, separate bike lanes, fewer pedestrians on the street, average naturalness and land use mix, and riding on secondary and tertiary roads. These aspects also improve the safety of using e-scooters. In turn, expanding dedicated bike lanes, optimizing street design, integrating bike infrastructure into different urban contexts, and providing rest facilities are effective strategies to promote the use of e-scooters in the urban area. To sum up, it can be said that e-scooters are a very good and increasingly popular means of individual transport around the world, and their comfort and travel safety will become an increasingly important element in choosing a given scooter model.

5. Conclusions

Electric scooters are a representative of a modern and environmentally friendly means of transport. Continuous technological innovations related to scooters are the future of urban mobility systems and there is great potential for further development.

The modernization project of the scooter assumed improving its functionality, driving comfort and safety of electric scooters use in urban road traffic. The goal was achieved by introducing a new design of front and rear suspension, that absorbs terrain unevenness more than original. In the proposed construction a suspension system consists of the coaxial shock absorber and spring mounted in structurally modified wishbones was used. Thanks to this, the forces generated between the road surface and scooter wheels and transferred to the transport platform are significantly damped in the new suspension system. Increased 11′′ tube tires reduce the amplitude of vibrations while driving (above 37%), which helps improve travel comfort. Now adjusting the hardness of the both suspension systems is also allowed, which is new functionality for this scooter type, especially in the meaning of the rear wheel. An additional change to the brake system, adding a disc brake on the rear axle affects braking efficiency and driving safety. The new brake shortens the braking reaction time and allows for efficient stopping and shortening the braking distance approximately of about 4 ms, while average braking distance of this type of scooters was earlier near 12 m. After the proposed modifications, at the maximum speed of the scooter, the braking distance is comparable to the braking distance of a cyclist, which confirms the effectiveness of the designed construction. Moreover, it is supposed the changes implemented will have a positive impact on the stability of the driver's posture.

The strength analyses carried out using the FEM show that the scooter's design is able to carry the maximum loads of 120 kg declared by the manufacturer. The newly designed scooter components are within the limits of permissible stresses and acceptable deformations, which confirms that the modernizations did not negatively affect the original design of the scooter.

In the future, the developed design can be optimized in terms of reducing its own weight through research on alternative constructional materials, also in those manufactured using additive technology. Another aspect that can be studied in the future work is survey research on safety and comfort of use after the prototype of the modernized scooter has been made. The typical urban scooter user is environmentally conscious, recognizes the benefits of sustainable transportation, and is open to this type of research, as confirmed by various references, e.g., Virin *et al.* (2025) or Campisi *et al.* (2023).

Author contributions

Jacek Caban and *Aleksander Nieoczym* conceived the study and were responsible for the design and development of the data analysis.

Jacek Caban, *Aleksander Nieoczym* and *Kazimierz Drozd* were responsible for data collection and analysis.

Aleksander Nieoczym, *Kazimierz Drozd* and *Edgar Sokolovskij* were responsible for data interpretation.

Jacek Caban, *Aleksander Nieoczym*, *Edgar Sokolovskij* and *Kazimierz Drozd* wrote the 1st draft of the article.

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