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Improvement of Steerability and Driving Safety of an Electric Three-Wheeled Vehicle by a Design Modification of its Steering Mechanism

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Abstract: Three-wheeled vehicles are transport means which generally combine properties of two-wheeled vehicles (principal motorcycles) and four-wheeled vehicles (standards cars). Three-wheeled vehicles have been designed and manufactured as units which are made up of one front wheel and two rear wheels, powered by an electric drive-train, and referred to in some countries under a non-English term as E-3kolka. These vehicles also comprise a special steering mechanism which improves their overturning stability when driving around curves. However, several tests have revealed certain deficiencies of the steering mechanism, where the main issue included unreliable self-restraining effect of steering wheel straightening after driving around a curve. This may even lead to unacceptable properties of the vehicle. Therefore, the authors of this paper suggest particular technical solutions to eliminate or completely avoid the described negative effects during driving. Proposed designs are mutually compared and a final decision is presented.

Keywords: Three-wheeled vehicle, design, CAD model, stability, safety

1. Introduction

In some regions of the world, three-wheeled vehicles are used for various purposes, such as recreation, transport of goods and persons usually for shorter distances. The very first three-wheeled vehicle was created in 1680 as a medical device. The first car of the Velorex type was also a three-wheeled vehicle and it was originally intended to transport disabled people. Until 1884, over 120 various models of vehicles with three wheels were patented by more than 20 producers.

Three-wheeled vehicles have several advantages, such as a simple steering mechanism, lower production costs, lower maintenance costs, lower operational costs, etc.

In principle, two types of three-wheeled vehicles are recognized, i.e. the first type having two front wheels and one rear wheel (tadpole) and the second type having one front wheel and two rear wheels (delta) [1-4]. It should be noted that the authors are concerned with a three-wheeled vehicle of the delta type.

The designed three-wheeled vehicle is powered by an electric power-train. It is a reasonable choice for the purposes the vehicle has been designed for: transportation in cities over shorter distances with possibilities of charging similarly to common electric vehicles [5-7]. When in operation, an electric power-train achieves zero gas emission, low noise level, high efficiency and low dependence on ambient temperature [8-10].

In contrast with the general advantages mentioned above, the delta type has difficulties when driving around curves, which results in its lower overturning stability in comparison with the tadpole type or with a standard four-wheeled vehicle [11-14]. Therefore, an experimental vehicle of the delta type comprised of an electric drive-train and a special steering mechanism has been designed [15]. It shall be referred to as E-3kolka (Fig. 1).



Fig. 1 E-3kolka – a prototype of an electric three-wheeled vehicle with a special steering mechanism. Source: authors

The main purpose of the special steering system of the E-3kolka is to improve its overturning stability. The system has been designed, simulated in MBS software [16-19] and eventually manufactured and mounted on the E-3kolka. Based on analytical and subsequently more complicated simulation calculations, it was found that the specially designed steering system improves the overturning stability.

However, experimental tests of the E-3kolka performed on a polygon have revealed that the steering system does not work flawlessly. Its deficiency consists in the fact that the required self-restraining effect is not reliable and it is not ensured in all positions of the steering wheel. Therefore, this paper puts forward particular ideas and technical solutions that are focused on how to eliminate or completely avoid the system's described deficiency.

2. Basic Model and Description

The primary model of the discussed vehicle (E-3kolka) has been deigned at the Department of Transport and Handling Machines in Žilina (Slovakia). A three-dimensional model of the E-3kolka created in the Catia software is shown in Fig. 2.

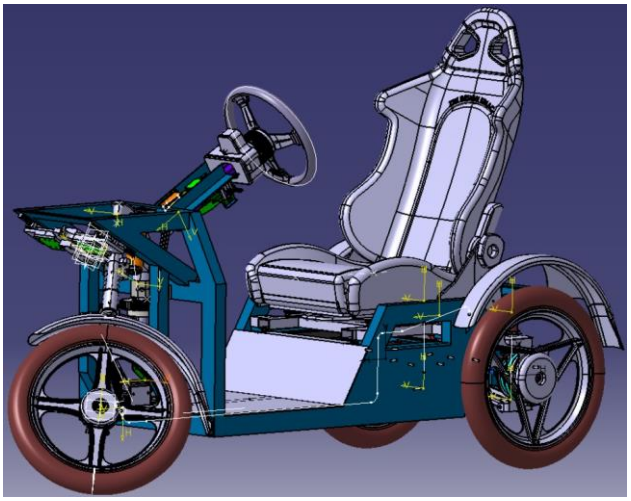


Fig. 2 E-3kolka – a prototype of an electric three-wheeled vehicle with a special steering mechanism. Source: authors

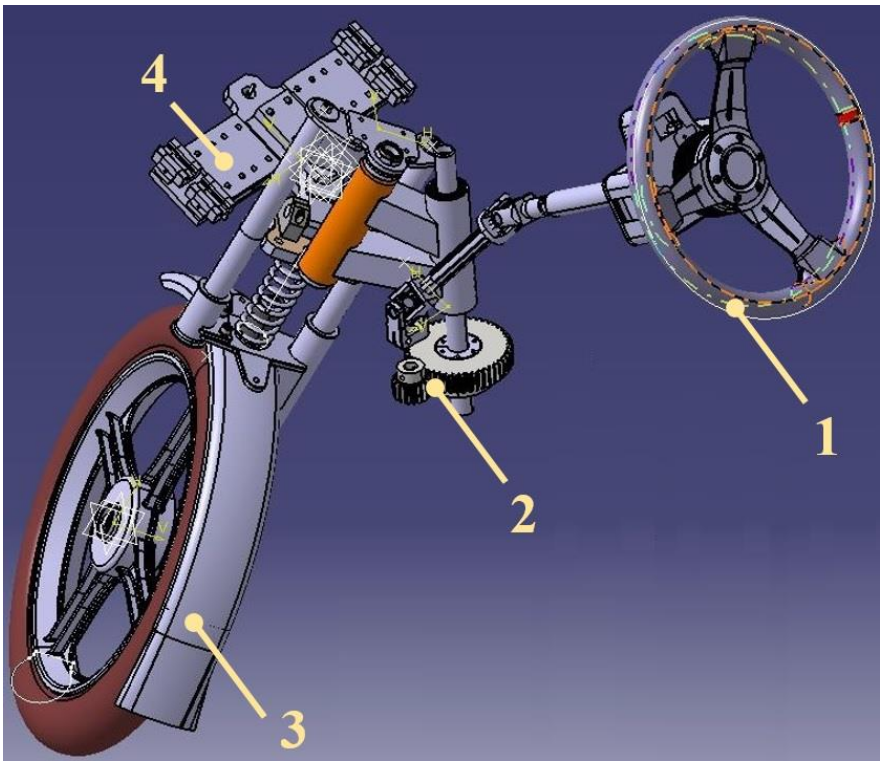


Fig. 3 A detailed view of the original steering mechanism. Source: authors

The existing prototype is composed of:

- a frame,
- a rear axle – independently suspended wheels,
- an electric drive-train – main components include an electric motor, batteries, charging, control devices, a differential, connecting shafts and others [8],

- a special steering mechanism,
- a driver's seat,
- a braking system.

Figure 3 shows a detailed view of the original steering mechanism with a steering wheel (1), a gear mechanism (2), a front wheel (3) and a linear guidance, which allows the side movement of the front wheel.

The frame structure is made of aluminum profiles connected by welded joints [20]. Other components are connected to the functional unit mostly by screw joints.

The steering wheel is connected with the frame by a holder. A connecting rod transmits torque to a pinion, with the torque being further transmitted within the gear mechanism to the front wheel. The entire mechanism is designed in such a manner that the front wheel does not only rotate around a rotation axis, but it also shifts to a side (depending on a left or a right curve). When a driver wants to return the steering wheel back to its original position, it does not work completely automatically (as it is usual with standard cars), but it requires a certain force to be generated by the driver. The reduced stability also appears when driving on road irregularities, which causes excitation of the mechanical system of the E-3kolka [21-24]. This fact reduces driving safety and also results in unexpected behavior of the vehicle along with reduced comfort for passengers [25,26]. This is the main motivation to continue in the E-3kolka research. Performed activities and efforts contributed to three technical solutions being presented and compared in the next section.

3. Description of Designed Modifications

Efforts to develop a practical three-wheeled vehicle with the described special steering mechanism have led to certain ideas of how to modify the steering system with a sufficient stability and in direct driving together with appropriate handling while driving around curves. Three different technical modifications were suggested varying by the number of used additional components, requirements to rebuild the existing vehicle frame as well as keeping the originally desired functionality of the steering mechanism.

3.1 Modification No. 1

The first technical modification, i.e. modification No. 1, combines the original steering system and two telescopic struts. The modification is shown in Fig. 4, whereas its detailed version is depicted in Fig. 5. There are marked telescopic struts (1), a gear mechanism (2), a front wheel (3).

One end of the struts is mounted to the vehicle frame and the other ends are located at the front fork.

The advantage of modification No. 1 is seen in its simplicity, and it does not need essential construction modifications of the original technical solution. Furthermore, it improves the stability when driving straight as well as around curves.

The disadvantage is an additional force which is needed when entering a curve and the necessity of changing the equipment after certain time due to its wear.

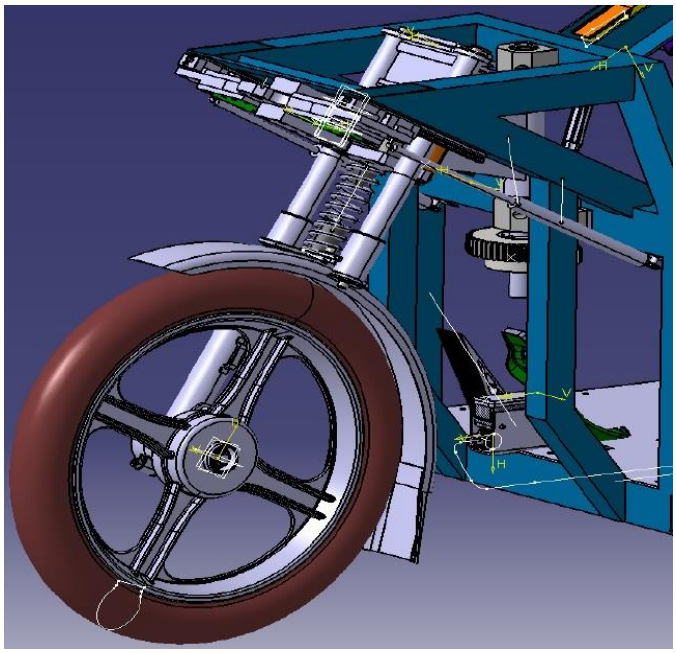


Fig. 4 A graphical view of modification No. 1. Source: authors

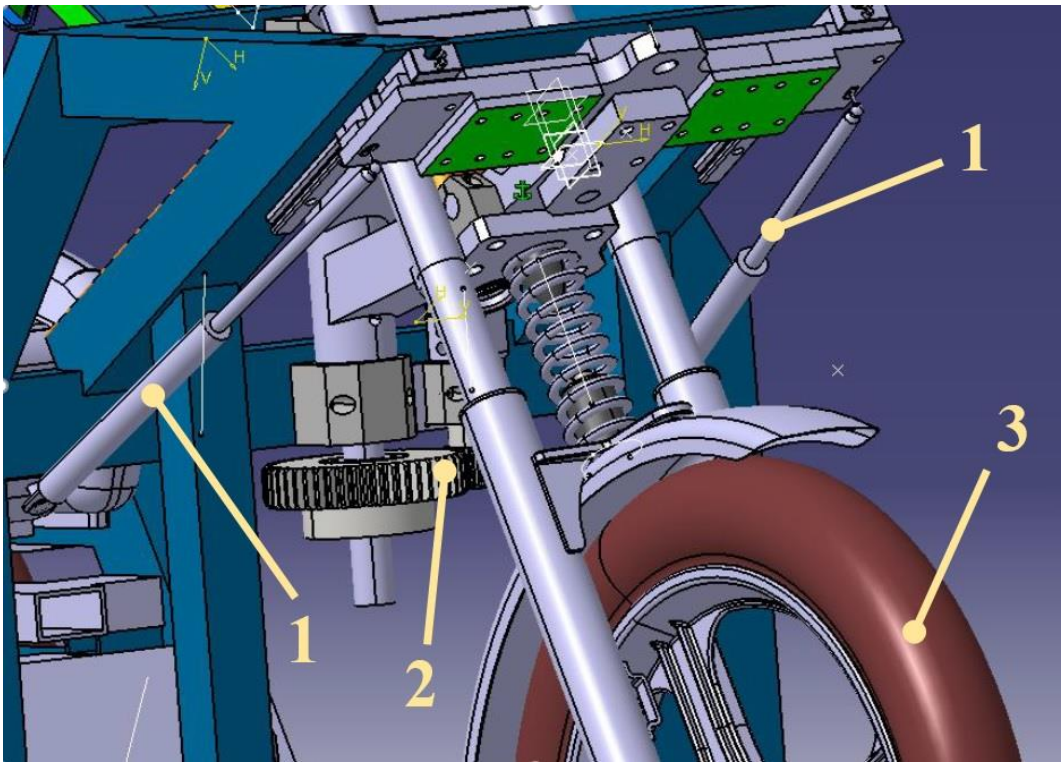


Fig. 5 A detailed view of modification No. 1 of the steering mechanism. Source: authors

A similar steering mechanism for stabilization of front wheels in practice is used on sports motorcycles. Selecting such telescopic struts is limited by a driver's effort or force that must be great enough to ensure backward movement of the front wheel.

3.2 Modification No. 2

The second technical modification, i.e. modification No. 2, requires to develop a specific frame design. The front part of the frame is re-designed as well as its attachment to the frame (Fig. 6).

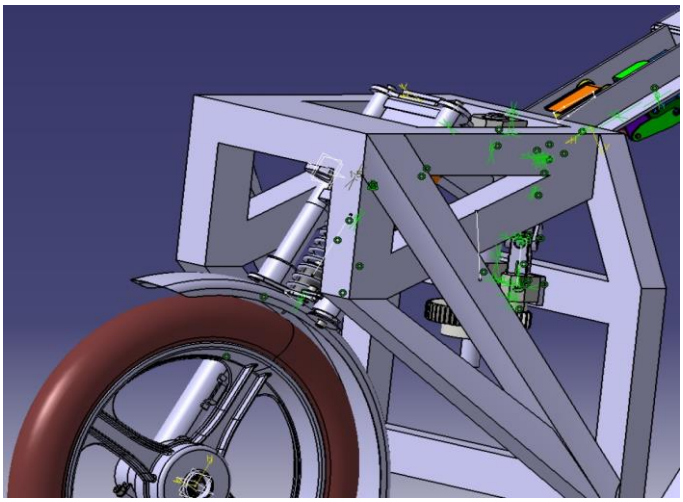


Fig. 6 A graphical view of modification No. 2. Source: authors

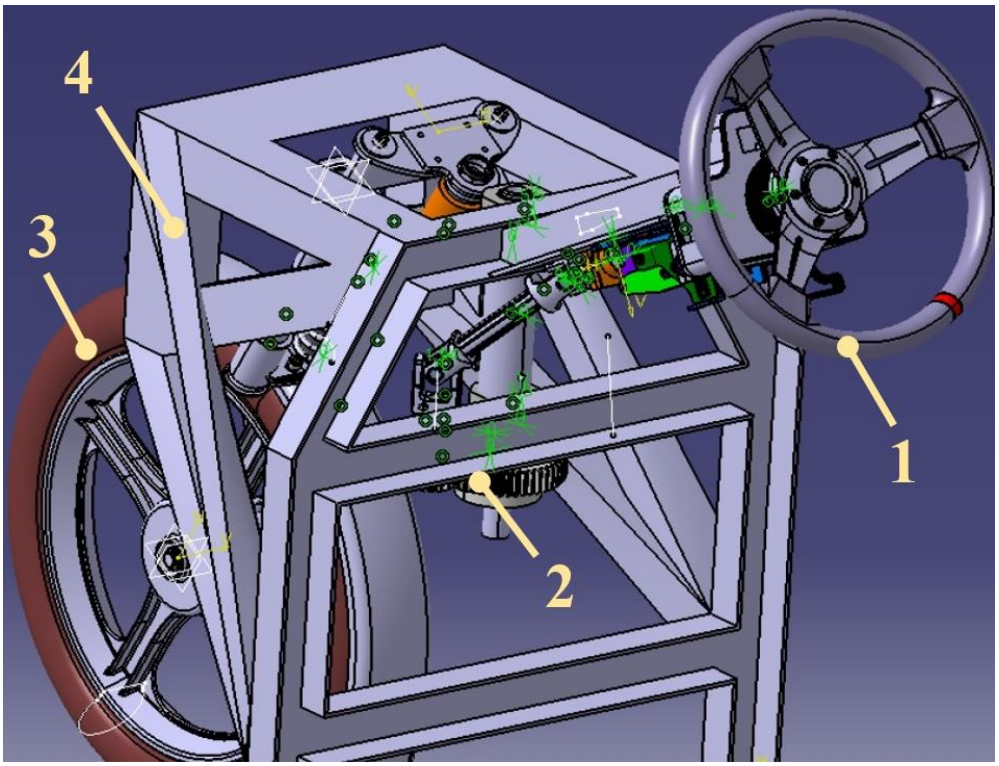


Fig. 7 A detailed view of modification No. 2 with marked main components. Source: authors

Figure 7 illustrates a detailed view of the modified front part of the vehicle frame, where individual numbers indicate a steering wheel (1), a gear mechanism (2), a front wheel (3) and a modified front part of the frame (4).

The aforementioned modification requires welding additional structural components to the frame. These components are proposed as U-profiles with properly aligned end parts for making weld joints.

The main objective of this modification is to ensure a certain change in the steering geometry. The front part of the vehicle would be slightly lifted, which leads to spontaneous backward movement of the front wheel to its straight position.

The advantage of modification No. 2 is seen in its improved stability when driving around curves and the ability for spontaneous backward movement of the steering wheel after its releasing by a driver without additional force.

The relative disadvantage of this modification is the design difficulty and the need to modify the frame itself.

3.3 Modification No. 3

The third technical modification, i.e. modification No. 3, represents the most fundamental design change in comparison with the original technical solution. Some components were removed from the original steering system, such as an arm, a linear guidance and a profile for guiding the linear guidance. A pinion is shifted to the steering rod axis. The great gear wheel was re-designed to a gear semi-wheel. Also, new holders were designed in relation to the pinion attachment and the front wheel shaft (Fig. 8).

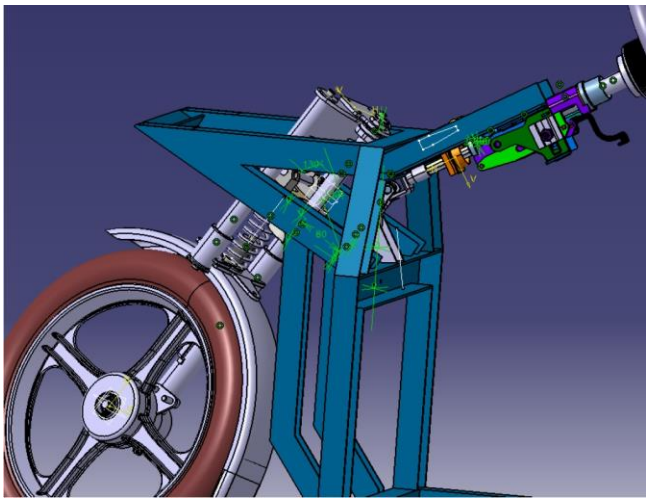


Fig. 8 A graphical view of modification No. 3. Source: authors

When taking a closer look at this modification (Fig. 9), it can be seen that the linear guidance used on the original steering mechanism (Fig. 3) is missing.

The holder is shifted to the symmetry axis, which means in practice the need of only one cross connection. Due to the designed changes, the fork does not perform semi-circular movement and the steering system rotates only around the rotate axis. This will lead to better driving properties and stability when driving straight.

As a result, the contact point of the front wheel with the ground does not move in semi-circular movement. It does not cause declination of the front part of the frame and it improves the directional stability. A negative aspect is the need of new attachment components. This modification is not even cost-effective due to the changes in the steering mechanism design.

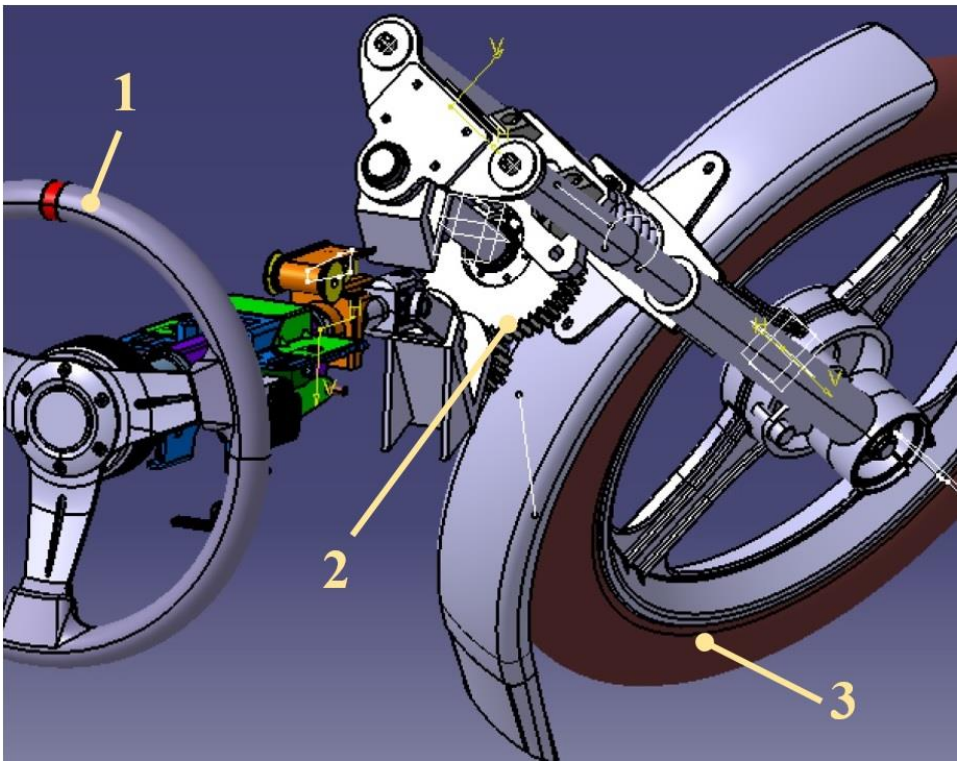


Fig. 9 A detailed view of modification No. 3: a steering wheel (1), a gear mechanism (2), a front wheel (3). Source: authors

4. Discussion

The first presented proposal is fairly simple without many construction changes. It comes from the original design that is complemented by two struts ensuring backward movement of the steering wheel together with the front wheel. It is not assumed that modification No. 1 would be costly regarding the use of two normalized struts. The front wheel still performs combined movement, i.e. rotation around the axis as well as translation side movement. The telescopic struts help to improve the required stability of the three-wheeled vehicle.

The second modification is more complicated for production (or modification of the existing one) regarding the necessary change in the frame's front part design, which would then be more expensive than modification No. 1. However, the main advantage of the second design is reflected in the spontaneous backward movement of the steering wheel together with the front wheel to the straight position due to gravitational effects.

The change in the steering mechanism according to the third design does not require any design modification of the original vehicle frame. The change relates only to the steering mechanism itself.

The modified steering system would be changed so that the axis of rotation is adjusted to the central axis of the vehicle. The modified steering system would no longer allow the wheel's side movement. This modification will ensure better stability of the three-wheeled vehicle when driving straight. However, the disadvantage would be seen in reduced stability of the vehicle when driving around curves, which would then make it similar to other three-wheeled vehicles on the market.

Brief comparison of the above modifications is shown in Table 1 involving three main parameters, i.e. estimated costs, changes in the vehicle's total weight and side movement of the front wheel (as the main factor in terms of safety).

Table 1 Comparison of the main parameters of the proposed modifications of the steering mechanism. Source: authors

Modification	Estimated costs	Changes in the total weight	Side movement of the front wheel
No. 1	€120	↑1.1%	✓
No. 2	€700 to €900	↑12 to 17%	✓
No. 3	€180 to €200	↓0.8%	×

Regarding modification No. 2, telescopic struts and additional parts (e.g. screws, bolt nuts) are required. Depending on the current market prices, the estimated costs amount to approximately €120. The total weight of the vehicle would be increased merely by 1.1%, whilst the side movement of the front wheel is preserved.

In terms of the estimated production costs as well as the changes in the total weight, modification No. 2 is the most expensive option. The vehicle frame is made of a special aluminum alloy that requires a special welding technique. Since production of the original vehicle frame is financially demanding, estimated costs for its modification range from €700 to €900. Moreover, additional material would lead to an increase in the vehicle's total weight, which is not favorable in view of operational and driving characteristics. The advantage is that the front wheel can still move aside (preserving the original steering system functionality).

Considering modification No. 3, it is assumed that the total weight would decrease merely by 0.8%. The main disadvantage is that the front wheel would no longer move aside, which would result in the standard steering system that can be found in other three-wheeled vehicles.

Based on the facts evaluated and described above, modification No. 2 (the second modification) of the E-3kolka is the most suitable design change likely to be used in practice. Despite the costly adjustments in relation to the basic frame, the main advantage of this modification is seen in the standard behavior of the steering mechanism that can be found in other common vehicles. Other components (e.g. the telescopic struts related to modification No. 1) would

not need to be applied and compound movement of the front wheel would be ensured. Therefore, the front wheel would move in the same manner as in the original technical solution [15].

5. Conclusion

The main objective of the presented work was to propose particular technical solutions to improve the driving stability of an electric three-wheeled vehicle referred to as E-3kolka. Three various technical solutions were described. They differ mainly by certain issues regarding the modification of the existing technical solution. The steering mechanism modifications were designed and shown by three-dimensional models created in the CAD software. Based on comparison of the proposed modifications, one of them was chosen as a potential technical solution that will be considered for application to the real prototype. Future research will be focused on implementing of modification No. 2 to the finite element method software in order to analyze the frame in terms of its strength. If the frame meets certain requirements regarding distribution of the stresses, multibody simulations will be performed to verify the correctness of the design in terms of driving stability.

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