Development and optimization of a three-wheeled electric vehicle frame using structural materials

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Abstract. The aim of this paper is to design a new electrical transportation device using structural materials. It concerns with the idea of a new, safe and ecological way of transportation for people in urban areas. The design consists in developing a three-wheeled electric vehicle frame that can carry loads up to 140Kg, is lightweight and easy to store in closed spaces. The design process consists in developing a 3D model, a physical prototype and the optimization of the frame using CAD software with the finite element method.

1. Introduction

The concept of a three-wheeled vehicle was developed, after the 17th century, for people and products transportation. First approaches concerned the position of the motor wheel, models of Delta and Tadpole, and manual or electric engagement systems.

This paper presents an electric Tadpole system.

Thus, the three-wheeled vehicle developed, uses structural materials in order to decrease the costs and to be easier to assemble, using standard technologies.

The structural materials used for testing are steel AISI 1060 and an aluminum alloy in order to reduce the weight of the vehicle.

This system was designed at first for urban areas, were the surfaces are plane, where the typical autonomy of the three-wheeled electric vehicle is enough, but also, the applicability of this vehicle can be extended through a suspension system.

2. Development of the three-wheeled electric vehicle

In order to develop this three-wheeled electric vehicle, the following objectives were established: foldable and easy storage, existence of a compact suspension system, adaptability for different terrain inclinations.

In figure 2, it may be observed the main components of the three-wheeled electric vehicle concept.

![Figure 1](image_url)
1. Handlebar
2. Frame
3. Fork
4. Joint
5. Driven wheel
6. Bridge
7. Motor wheel

![Components of the three-wheeled electric vehicle](image)

**Figure 2.** Components of the three-wheeled electric vehicle

### 2.1. Folding system

The development of the folding system of the three-wheeled electric vehicle takes into consideration two main factors: the vertical position adjustment using a circular profile and the shape of the handle bar, which can be adjusted and set on a vertical axis (position), with an inclination up to $120^\circ$. This position can be secured using a clamping mechanism.

![Folding system based on joints](image)

**Figure 3.** Folding system based on joints

This folding system, based on bridge 4, Figure 2, offers the decrease in height up to 50%, 870mmx750mmx618mm, half of the initial height (1240mm).

### 2.2. Suspension system

The suspension system contains 4 elastomeric elements fixed in a polygonal profile, fixed in another polygonal profile. This type of suspension is used in automotive industry, because of the low weight, in comparison with the classic spring and damper system.
The driven wheels can change position independently, that assures movement on different surfaces, with different inclination for the vehicle.

Figure 4. Suspension system

Figure 5.

3. Frame optimization

The main component of the three-wheeled electric vehicle system is the frame. For the tests it is heavily loaded, to assure the role of folding, suspension and displacement on different surfaces. The frame needs to be light enough to be carried around. The weight target for the frame is under 4Kg.

The structural materials used are aluminum alloy and carbon steel. This type of materials increases the resistance for mechanical solicitation, in time, for constant or variable loads. Also, these materials are offering already well known assembly solutions, which give an advantage, not to loose any material in unsuccessful attempts of assembly.

So, the main advantages in using structural materials, are the “know how” technique of assembly and ecological criteria, using the minimum of resources (common resources) in an innovative and intelligent way. The materials mechanical properties are presented in table 1.

Table 1.

| Material          | Density    | Young's Modulus | Poisson's Ratio | Yield Strength | Ultimate Tensile Strength | Thermal Conductivity | Thermal Expansion Coefficient | Specific Heat |
|-------------------|------------|-----------------|-----------------|----------------|---------------------------|----------------------|-------------------------------|---------------|
| AISI 1061         | 7.85E-06 kg / mm^3 | 204773 MPa      | 0.29            | 372.3 MPa      | 512.3 MPa                  | 0.045 W / (mm°C)     | 1.17E-05 / °C                 | 480.1 / (kg°C) |
| AISiMg            | 2.67E-06 kg / mm^3 | 71000 MPa       | 0.33            | 240 MPa        | 460 MPa                    | 0.165 W / (mm°C)     | 2.1E-05 / °C                  | 880 / (kg°C)  |
In order to optimize the frame, various static stress tests were made in Fusion 360, using the Nastran solver, to check the total weight and that the vehicle will withstand the forces applied when in use. The weight of the frame plays a key role in the final product development. The vehicle needs to be light enough so that it can be lifted and carried in various spaces but also strong enough so it can perform the task in hand.

The first test was made using steel AISI 1061 as a frame material because it is a common structural steel and also cost effective. In order for the static stress test, using the finite element method, to be valid, a convergence analysis was made, shown in figure 6. For this test an adaptive mesh refinement strategy was used.

![Figure 6. Convergence Plot, Static Stress Steel AISI-1061](image)

The conditions applied for the study are presented in figure 7, and to validate the solutions the finite element method was used. The minimum safety factor resulted after the simulation was 7.94 for steel AISI 1061, with a load of 1200N applied on the frame (simulating the maximum load for an average fully equipped adult rider). The maximum deformation on the frame was 0.289mm. This result shows that the frame is overbuilt with a total weight of 10.86Kg. The current weight of the frame states that the vehicle is not user friendly for carrying.

![Figure 7. Study conditions](image)

In order to reduce the weight of the steel frame a topological optimization was approached. The optimization process followed the same steps as the static test with the added optimization criteria, reduced weight and maximize the frame stiffness. The resulted topological optimization is shown in figure 8. The software allowed only for a small weight reduction of the frame from 10.86Kg to 9.95Kg, insufficient for the frame weight target.
In order to achieve the weight target but still maintaining the structural integrity of the frame the AlSiMg alloy was used as a frame material. In order to validate the material choice, an analysis with the finite element method was made. The study process is identical to the one made on the steel frame. The same conditions were applied for constraints and loads. The resulted convergence plot is shown in figure 9.

The results of the test shows that the AlSiMg alloy is strong enough to resist the load of 1200N with a maximum deformation of 0.80mm and a minimum safety factor of 5.78 which is slightly above the minimum safety factor for this type of application, shown in figure 10. The weight of the frame has reduced to 3.69Kg, achieving the weight target.

This result on its own is good enough for the final product target weight but we tried to reduce the frame weight even more, in order to make it more cost efficient and user friendly. In order to make this possible...
another topological optimization was made applying the same rules as for the steel one. The results are shown in figure 11.

![Resulted topology](image1.png) ![Topological optimization validation](image2.png)

**Figure 11.** Topological optimization results for AlSiMg alloy frame

The study shows that the weight can be reduced from 3.69Kg to 3.38Kg and can further be improved through topological optimization.

### 4. Conclusions

In conclusion the frame can be built with standard structural materials commonly available and afterwards they can be improved through additive manufacturing in order to optimize the material usage and the material costs for the frame. Steel structural materials can be used as well for similar products but with higher load carrying capacity with more powerful drivetrains. For the current type of application an AlSiMg alloy needs to be used or similar in order to make the final product easy to carry and manoeuvre and also to be strong enough for the everyday use.

### References

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