
Cargo bikes – sustainable means of transportation

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Nowadays, mobility in cities is undergoing a visible change. Cargo bikes are becoming a key alternative to cars. They are not only flexible and fast but moreover environmentally- and climate-friendly. Young families, craftspeople and delivery services are using cargo bikes and the demand thereof is skyrocketing. This development is particularly favorable, given the climate targets that have been set not only for Germany but worldwide. Therefore, Fraunhofer LBF develops sustainable, comfortable, lightweight solutions for the next generation of cargo bikes. The key aspects of development lie in investigation of a multifunctional frame with integrated sensor and battery systems and mission-depending cargo boxes. As the starting point for these advancements, a commercial cargo bike is used.

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1. Introduction

In 2020 for the first time more than 100.000 cargo bikes were sold in Germany of which 78.000 had electric drive [1]. There are many good reasons to expect a significant global rise in sale for these bikes within the next few years. One important reason is the global climate. The negotiated Paris Agreement of 2015 set the limit of global warming to 2 °C. This necessitates an extreme reduction of the global greenhouse gas emission. Germany has set its goal to reach an emission reduction of 65 % until 2030 in comparison to the emission values of 1990. A shift in the transportation device from car to cargo bike, is hence a good contribution in that direction. Especially for last-mile-logistics cargo bikes are very important [2-4]. Another benefit in using cargo bikes, is that it improves the quality of life. It has positive effects on health, for noise reduction in urban environment, for fast travel beside the road, for prevention of parking problems and it becomes a life-style-piece [5]. Particularly during the corona pandemic, the need for health-protecting transportation-alternative is rising and the cargo bike is one important option. To shift the cargo bike out of its technological niche into a standard means of transportation, especially in Europe, improvements are necessary, i.e. in safety, in comfort, in battery system, in the reduction of weight and in the integration of new features such as sustainable cargo boxes, sensor systems for monitoring the payload and the environment. In other markets, such as India, the requirements can be different with focus on efficient, inexpensive and agile cargo bikes. This paper presents the latest investigations in these research fields of the Fraunhofer LBF.

2. Experimental

2.1 Multifunctional lightweight frame

A commercial tricycle shown in Figure 1 presents the base case for the investigations. The front end of the tricycle was selected to demonstrate the targeted lightweight design. As a basis for this redesign, the initial data for the weight and geometry of all individual components of the front end were recorded. Driving measurements were then carried out. In the next step, the frame was redesigned by creating computer added design (CAD) models and finite elements models (FEM) derived from the initial data. Figure 2 shows a comparison of the old design and the new one in CAD.



Figure 1: Commercial tricycle with checker plate on the left hand side and with a direct view onto the front end frame on the right hand side.

The core of the new design is a tube out of an aluminum alloy (AlMgSi1) with an inner diameter of 70 mm and a thickness of just 5 mm. This tube is not only an element of the frame. It is also the housing of the new tubular designed energy system explained under 2.2. U-shaped profiles are welded to the left- and the right hand side of the tube. Also, in the new construction the checker plate is welded to the frame elements, so it gets a load-bearing function. Four load sensor systems developed for this application are mounted directly onto the checker plate as joining element for the cargo box. They are described further in 2.3 and the cargo box systems in 2.4.

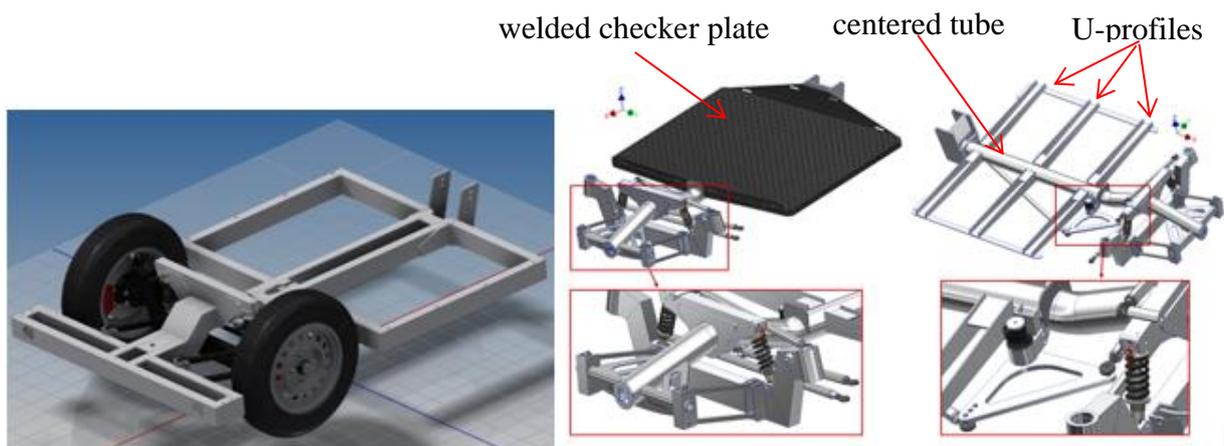


Figure 2: CAD design of the old front end on the left hand side and the new design on the right.

The new frame encloses the design and fabrication of lightweight corrugated rims (wobbly-web wheel rims), also shown in Figure 4 together with the whole modified cargo bike.

2.2 Tubular energy system (TES)

As shown in Figure 1, the commercial tricycle has a battery system mounted outside to the frame. It exists of 40 Li-Ion-cells and has a capacity of 500 Wh. The newly developed tubular energy system TES consists of 10 modules, each with eight Li-Ion cells (18650 round cells) connected by resistance spot welding with power connectors on the top and bottom as shown in Figure 3. These connectors are made of diffusion-annealed steel with a specially-shaped electrolytic nickel coating. On the material side, this ensures low contact resistance and high corrosion protection.

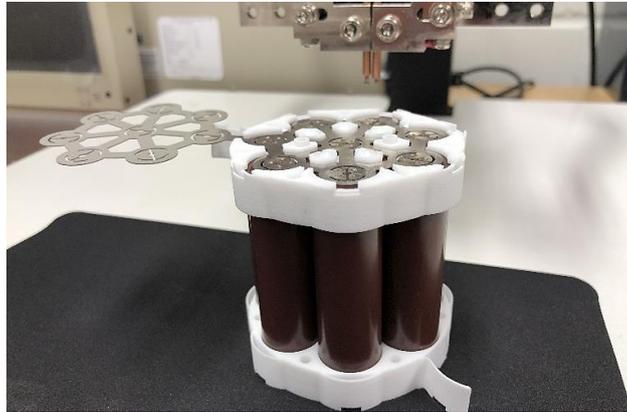


Figure 3: One module of the TES after the resistance spot welding process.

TES provides a capacity of 1.000 Wh. It is designed in a way that it can be easily integrated into the frame tube. The placement of the TES, shown in Figure 4, guarantees a weather-resistant and thief-proof place without the need of an additional case.



Figure 4: The modified cargo bike is shown on top and the TES, integrated in the frame tube under the checker plate, is arranged below.

The TES has its own battery management system and an app developed for the driver. This is very important as depending on the season, cargo bikes are not used for a longer period of time. In order to guarantee the desired reliability of the energy storage, the TES is equipped with an energy efficient storage monitoring system that continuously detects the charge and aging status of the modules and, if necessary, sends a request directly to the drivers smartphone to recharge the battery.

2.3 Load sensor system as joining element

The load sensor system is based on a capacitive measuring principle [6]. The schematic set-up and the real one are shown in Figure 5. An arrangement of thin elastomer foils in combination with micro-patterned metal electrodes is housed in an aluminum case with threaded connection. The whole system has a height of just 8 mm and is placed inbetween the cargo bike frame and the transport box floor. With four of these sensor systems in each corner, the box is joint with the frame very stably. These sensor systems measure the distribution and the mass of the payload in the box during the ride.

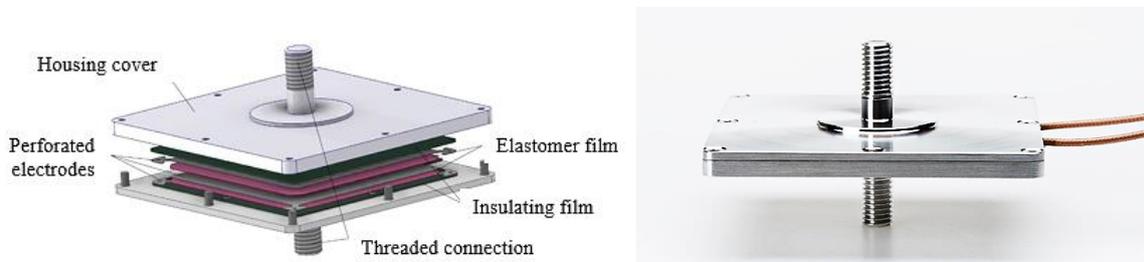


Figure 5: Schematic set-up of the sensor system on the left hand side and the ready-for-use sensor on the right hand side.

2.4 Mission depending cargo box development

Commercial cargo boxes are fabricated mainly out of aluminum, wood or plastic. According to customers needs, three different cargo box systems were designed with regard to sustainability and ultralightweight in combination with safety and bio-compatibility. Therefore a frame construction out of aluminum alloy was designed for different inlets to easily be integrated into this frame.

The inlets for the ultralightweight box are fabricated by additive manufacturing made of polyamide (PA6) and have different lightweight designs, like a honeycomb structure. For safety, box crash protecting structures were embedded (Figure 6 left). They absorb the impact energy and convert it into deformation energy, as demonstrated in the center of Figure 6. Also carbon fiber reinforced plastic is used for the inlets.

One hundred percent biological box inlets were fabricated out of cork granules, meadow grass, flax fiber, bark mulch in different combinations as shown in Figure 6 (to the right). Each natural inlet was bound with the biopolymer polylactide (PLA).

One hundred percent sustainable boxes with inlets out of recycling materials were fabricated as sandwich systems consisting of top layers (organic sheet made out of flax fiber reinforced recycled polypropylene (PP)) and cores (cork grist, polyurethane (PU) out of old mattresses or tearing fiber fleeces out of old textiles).

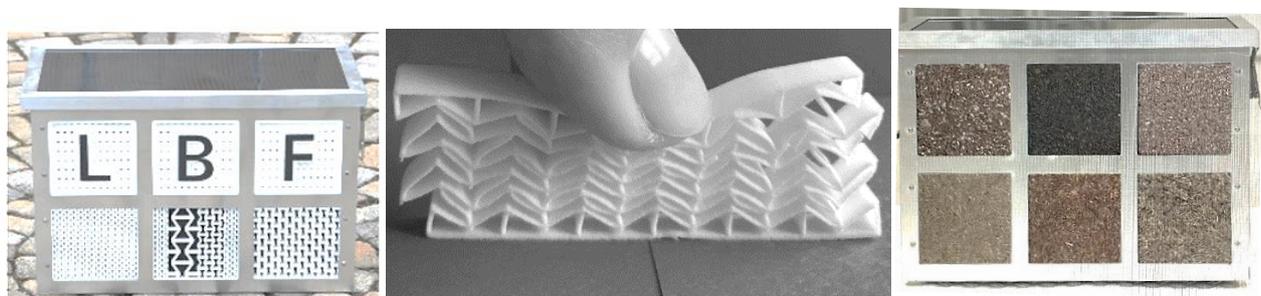


Figure 6: Transport box with ultralightweight inlets out of PA6 in different crash designs and the demonstration of the possible deformation of these structures in the center. On the right-hand side the box with 100 % natural inlets is shown.

3. Results and Discussion

A weight comparison of all changed parts of the front end is summarized in Table 1. It was possible to manufacture a frame that is 39 percent lighter than the commercial front end, while still having the capacity to carry the same loads of about 200 kg.

Table 1: Weight comparison between the original parts of the front end and the new ones.

Destination		Weight	Savings
Tricycle front part		105,9 kg	-39 %
Lightweight front part		64,7 kg	
Destination	Material	Weight	Savings
Original frame	Al	47,8 kg	-48 %
Lightweight frame	Al	24,7 kg	
Original axis	Steel	8,4 kg	-58 %
Lightweight axis	Al	3,5 kg	
Coupling elements	Steel	9,7 kg	-73 %
Lightweight coupling elements	Al	2,6 kg	
Original wheel rim	Steel	5,92 kg	-61 %
Corrugated rim	Al	2,3 kg	

With the new TES, it is possible to integrate the battery safely into the frame structure. This offers the advantages to increase the capacity up to 1.000 Wh, to extend the time of bicycling and to reduce the weight, as in this method of battery integration there is no need of a normal housing.

The joining elements with integrated sensor layer system show a linear capacitance dependency on the applied load (Figure 7 left). In this application, they not only measure the mass distribution in the box but also give the driver a monitoring system during the tour on the stability of the payload. The values are shown directly on a display mounted in front of the driver (Figure 7 right).

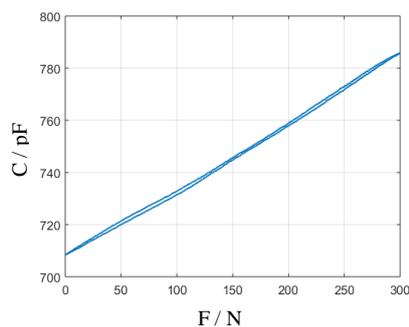


Figure 7: The characteristic linear dependency of the sensor capacitance on the load for two load-unload cycles on the left hand side and the display arrangement for the monitoring of the sensor signals on the right.

In view of a sustainable life, alternative cargo box systems will be in fashion. They ensure an effective means of transportation, due to the fact that box systems, fabricated out of natural and recycled materials show a very good thermal isolation so they enable the driver the transportation of cooked or cool food. Special lightweight crash structures offer the transportation of fragile goods.

4. Summary and Outlook

A change in mobility is taking place. Even for last-mile-transportation cargo bikes are playing an increasing, important role. Therefore it is important to introduce new investigations into this technology to improve the safety, the comfort, the quality and the sustainability of these vehicles. This paper shows some effective changes with regard to the battery system, the cargo box and the multifunctional lightweight frame. In the future, an active stabilization system for long john bikes, rain protecting systems for display and driver with special bio-based coatings and different sensor systems based on dielectric elastomers will be presented.

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