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DEVELOPMENT OF SIMPLE HYBRID DRIVEN VEHICLE AND USE OF LAYERED TECHNOLOGIES IN PROTOTYPE PRODUCTION

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Abstract:
Purpose of this paper is to present simple hybrid driven vehicle. Desire for a new kind of hybrid driven and ecologically acceptable vehicles led to the development of a new contemporary vehicle. Vehicle, capable of transporting two persons, is mainly driven by a human power and backed-up by an electro-motor. Suitably regulated, such a concept may bring a revolution in the city and suburbs transportation. Methodology used for vehicle design and production is based on modern CAD/CAM based with use of layered and rapid manufacturing technologies. For steering mechanism, an analytical mathematical background was used so that mathematically correct wheel path was achieved. In the course of the work, mathematically correct equation for steering mechanism was derived and later used for development of steering mechanism. Flexible torque regulation of the back-up electro-motor that enables us constant load regardless of terrain is also presented. With the project of hybrid drive vehicle, a concept of vehicle that can be ideal for city and sub city transport is presented. With flexible torque regulation, an adaptive exercise machine that can be used to exercise with desired load at any time during transportation is implemented.

The whole vehicle presents a modern and ecologically acceptable transport solution, at the same time this is an instrument of simultaneous recreation as well as a mean of physical condition improvement. Paper presents development of cost efficient vehicle with some unique solutions, like Bowden cable steering mechanism and flexible torque regulation, and production with help of modern layered & rapid manufacturing technologies.

Key Words: Hybrid Drive, Layered Technologies, Alternative Vehicles, Ecologically Transportation, Bowden Steering

1. INTRODUCTION

There are only a few commercially available hybrid drive vehicles and car is still a dominating transport mean in human transport on short and middle distances. Social and economical dependence cannot be changed overnight, but high fuel prices, nature pollution and growth of illnesses caused by lack of exercise are alerting signs to get motivation for developing hybrid driven vehicles.

We tried to combine all bike qualities with some modern techniques and simple, but efficient bad weather protection. Combining modern techniques like CAD, CAM, rapid prototyping, rapid tooling, rapid manufacturing, there is a way to made some functional prototypes in a couple of days. We used all on a Faculty of Mechanical Engineering in Maribor available resources and project work [1].

2. CONCEPT

There are basic attributes to build user and environment friendly vehicle. Presented concept is simple and should combine advantages of bicycle like small weight, human drive, small dimensions and some advantages of other transports, like all weather protection, assistant drive and safety means [2]. Three wheels are sufficiently stable and cheaper as four, also we can apply drive much simple and with less costs. Vehicle has assisted drive in a form of electrical motor with flexible regulation of torque, which is meant only to be used on a steep slope and can also fill up accumulators on a down-hill (4 Q operation modes).

During the development process the following conditions were tried to be fulfilled:
- primary drive by human power,
- secondary electrical drive,
- aero dynamical weather protection,
- possibility of simple modular upgrades,
- use of cost efficient materials and process,
- use of serial components, wherever possible,
- innovative solution of some primary problems (steering, suspension,…),
- recuperation while breaking and downhill driving.

3. PLANNING

For planning in a time of CAD programs there is a logical decision for one of them. We used CAD program from automotive industry - CATIA. CATIA (Figure 1) enables good human interface integration in vehicle with build in sub programs. The first fittings of all components took place in a “virtual” environment of a CAD package where size and collision check gave some promising results. Good CAD packages nowadays enable quite adequate shape, size, position and collision checking. In this way optimal placement and dimensioning of all mechanical components were performed in a pre-prototype phase (Figure 2).

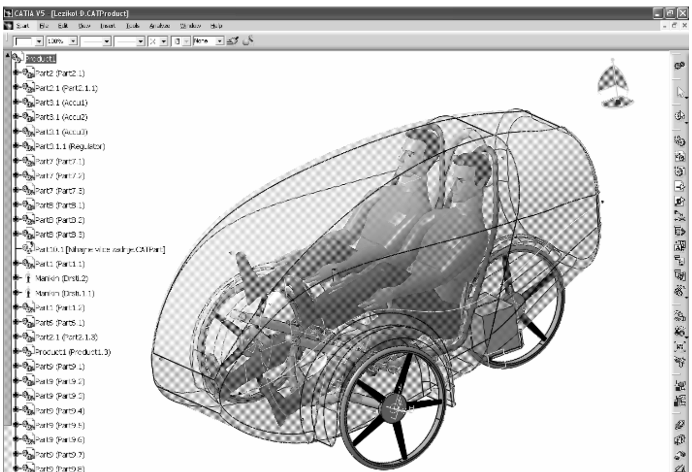

Figure 1: Planning with CATIA CAD program.

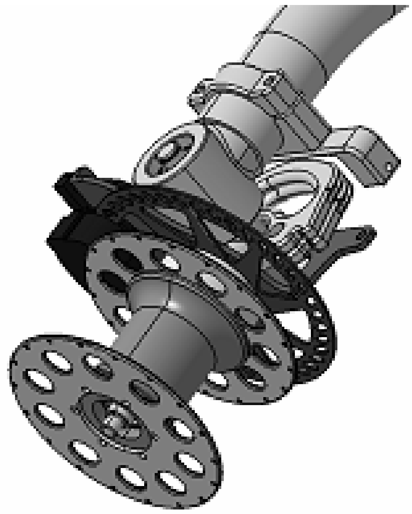

Figure 2: Placement of the steering rope - wheel in CATIA.

4. HYBRID DRIVE

Double or hybrid drive (Figure 3) is crucial for more comfortable and less straining way of transport. Primary drive was realised with classic chain drive solution, with possibility of double drive with two people on board. Produced torque is combined on front shaft. The rear wheel is driven across the classical and affordable “mountain-bike” transmission with 24 gears (3 front chain wheels x 8 rear chain wheels) and the rear shaft, on which the secondary electrical drive is connected.

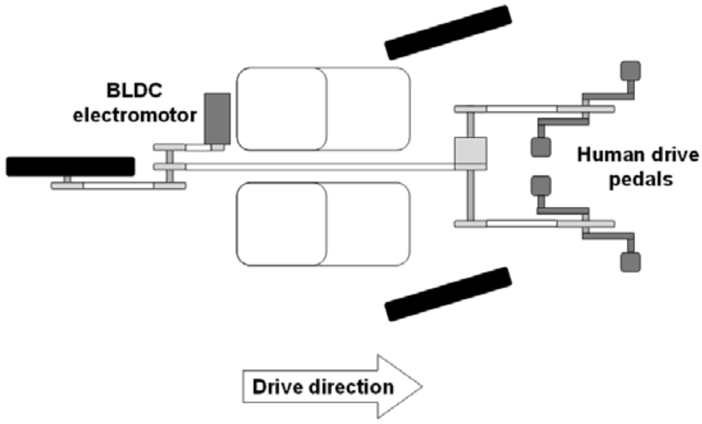

Figure 3: Drive concept.

5. FLEXIBLE REGULATION OF TORQUE OF ASSISTANT DRIVE

Regulation of secondary drive is realized with measurement of produced torque on pedals. Bending of the beam that supports the pedal shaft is measured with strain gauges. The strain is converted into the value of produced torque. Appropriate strain gauge placing point was chosen with CATIA-s Generative Structural Analysis (Figure 4) module. Driver chooses desired torque (own contribution of torque) on regulator, which represents the peak load threshold. Whenever the threshold is exceeded the secondary motor produces torque difference. This means, that if our secondary drive has enough power or we are driving on a roads with sheer slope our contribution of torque can be constant. When our body is producing constant torque we can easily get load that is most suitable to our body (in a case of series exercising we are talking about fat burning zone and aerobic zone). Firstly this means that with flexible regulation of torque we are getting serious aerobic tool that can be used as an exercise tool on our way to work and secondly this is a tool that can help us, to get our ride free of sweat and still do something for environment. For future development some modern adaptive regulation methods [3] are taking into consideration.

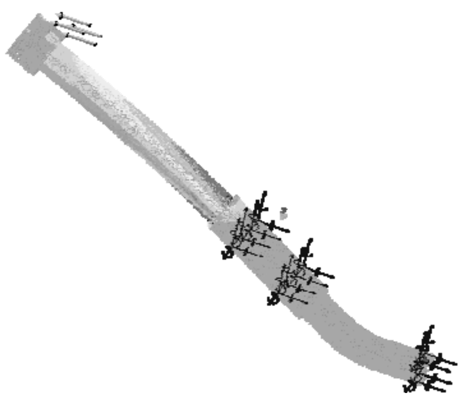

Figure 4: Generative Structural Analysis for the best placing point of strain gauges.

For testing and simulations the vehicle model was made in Matlab/SIMULINK (Figure 5). The model captures all parameters of the vehicle (weight, aerodynamics, friction,…), providing a possibility of virtual testing of different road configurations (so the proper choice of secondary drive can be made). Test results were used to choose optimal pneumatic tyres, regulator parameters and transmission rate.

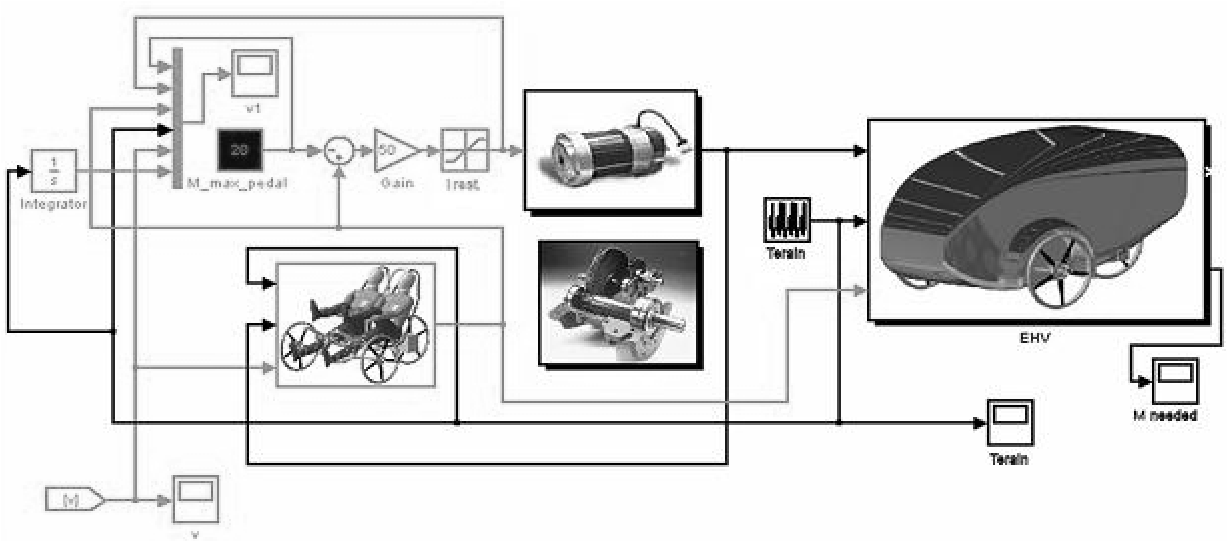

Figure 5: Vehicle model with transmission in Matlab/SIMULINK.

4Q Drive Controller used on the prototype was developed by students on Faculty of Electrical Engineering and Computer Science in Maribor [4-6].

6. STEERING GEOMETRY

While driving through a bend the inner wheel drives along a curve with smaller radius as the outer wheel. It also passes a shorter distance than the outer wheel. In order to ensure a stability of the ride along a bend and to minimize the tire wear (and friction losses) the steering angle of inner wheel has to be bigger than the steering angle of outer wheel (Figure 6).

To understand the steering principle the 'drive-through a curve' conditions were analytically described by the function of the wheel turn depending on a radius of a curve [7].

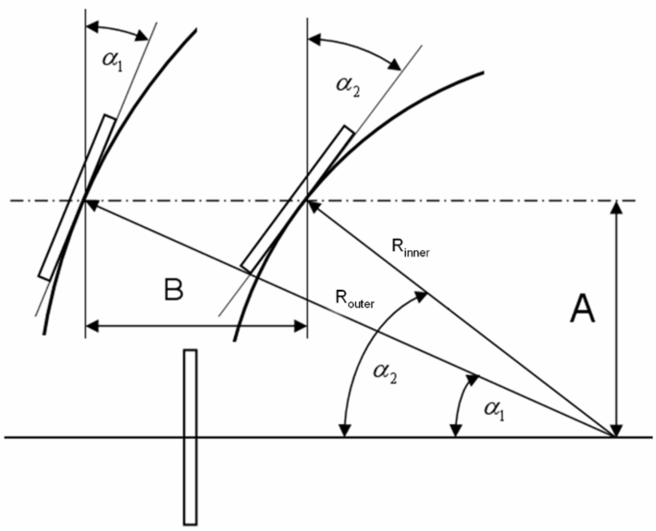

Figure 6: 'Drive through a curve' conditions.

Analytical description is based upon the geometrical situation shown in Figure 7.

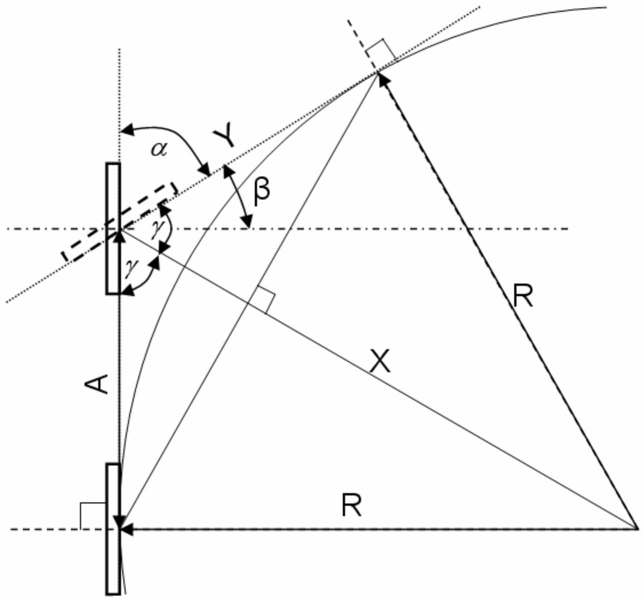

Figure 7: Geometry of turning.

Figure 7 shows the situation of a vehicle with two wheels driving through a bend. R stands for a radius of the bend, A is the inter-axis distance, and α is a steering angle. Using some trigonometry [7], we can see that α and R is related:

$$\alpha = \pi - 2\gamma = \pi - 2arctg\frac{R}{A} \tag{1}$$

Further on a quadratic equation is gained showing the connection among steering angle α bend's radius R and the inter-axis distance A

$$2RA = \sin\alpha(R^2 + A^2) \tag{2}$$

Solving the equation (1) a valid solution is gained for α in interval between 0° to 90°:

$$R = \frac{A}{\sin\alpha}(1 + \cos\alpha) \tag{3}$$

Equation 3 shows the dependence of the steering angle α from the radius of a road's bend R, which is essential for further development of the steering mechanism. It is true for the single-track vehicles. To broaden its validity to dual-track vehicles the inter-track distance B (Figure 6) has to be considered. To take the inter-track distance into consideration Equation 1 was modified for outer wheel:

$$\sin\alpha_1 = \frac{2(R + \frac{B}{2})A}{(R + \frac{B}{2})^2 + A^2} \tag{4}$$

And situation for inner wheel is of course analogue:

$$\sin\alpha_1 = \frac{2(R - \frac{B}{2})A}{(R - \frac{B}{2})^2 + A^2} \tag{5}$$

6.1 The steering mechanism

Researches and experiments showed that an optimal solution of the steering mechanism could be constructed using Bowden cables and rope wheels with variable diameter. The idea was to use one steering rope-wheel with constant diameter, and two adjusting rope-wheels with variable diameters (Figure 8). The steering rope-wheel will be connected to the adjusting rope-wheels by Bowden cables. Since the cables can be considered rigid the travel of the cable along the steering rope-wheel's circumference would cause the same travel on the adjusting rope-wheels. But because of the variable diameter of the adjusting rope wheels the steering angle of the adjusting rope-wheel would differ from the steering angle of the steering wheel. The question was what is the relation between the adjusting wheel's diameter and the radius of the road's bend that the vehicle has been driving through?

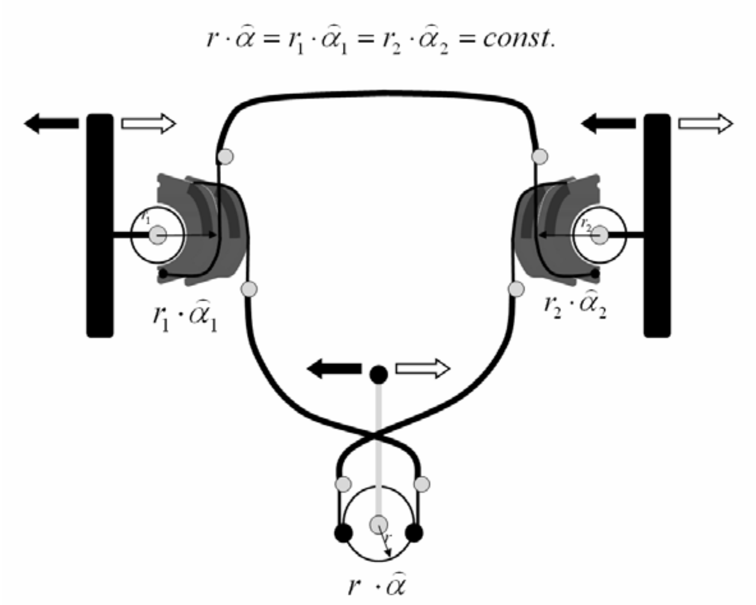

Figure 8: Steering by Bowden cables.

Using algebra again and considering the assumption that turn of the steering rope-wheel for angle α induces the rope's move for the length of the arc l that is

$$l = r \cdot \hat{\alpha}\ , \tag{6}$$

This simultaneously causes a turn of the adjusting rope-wheel for angle α_1:

$$\alpha_1 = \frac{l}{r_1}\ , \tag{7}$$

Where r_1 is a variable. It follows that

$$r \cdot \hat{\alpha} = r_1 \cdot \hat{\alpha}_1 = r_2 \cdot \hat{\alpha}_2 \tag{8}$$

Where r_1 and r_2 are variables. Concerning the Equation 1 and the inter-track distance B, turn of the outer adjusting rope-wheel α_1 can be described as:

$$\alpha_1 = \pi - 2arctg\frac{R + \frac{B}{2}}{A} \tag{9}$$

Therefore, driving through the right bend can be analytically described:

$$r_1 = \frac{r \cdot \alpha}{\alpha_1} = r\left(\frac{\pi - 2 \cdot arctg\frac{R}{A}}{\pi - 2 \cdot arctg\frac{R + \frac{B}{2}}{A}}\right) \tag{10}$$

Conditions by driving through the left bend are mirrored image of the Equation 10 and therefore analogue.

7. CONSTRUCTION OF THE STEERING MECHANISM

To construct the adjusting rope-wheel a dependence of adjusting rope-wheel's radius change from the wheel's turn angle has to be analytically described. The description is calculated by combining the equations 1 and 10:

$$r_{1,2} = r\left(\frac{\pi - 2 \cdot arctg\frac{\frac{A}{\sin\alpha}\cdot(1+\cos\alpha)}{A}}{\pi - 2 \cdot arctg\frac{\frac{A}{\sin\alpha}\cdot(1+\cos\alpha) \pm \frac{B}{2}}{A}}\right) \tag{11}$$

Radius of the steering rope-wheel was set to 60mm. The turn angle of front - steering - wheels was limited to the interval between 0 and 26 deg. According to Equation 3 minimal turn curvature R is therefore 5,025m assuming the inter-axis distance A = 1,16m and inter-track distance B = 1,26m. To calculate the variable curvature of the adjusting rope-wheel the equation 11 was used to calculate a graphical function for the angle interval between 0 and 26 degrees. The resulted curve is shown in Figure 9.

The next step was design of the adjusting rope-wheel. The whole platform of the vehicle was already designed using the package as well as the previous models of the steering mechanism that were unsuccessful. To design a new steering mechanism the curve from Figure 4 was used as a construction path for making a lead groove of the new rope-wheel.

The cross-section of the groove was circular with a radius corresponding to a steel-rope diameter. Around the groove a support structure has had to be made that would satisfy several demands:

- technological – simple production of the final part
- aesthetical – user should not discern the rope-wheel,
- mechanical – it should withstand the forces applied by turning and
- safety – overloading should be considered.

The first design attempts were simple replacement of those unsuccessful solutions. Several different prototypes made by a PolyJet [8] process were tested "on-site" before the optimal one was found (Figure 10).

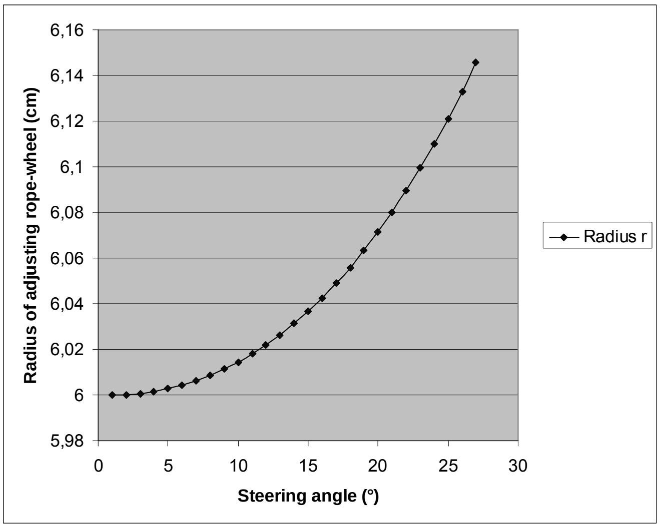

Figure 9: Radius change as a function of steering angle.

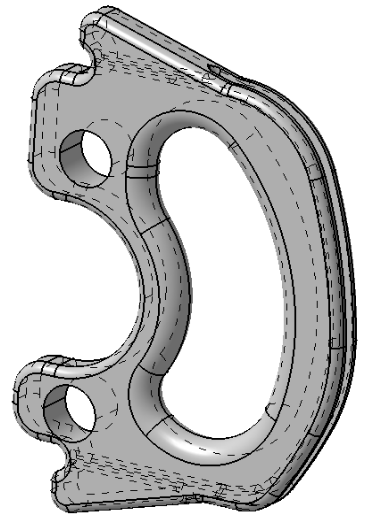

Figure 10: The adjusting rope wheel.

8. PRODUCTION

For production all available modern production technologies from rapid prototyping and manufacturing field [7, 9, 10] were used, so some problems [11] were eliminated at the beginning.

For first shape testing purposes and for adjusting rope-wheel a prototype made by PolyJet™ process on EDEN 330 machine by Objet was used (Figure 11). Model was build for basic tests like shape ''feeling'' and aero dynamical tests in wind tunnel.

The prototype of adjusting rope-wheel enabled functional testing and measuring of steering angles of an unloaded prototype but steering of a loaded vehicle caused stresses that exceeded the tensile strength of the FullCure® material as described by Objet Geometries [12]. Therefore a silicon rubber tool [13] was made using the PolyJet™ prototype as a pattern. The idea was to cast polyurethane parts with a tensile strength of 70 MPa to obtain a part with sufficient mechanical properties and low weight. As an alternative if the polyurethane parts would show a wear resistance too low for regular use the same silicone rubber tool was used to make wax patterns for investment casting [13] of aluminium rope-wheels (Figure 12).

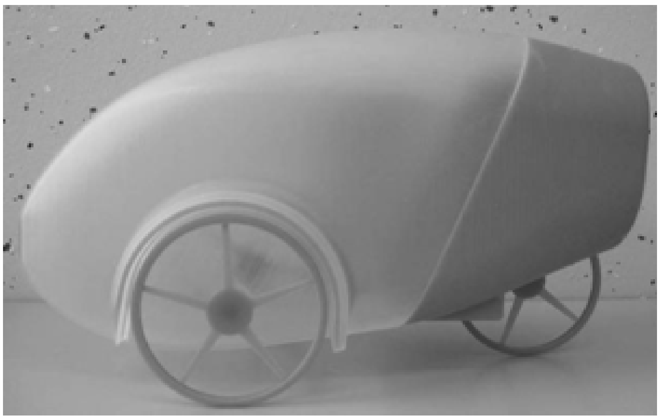

Figure 11: Shape testing prototype made by a PolyJet process on EDEN 330 by Objet.

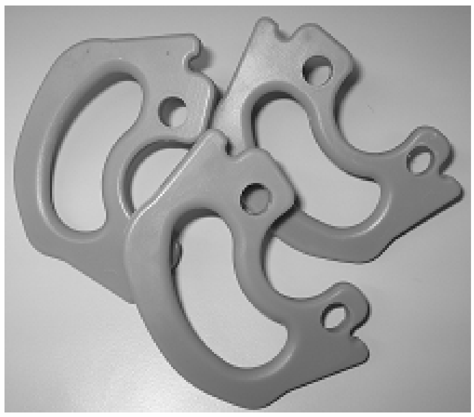

Figure 12: Wax parts made from silicone rubber mould for investment casting.

The process from the conception of the idea, through prototype testing and redesigning to final function parts took extremely short time. For example to complete 4 polyethylenes adjusting rope-wheels and 4 aluminium rope-wheels took only 8 working days. The final parts were used for functional tests with the fully loaded vehicle. The tests showed the correctness of analytical calculations, assumptions used for analytical description and the usefulness of the mechanical solution. For testing purposes the framework was build from CroMo steel for fast and simple correction, all calculations were made also for aluminium frame. For production and final weather protection fitting glass fibre reinforced materials with supported manufacturing procedures [14] were applied.

Figure 13: First test with prototype while assembling.

9. CONCLUSION

Lack of user friendly ecologically expectable vehicles was our motive in hybrid vehicle project. Goal was to present a vehicle that could be home (garage) build, but has some innovative solutions like Bowden rope steering and flexible torque regulation. With the project of hybrid drive vehicle we want to present a concept of vehicle that can be ideal for city and sub city transport. With flexible torque regulation we get an adaptive exercise machine that can help us to exercise with desired load at any time during transportation. So a lack of movement that is strongly present in developed countries and presents a large health problem is solved.

For prototype production some parts were manufactured with use of additive technologies and then used as final production parts or as a tool for production of finished parts. Use of additive technologies has considerably shortened production time of those components. Those techniques are nowadays accessible to practically everyone, since there are a lot of companies providing service to customers, so modern production processes are finding its place even in ‘’garage’’ production.

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