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DEVELOPMENT AND PRODUCTION OF STEERING MECHANISM FOR THREE WHEEL VEHICLES

Spela Drstvensek
Primary School Tone Cufar Maribor
Zrkovska cesta 67, Maribor
Slovenia

Bogdan Valentan
University of Maribor, Faculty of Mechanical Engineering
Smetanova ulica 17, Maribor
Slovenia

Tomaz Brajlih
University of Maribor, Faculty of Mechanical Engineering
Smetanova ulica 17, Maribor
Slovenia

Igor Drstvensek
University of Maribor, Faculty of Mechanical Engineering
Smetanova ulica 17, Maribor
Slovenia

ABSTRACT
Development of a steering mechanism in a human powered vehicle (HPV – Fig. 1.) [1, 2] with two steering wheels tackles two major issues: the lack of space to accommodate steering rods between front wheels, and conditions that occur while the vehicle is driving along a curve. The second are analytically described by the function of the wheel turn depending on an optional radius of the curve. The constructional solution [3] is based upon two rope-wheels with variable radii and Bowden cables. Unlike the Ackerman's mechanism, presented solution enables the optimal travel of both wheels through a curve. To prove the practical aspects of the mechanism several working prototypes were produced using various rapid prototyping and tooling techniques from three-dimensional printing to investment casting of aluminum working parts.
Keywords: Steering, Mathematical modeling, Bowden, Human Powered Vehicle, Rapid Tooling.

1. INTRODUCTION
Thanks to rising prices of oil nowadays society is slowly but steadily starting to realize the importance of environmentally friendly behavior. Unfortunately the technical development is heavily influenced by oil companies and therefore tends to consume more energy to increase their profits. To overcome the Catch 22 situation a pilot project of hybrid human powered vehicle development was started at the Faculty of Mechanical Engineering. The main goal of the project was a development of a light-weight, low-cost, vehicle with additional electric engine – hybrid drive (Fig. 1). The vehicle can hold two persons in a recumbent position that enables better power distribution and lower profile of the vehicle's body thus causing a lower draw force [1, 2]. Unfortunately a very low sitting position rendered the use of well known steering solutions nearly impossible. Ackerman's pole that is usual solution in cars would interfere with legs and make the driving impossible [3]. Besides it's also very heavy and therefore unsuitable for such a vehicle. Presented paper focuses on the development of an alternative steering mechanism and its production in a prototyping phase.

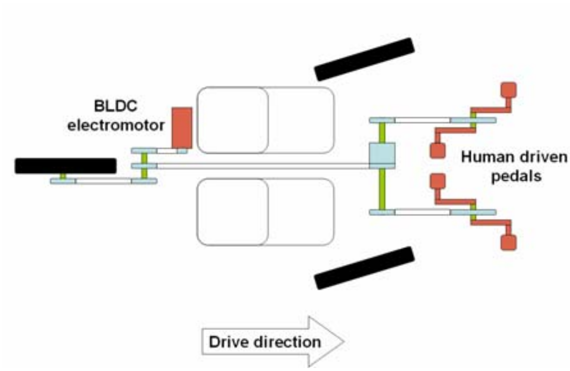
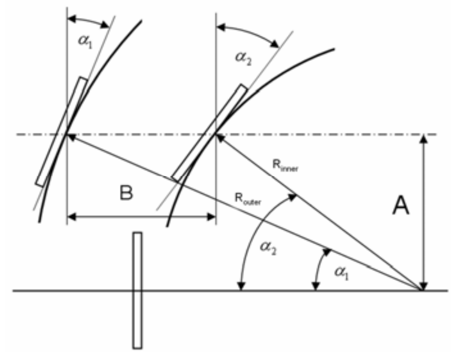


Figure 1. Principal construction of the HPV

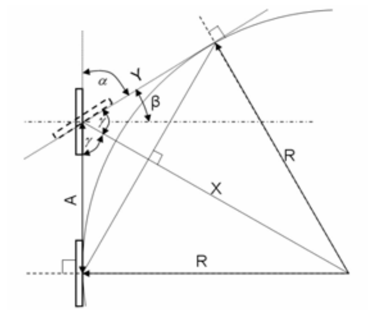
2. STEERING

2.1. 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 (Fig. 2a).



a)



b)

Figure 2. a) - 'Drive through a curve' conditions. b) - Geometry of turning.

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. Analytical description is based upon the geometrical situation shown in Fig. 2b.

Fig. 2b shows the situation of a vehicle with two wheels (bicycle) driving through a bend. R stands for a radius of the bend, A is the interaxis distance, and α is a steering angle. Consequentially, angle γ is: $tg\gamma = R/A$. According the Pythagoras' theorem we can write:

$$X^2 = A^2 + R^2 \qquad \ldots(1)$$

It follows from the similar triangles that: $Y^2 = A^2 + R^2 - R^2$, and so: $Y = A$. In Fig. 2b is

$$\alpha = \pi - 2\gamma = \pi - 2arctg\frac{R}{A} \qquad \ldots(2)$$

Considering adding theorem and eq. 1 it follows, $\sin\gamma = R/X$, $\cos\gamma = A/X$. The angle α is:

$$\sin\alpha = 2\sin\gamma\cos\gamma = \frac{2RA}{X^2} = \frac{2RA}{R^2 + A^2} \qquad \ldots(3)$$

If the eq. 3 is solved for R the quadratic equation is gained with the solution:

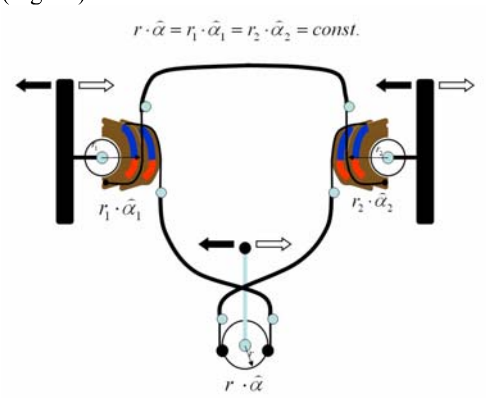
$$R_{1,2} = \frac{2A \pm 2A\cos\alpha}{2\sin\alpha} = \frac{A(1 \pm \cos\alpha)}{\sin\alpha} \qquad \ldots(4)$$

Eq. 4 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 (Fig. 2), has to be considered. To take the inter-track distance into consideration eq. 3 was modified for outer and inner wheel:

$$\sin\alpha_1 = \frac{2(R+\frac{B}{2})A}{(R+\frac{B}{2})^2 + A^2} = O \Rightarrow \alpha_1 = \arcsin O \quad \sin\alpha_2 = \frac{2(R-\frac{B}{2})A}{(R-\frac{B}{2})^2 + A^2} = I \Rightarrow \alpha_2 = \arcsin I \qquad \ldots(5)$$

2.2. 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 (Fig. 3a).



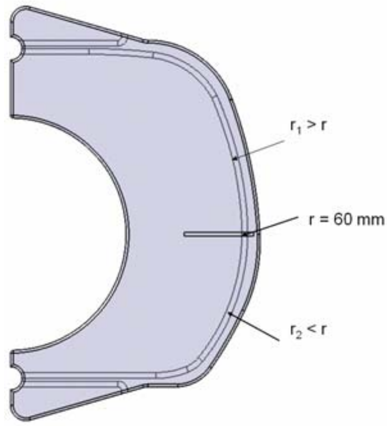


Figure 3. a) Steering by Bowden cables. b) The Adjusting rope-wheel.

The steering rope-wheel would 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?

Turn of the steering rope-wheel for angle α induces the rope's move for the length of the arc $l = r\cdot\hat{\alpha}$ .The same move of the rope causes a turn of the adjusting rope-wheel for angle $\alpha_1 = l / r_1$.

It follows: $r\cdot\hat{\alpha} = r_1\cdot\hat{\alpha}_1 = r_2\cdot\hat{\alpha}_2$,where r_1 and r_2 are variables. Concerning the eq. 2 and the inter-track distance B, turn of the outer and inner adjusting rope-wheel α_1 and α_2 can be described as:

$$\alpha_1 = \pi - 2arctg\frac{R+\frac{B}{2}}{A},\ \alpha_2 = \pi - 2arctg\frac{R-\frac{B}{2}}{A} \qquad \ldots(6)$$

Driving through the right bend can be analytically described by:

$$r_1 = \frac{r\cdot\alpha}{\alpha_1} = r\left(\frac{\pi - 2\cdot arctg\frac{R}{A}}{\pi - 2\cdot arctg\frac{R+\frac{B}{2}}{A}}\right) \qquad \ldots(7)$$

Conditions by driving through the left bend are mirrored image of the eq. 7 and therefore analogue.

3. 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 4 and 7:

$$r_{1,2} = r\left(\frac{\pi - 2\cdot arctg\dfrac{\dfrac{A}{\sin\alpha}\cdot(1+\cos\alpha)}{A}}{\pi - 2\cdot arctg\dfrac{\dfrac{A}{\sin\alpha}\cdot(1+\cos\alpha)\pm\dfrac{B}{2}}{A}}\right) \qquad \ldots(8)$$

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 eq. 4 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 eq. 8 was used in CAD software as a graphical function calculated for the angle interval between 0 and 26 degrees. The resulted curve (Fig. 3a) was used as a construction path for making a lead groove for a rope shown in figure 3b.

4. PRODUCTION OF A PROTOTYPE

The first conceptual prototypes of the adjusting rope-wheel were made by a PolyJet™ rapid prototyping system. Since the mechanical properties of the used materials do not satisfy actual conditions and demands [4] the prototype was used for testing the fitting suitability. Later on it was used as a pattern in a Silicone Rubber Molding process. The process was used to obtain molds for small batch production of functional parts out of different types of polyurethane. They were used for functional tests with the unloaded vehicle and for short run testing with the fully loaded vehicle. The tests showed the correctness of the assumptions used for analytical description of the steering mechanism and the usefulness of the mechanical solution. Therefore the final version of the rope-wheel was cast out of aluminum using the investment casting procedure. To obtain the wax parts for the procedure the same silicone molds were used as for the polyurethane parts.

5. CONCLUSION

Developed steering mechanism represents a unique approach to the problem of steering a dual track vehicle. The analytical solution is an example of basic engineering approach to the problem upgraded by the contemporary prototyping techniques that lead to the working prototype in a time frame of 10 days. The approach shows a broad range of possibilities of rapid prototyping and tooling techniques in both shortening a development and lead time as well as testing many different solutions and construction variants.

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