1. Ahmad ZAYADI[1], 2. RULIYANTA[2, *], MARSUDI[3], Julian T. ANWAR[4]

Universitas Nasional, Indonesia (1, 2, 4), Universitas Dirgantara Marsekal Suryadarma, Indonesia (3)
ORCID: 2. 0000-0002-2439-330X (Corresponding Autor: ruliyanto@civitas.unas.ac.id)

doi:10.15199/48.2024.06.44

Electric bicycles for transportation of the physically disabled in indonesia

***Abstract**. The high number of disabled people in Indonesia, which reaches more than 22 million people, requires special transportation facilities. Three-wheeled electric bicycles are an alternative to overcome this problem. Our bicycle design results of the displacement error presentation are n = 2.17%. Based on the calculation above, the presentation shows a displacement ratio of 2.17% or below 5%, so the theoretical calculations and the simulations tested are both correct. Percentage of von Misses error results in theory and simulation n = 1.05 %. With a 60-volt and 24 Ampere battery, it can move the bicycle up to 14 km with a maximum load of 100 kg.*

***Streszczenie.** Duża liczba osób niepełnosprawnych w Indonezji, która sięga ponad 22 milionów, wymaga specjalnych środków transportu. Alternatywą dla rozwiązania tego problemu są trójkołowe rowery elektryczne. Wyniki naszego projektu roweru dotyczące prezentacji błędu przemieszczenia wynoszą n = 2,17%. Na podstawie powyższych obliczeń prezentacja pokazuje współczynnik przemieszczenia wynoszący 2,17% lub mniej niż 5%, zatem zarówno obliczenia teoretyczne, jak i przetestowane symulacje są prawidłowe. Procent wyników błędu von Missesa w teorii i symulacji n = 1,05%. Dzięki akumulatorowi 60 V i 24 A może przejechać rowerem do 14 km przy maksymalnym obciążeniu 100 kg.* (**Rowery elektryczne do transportu osób niepełnosprawnych fizycznie w Indonezji**)

Keywords: Electric Bicycle, Physical disable, BLDC motor, Three wheels.
Słowa kluczowe: Rower elektryczny, niepełnosprawność fizyczna, silnik BLDC, trzy koła.

Introduction

Currently, the number of people with disabilities in Indonesia has reached 22.97 million people or around 8.5% of Indonesia's population, with the highest number of people with disabilities in old age [1]. About 82 percent of people with disabilities are in developing countries and live below the poverty line [2]. The Law of the Republic of Indonesia concerning Persons with Disabilities and Government Regulations specifically regulate persons with disabilities. Article 14 confirms a 1 percent quota for employment of people with disabilities in government and private companies. Article 5 states that "every person with a disability has the same rights and opportunities in all aspects of life". Article 6 lists various rights for persons with disabilities such as education, employment, equal treatment, accessibility, rehabilitation.

The next problem that arises is that people with disabilities are not allowed to drive their own motorized vehicles. This is because legally they do not have a motor vehicle driving license. This letter was not issued because of his physical condition.

To overcome this problem, this research proposes designing a special vehicle for people with disabilities. The vehicle designed is a three-wheeled bicycle with an electric drive. In this study, the feasibility of the bicycle was measured based on the load capacity of the materials used. We also measured the capacity of the 500-Watt battery used by measuring travel time with various weights.

Riding a bicycle affects physical health, especially the human heart [3]. Apart from exercise, bicycles are used for transportation to the office. In the design of electric bicycles, the speed is regulated using computing [4]. In this study, bicycles were used in normal people's physical conditions. Designs for tricycles had previously been made. For example, [5]investigated the stability of a tricycle with various front wheel sizes. Other researchers investigated electric bicycles using solar power [6]. Meanwhile, other researchers designed a three-wheeled motorbike to be physically disabled [7]. Of course, in this design it is mandatory to follow electric bicycle regulations [8]. In Maltese regulations, bicycle speed is expected to be no more than 32 km/hour. An electric bicycle or also called an e-bike is a bicycle with an additional electric motor system as a source of propulsion besides the pedals[8], [9]. There are various variants of electric bicycles, including pedals which have a small motor system to electric bicycles with almost the same speed as engine-powered motorbikes. Electric bicycles use rechargeable battery power with an average speed of 25-30 km/hour. Meanwhile, according to other regulations in Indonesia, the speed of electric bicycles can only be a maximum speed of 25 km/hour [10].

The bicycle frame is one of the most important components of a bicycle, functioning as the main support where all the resultant forces from all components are centred [5], [6]. The type of frame used to make bicycles is hollow.

Method

The initial design for designing this electric bicycle is shown in Figure 1. Bicycles for people with disabilities use three wheels. This bicycle was chosen so that users do not need to put their feet down when the bicycle is stopped. In bicycle design, Autodesk Inventor software is used to test the strength of the designed bicycle frame.

From Figure 1, *L* is 1300 mm (the distance between the front wheel axle and the rear wheel axle), and a is 650 mm (the distance from the front wheel to the load centre). The distance between the rear wheel axle and the load centre is given by b of 650 mm. The magnitude of *W* is 981 m/s2, which is assumed to be the weight of the rider plus the weight of the bicycle multiplied by the acceleration due to gravity.

Von Mises stress is an indicator that measures material failure by analysing the resultant three main stresses, commonly called Principal Stress; failure is predicted if the Von Mises stress value is greater than the yield stress of the material ($\sigma_y > \sigma_x$). The results of von Mises analysis using software for the maximum stress value of the ASTM A36 hollow material is 124 MPa. In comparison, the yield strength value of the ASTM A36 hollow material is 250 MPa, so the structure does not experience plastic deformation, as in Figure 2 below. Meanwhile, Equation 1 is a way to calculate Von Misses pressure [11]–[13].

$$(1) \qquad \sigma_{\max} = \frac{\sigma_y + \sigma_x}{2} + \sqrt{\left(\frac{\sigma_y + \sigma_x}{2}\right)^2 + (\sigma_{xy})^2}$$

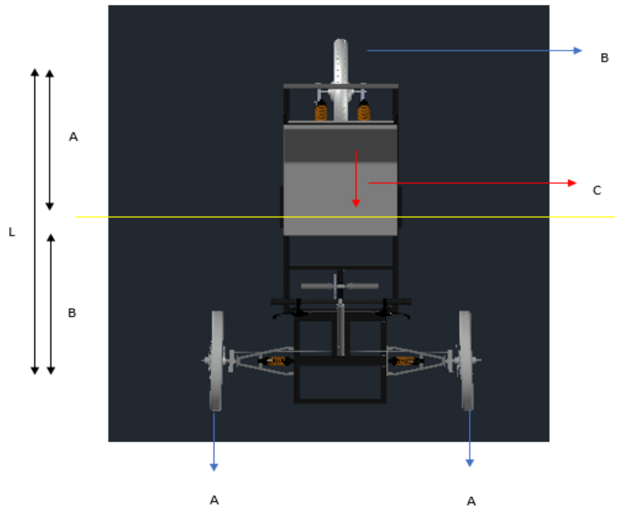

Fig. 1. Initial design of an electric bicycle with three wheels

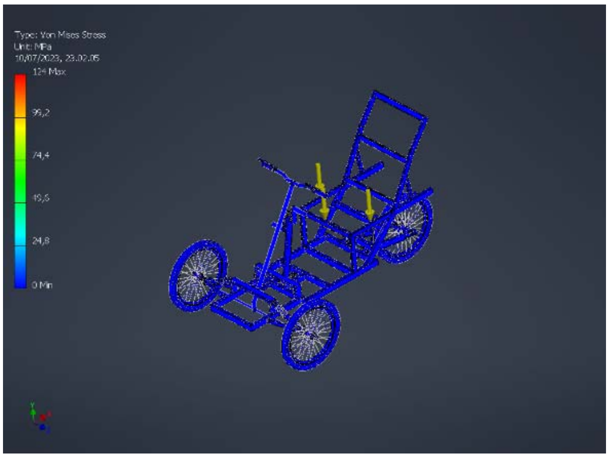
Fig. 2. Simulation result for Von Mises stress

Our design calculates the total mass of the vehicle, namely the weight of the bicycle plus the weight of the rider. The weight of the designed bicycle is 30 kg, and the maximum passenger weight that can be accommodated is 70 kg for a total of 100 kg. If the magnitude of the earth's gravity is 9.81 m/s^2, then the total force is 981 N. In other words, the magnitude of the normal mechanical force F_N is calculated as follows:

(2) $$F_N - M_T \times 9.81$$

The M_T value is 100, so the F_N value is 981 N. Next, to calculate the static friction force, Equation 3 can be used.

(3) $$F_S = F_N + \mu S$$

where: F_S – static friction force, μS – coefficient of friction.

If the coefficient of friction is 0.7, then the magnitude of the static friction force is 876.7 N. Next, the magnitude of the kinetic friction force is found using Equation 4, namely:

(4) $$F_K = F_N + \mu K$$

where: F_K – kinetic friction force, μK – kinetic coefficient.

Based on calculations, this will produce a kinetic friction force of 588.6 for a kinetic coefficient of 0.6. The amount of torque required to move the bicycle must be greater than the static friction force multiplied by the radius of the wheel [14], [15]. This torque can be calculated with Equation 5, namely:

(5) $$T_S > F_S \times R_W$$

where: T_S – Torque, R_W – Wheel radius.

If the radius of the wheel is 0.25 m, then the amount of torque that must be applied so that the wheel rotates must be greater than 171.675 N. For the bicycle to move, the pedal force must be greater than F. Equation 6 is used to calculate the pedal force:

(6) $$F > \frac{F_S}{R_{PS}}$$

If the R_{PS} is 0.2, then the force needed to make the bicycle move is 137.34 N. The force after the bicycle moves can be calculated using Equation 7:

(7) $$F = \frac{F_K \times R_{PS}}{R_W}$$

This calculation gives a force result of 470.88 N. Next, to calculate the power produced by the driving motor, use Equation 8:

(8) $$P_{out} = 9.81 \times \mu \times M_{Tot} \times V_{Avr} \times \eta$$

From Equation 7 above, the electric motor required has a power of 470.88 watts for a value of η = 100/85. In this design, the motor used is 500 watts. If the target bicycle has 10 km, then the bicycle will have a speed of 1.51 m/s. This value is used to calculate battery capacity. Because the electric motor used has a power of 500 watts and a maximum distance of 10 km, the battery designed has a voltage specification of 60 V with a current of 24 A or 1440 watts [16].

In this design, a BLDC motor is used [14]. To determine slip and efficiency in BLDC motors, use Equation 9 to calculate synchronous speed and Equation 10 to calculate slip.

(9) $$n_s = \frac{120F}{p}$$

(10) $$Slip = \frac{n_s - n_r}{n_s} \times 100\% .$$

where: n_s – slip, n_r – rotor speed, p – number of poles.

Results and Discussion

The results of the bicycle design are given in Figure 3. The results of the bicycle mechanical measurements are given in Table 1 below. The complete frame calculation results obtained can be seen in the Table 1 below. Stress in ASTM A36 steel with dimensions 50 × 25 × 2 mm.

Table 1. The complete frame calculation results

Index	Value
Moment of inertia (I)	90,078.66 mm^2
Centre of gravity distance ($Y = a$)	12.5 mm
Maximum load (M_{max})	159,087.5 N.mm
Maximum tensile stress (f_{max})	125 N/mm^2
Safety factor (SF)	4
Permissible tensile stress (f_{ci})	31.25 N/mm^2
Tensile stress in the frame (f_c)	22.07 N/mm^2

So, because (f_c) < (f_{ci}), the choice of frame material with an ASTM A36 hollow profile with dimensions of 50 × 25 × 2 mm is safe to withstand the load. Meanwhile, the stress in ASTM A36 rectangular hollow profile steel with dimensions of 40 × 20 × 2 mm is given in Table 2 below.

Fig. 3. Designed three-wheeled electric bicycle

Table 2. The stress in ASTM A36 rectangular hollow profile steel

Index	Value
Moment of inertia (I)	44458.66 mm^2
Center of gravity distance ($Y = a$)	10 mm
Maximum load (M_{max})	159,087.5 N.mm
Maximum tensile stress (f_{max})	125 N/mm^2
Safety factor (SF)	3
Permissible tensile stress (f_{ci})	41.66 N/mm^2
Tensile stress in the frame (f_c)	35.78 N/mm^2

So, because (f_c) < (f_{ci}), the choice of frame material with an ASTM A36 hollow profile with dimensions of 40 × 20 × 2 mm is safe to withstand the load. The results of the analysis of the maximum deflection that occurs in the main frame are given in Table 3.

Tabel 3. The results of the analysis of the maximum deflection

Index	Value
Moment of inertia (I)	9,154,166,666.67 mm^2
Modulus of elasticity (E)	2 × 105 N/mm^2
The tilt angle that occurs (i)	1.131 rad
Maximum deflection (yc)	1.8 × 10^5 mm

Meanwhile, based on the simulation results of frame strength analysis using theory and software, the loading force for the overall load is F= 981 N. If the surface area A=117×10^4 mm^2, the value of the moment equation for the hollow shape M = 882.900 N.mm with hollow centre of gravity Y = 12.5 with moment of inertia of I = 90,078.66 mm^2 and axis shear stress 〖r〗 = 0.188 N/mm^2 at Normal stress σ_t = 122.51 MPa produces Von Misses stress σ_{max} = 122.69 MPa.

The results of the von Misses simulation analysis using keel software for the maximum stress value of the ASTM A36 hollow material is 124 MPa. In comparison, the yield strength value of the ASTM A36 hollow material is 220 MPa, so the structure does not experience plastic deformation, as in the image below. Percentage of von Misses error results in theory and simulation n = 1.05 %. Judging from the results of the comparison presentation for making an electric bicycle frame, it can produce values below the yield strength value of the frame, and the error value is below 5%, it is concluded that the frame of this three-wheeled electric bicycle is safe in terms of von misses.

From the results of theoretical calculations, the displacement value is found to be δ = 0.103 mm, while the software simulation for the displacement/deformation value of ASTM A36 material is 0.1011 mm. It can be concluded that the displacement results are still below the safe limit, namely <1.

The results of the displacement error presentation are n = 2.17%. Based on the calculation above, the presentation shows a displacement ratio of 2.17% or below 5%, so the theoretical calculations and the simulations tested are both correct.

From the software simulation results, the safety factor value for ASTM A36 material is 1.79 ul, and the safety factor value in the software has a maximum value of 15 ul minimum of 1.67 ul. If the safety of the factor value is below 1, it is called structural failure. The results of the safety of factor presentation are n = 7.18 %. Judging from the calculation results of the safety of factor comparison presentation above, the value of n = 7.18% and <10 means that the error presentation is good, and the value of the safety factor is still below the standardized safety of factor value. i.e., > 1.

The complete results of the electric motor calculations can be seen in the data below. The torque required to move the bicycle must be greater than TS > 171.675 N. Thus, for the bicycle to move, the hand pedal force must be greater than F > FS / R.PS, namely F > 137.34 N. After the bicycle moves, then the force (F) required is F = 470.88 N. The power produced by the driving motor 〖P 〗_out= 470.88 Watt. From the calculation above, the power required for an electric motor is 470.88 Watts because there are no electric motors with that power on the market, so an electric motor with a power of 500 Watts is used.

The speed of a bicycle traveling 10 km in one hour or 3600 seconds produces a travel speed of 1.51 m/s. The battery is the power source for the electric motorbike because the electric motor used has a power of 500 Watts. Because this electric bicycle has a maximum travel distance of 10 km, the battery used and available on the market is 60 V with a current of 24 A.

So, from the calculation results above, it is known that the slip value of the BLDC electric motor used is 5.3%, and the efficiency resulting from this 500-watt capacity electric motor is 90%. The results of measuring bicycle distance with varying loads are shown in Figure 4, with an average speed of 10 km/hour on a flat road.

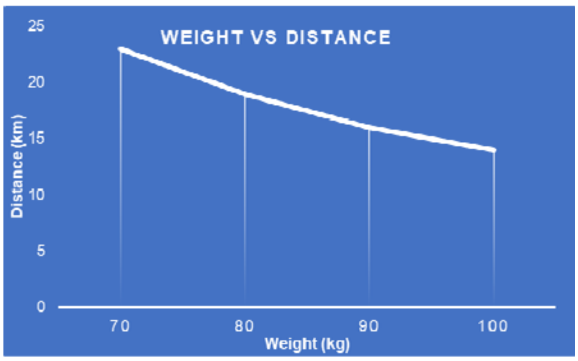

Fig. 4. Battery electricity consumption, distance to weight ratio

Based on Figure 4, the heavier the bicycle, the greater the energy required to move it. One way to save energy is to choose lighter bicycle materials. The distance the bicycle travels will be greater if the bicycle load is lighter.

Conclusion

From the design results, the three-wheeled electric bicycle we designed was quite effective. The results of the displacement error presentation are n = 2.17%. Based on the calculation above, the presentation shows a displacement ratio of 2.17% or below 5%, so the theoretical calculations and the simulations tested are both correct. Percentage of von Misses error results in theory and simulation n = 1.05 %. With a 60-volt and 24-ampere battery, it can move the bicycle up to 14 km with a maximum load of 100 kg. It is hoped that this bicycle will be able to overcome the problems of people with physical disabilities in Indonesia.

For the next study, we suggest controlling the speed of electric bicycles using computerization to maintain energy efficiency in the battery. The materials used for bicycle numbers use lighter materials.

Authors: *Associate Professor Dr. Ir. Ruliyanta, M.T., Department of Electrical Engineering, National University, Indonesia, E-mail: ruliyanto@civitas.unas.ac.id; Assistant Professor Ahmad Zayadi, S.T., M.T., Department of Mechanical Engineering, National University, Indonesia, E-mail: zayadi@civitas.unas.ac.id; Associate Professor Ir. Marsudi, M.Sc. Department of Mechanical Engineering, Marshal Suryadarma Dirgantara University, Indonesia, email: marsudi@unsurya.ac.id.*

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