Design, Frame Analysis and Manufacture of Handcycle Prototype

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Abstract. Handcycle is a transportation tool for individuals with lower limb disabilities. This study designed a handcycle as a mode of transportation to facilitate the accessibility of persons with disabilities. The design of the handcycle was designed on a prototype scale. It referred to recumbent and synchronous frame geometry types for arm crank set up to do finite element analysis studies using Autodesk Fusion 360 software to find the value of the strength of the handcycle frame design. A decent frame at 160 kg loading with a critical value of 330 MPa was designed and became a reference for the handcycle production process.

Keyword : handcycle, recombang, frame analysis, FEA

1. Introduction

Persons with disabilities in Indonesia have counted for 2.45% of the population. About 10.26% of them have suffered defect in the lower limb [1]. Handcycle is a combination of wheelchairs and bicycles that began to be developed since 1900 [2]. This has been an alternative transportation for them who had a lower limb defects [3][4]. Handcycle has begun to be contested as one of the Paralympic sports since 2004 [5].

Handcycle is a bicycle whose riders in the front ride it using an arm in chain and crank transmission. Handcycle riders have relied on the handcycle design [6]. Handcycle has two types of arm cranksets: synchronous and asynchronous. The synchronous design has equated the motion of the crank in the same direction of motion, in contrast to the asynchronous crank paralleled like a crank chase on a bicycle. Frame geometry is divided into three i.e. upright styles, hand cycle attachment, and recumbent [2]. Anthropometric data must be recognized to determine the characteristics of persons Anthropometric data must be recognized to determine the characteristics of persons with various disabilities [7][8].

There has been no handcycle product made in Indonesia. Based on Indonesian anthropometric data and compared to existing anthropometric data, frame design and finite element analysis studies, prototyping has been performed. This study has designed handcycles and has made prototypes based on frame design, finite element analysis, and anthropometry.

2. Methodology
Handcycle is design based on anthropometry data. The characteristics of anthropometry data from Indonesian National Standards for People With Disability in Indonesia [9] is given in Table 1. The geometry design of the frame used a recumbent model that allows straightening the foot position. The handcycle was designed to incorporate all the subsystems of the vehicle. A CAD Model was prepared in Autodesk Fusion 360 to make the design process easier to incorporate.

Table 1. Anthropometry Data People with Disability

| No  | Measurement            | Male                  | Female                |
|-----|------------------------|-----------------------|-----------------------|
|     |                        | Avg.  | 5%ile | 95%ile | Avg.  | 5%ile | 95%ile |
| 1   | Sitting shoulder height | 569.0 | 563.1 | 575.0 | 506.9 | 499.4 | 514.3 |
| 2   | Elbow height sitting   | 216.7 | 214.3 | 225.1 | 131.8 | 124.9 | 138.7 |
| 3   | Popliteal depth        | 485.5 | 481.5 | 489.5 | 459.5 | 452.4 | 466.6 |
| 4   | Popliteal height       | 430.3 | 425.9 | 434.7 | 339.2 | 331.3 | 347.0 |
| 5   | Shoulder breadth       | 460.6 | 455.9 | 465.2 | 416.8 | 410.0 | 423.6 |
| 6   | Hip breadth            | 328.9 | 324.0 | 333.9 | 320.9 | 313.2 | 328.5 |
| 7   | Elbow breadth          | 455.5 | 451.9 | 459.1 | 446.7 | 442.8 | 450.5 |

Material Selection
The frame was made with material that is widely available on the market, safe, has reliability, low cost, and good weldability. In the simulation, the material used was structural steel with material properties given in Table 2.

Table 2. Material Properties

| Density          | $7.8 \times 10^6$ kg/mm$^3$ |
|------------------|-----------------------------|
| Young’s modulus  | 200 GPa                     |
| Poisson’s ratio  | 0.26                        |
| Yield strength   | 248.2 MPa                   |
| Ultimate tensile strength | 475.7 MPa     |
| Cost (IDR/ kg)   | IDR 12,000                  |

Frame Design
CAD was designed by Autodesk® Fusion 360 software by considering three criteria i.e. availability of steel tube material forms, manufacturing processes, and ergonomic factors from anthropometric data.
Figure 1. Handcycle Frame Design

Finite Element

Frame simulation is calculated using a static loads method with constrained fixed and meshing divide of 202,049 nodes, 95,016 tetrahedral elements for complex geometry model. Tetrahedral solved problems with high strain gradients element [10]. It is based on user load handcycle with a maximum weight. The load on the frame is 1570 with a maximum driver mass of 160 kg.

Figure 2. a) Static Load on the Frame; b) Mesh Viewed

3. Result and Discussion

The results of the analysis showed that frame design was safe and did not fail to static loading. The maximum value Stress von Mises from Fig. 3 of 330 MPa was found only in a few areas of the frame. The maximum displacement is given in Fig. 4 occurring at 5.66 mm that was still within safe limits and did not interfere with the function of handcycle work. In general, frame design had a safety factor value of 6 Fig 5.
Figure 3. Stress von Mises result

Figure 4. Displacement Result

Figure 5. Safety Factor

Handling Ability
Handling Ability calculated the ability of handcycle to turn Fig. 6. The maximum swivel angle limit can be detected through measurements when the bicycle handlebars turned right at 20º, if more than 20º there would be friction in the chain against the bicycle frame. Whereas, to turn to the left there were no obstacles.

**Figure 6. Angle Limit**

**Assembly Design**

The final result of the handcycle assembly design Fig. 8 was equipped with an adjustable chair to adjust the driver's distance to the crank. This design was a reference for the handcycle manufacturing process.

**Figure 7. Handcycle from Sideview**
Manufactured Product

Completely manufactured handcycle Fig. 9 had weight of 24 kg and production costs of IDR 3,500,000. This product was easy to use in sports for people with lower disabilities. More studies are needed to analyze biomechanics and develop more ergonomic designs.

Figure 8. Final Assembly Design

Figure 9. Handcycle Prototype

4. Conclusion

Handcycle can be designed and made according to the required criteria. This design is the initial stage of the development of handcycle in Indonesia. The safety frame design is used by riders with a maximum weight of 160 kg. Development is needed to reduce the weight of handcycle and develop more dynamic designs.

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