PORTABLE AND COMPACT TIRE-CLAMPING MECHANISM FOR MEDIUM SIZED TIRE

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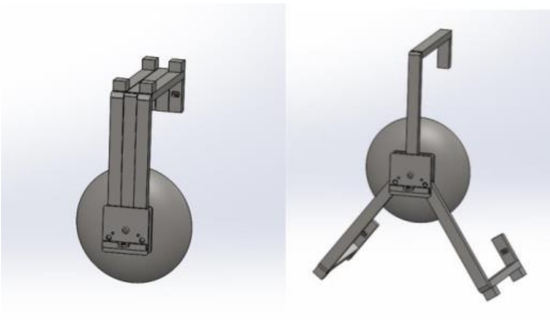
GRAPHICAL ABSTRACT



ABSTRACT

The purpose of this paper is to improve an existing tire or wheel clamp design that is in comprehensive use in Universiti Teknologi Malaysia. The wheel clamp targets to replace the heavy and inconvenient old design, and if the new design is well received by its user, it may expand its use in many places in the future. This design is more lightweight and compact if compared to most existing product in market. The usage of three arms to lock the wheel or tire ensures its stability. Computer Aided Design model of the design is developed using Solidworks software and analysed by using Finite element analysis in Solidworks simulation. Stress, strain, displacement, and factor of safety analysis results from FEA analysis are studied and discussed with a focus on the critical location of the design. Four situations are considered for the design; someone is pulling the centre arm (tension and bending moment), bending bolts and nuts cover, pulling padlock, and driving while clamp is still clamped at the wheel. A half scale model of the initial design is printed in three dimension to check its functionality. Further improvements of the design are showed through simulation and animation using Solidworks.

KEYWORDS

Tire-Wheel Clamp; Medium-Sized Tire, Solidworks Simulation, Finite Element Analysis

1.0 INTRODUCTION

Tire or wheel-clamping is created to clamp one of four tires so that the clamped vehicles cannot move. Design of a tire-clamping is required to make the tire that has been clamp cannot be removed from the vehicle [1]. The usage of a tire-clamping is made by the customers whether to clamp self-car, preventing car from being stolen or for a local authority to clamp vehicle that park illegally [2].

There are several existing design and mechanism for tire-clamping. Tire-clamping consist of arms (most of them have three), lock mechanism, bolts and nuts cover and some of them have needle to flat the clamped tire if the vehicle try to move without unlocking the tire-clamp. For the arm, it needs to be made from suitable material that can resist external force. If the material used is good, it can clamp the tire without broken or failed when people try to force unlocking it.

In some case, local authority used motorcycle to bring tire-clamp to the illegally park vehicle. When the tire-clamp is too big and heavy, it is dangerous to move around with one hand on the motorcycle handle and the other hand to lift the tire-clamp. This dangerous act can be sued by OSHA or any safety authority as it is dangerous to the rider self and also to other people around. So, the design of tire-clamp needs to be portable and compact for it to be easily to be brought around without break any road or safety law.

The objective of this paper is to improve the existing tire-clamp mechanism to be portable and easy to use. This paper will present the required improvement, the design modification, and the engineering analysis involved before it can be concluded as a good design..

2.0 METHODOLOGY

Systematic design process as in Figure 1 needs to be followed to ensure the best outcome in generating ideas. The design process can be a very complicated and iterative process. The steps in the design process are reiterative which means that regardless of how far one process. The needs of repeating certain design process are due to the connection between processes and continuous evaluation of the design. The first steps of the process (Problem statement) needs to be observed carefully, as it will provide the ultimate goal of the design. During the design phase, product design specification (PDS) can be constantly altered in need of design analysis and problem statement update. In the end of final design, the PDS will become the final specification of the product.

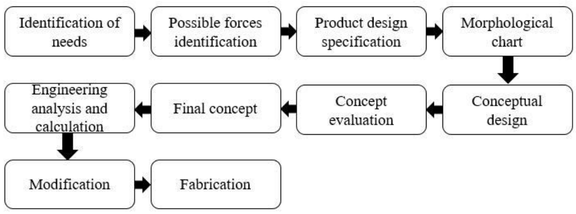


Figure 1: Flowchart of methodology

2.1 Detail design

Design details follow a process that involves conceptual design, when performed properly will result in a well-designed solution. In a conceptual design, which is phase one of a detailed design, the final concept is the main output. The final concept produced the ideas with little detail, but it is the first step to the final design. Detail design is the phase where the design's plans, specifications, and estimates are produced. Detail design will include the overall dimension, material selection, joining part or connectors, and modification. The mass and estimated cost of building one prototype are also included in the detail design.

2.2 Overall dimension

Based on Wheel and Tire Guide in Figure 2, Wheel Drive Volvo Models by Scott Hart [3], the wheel clamp must at least build with a minimum opening, 24.2 inches or 622 mm, and maximum opening, 25.5 inches, or 648 mm. The width of the clamp also must follow the maximum width of the tire which is 225 mm. Thus, following the specification size of the tire, the finished product dimension of the wheel clamp including the thickness of the arms is set approximately 660 mm x 660 mm x 225 mm.

Figure 2: Wheel and Tire Guide, Wheel Drive Volvo Models

2.3 Material Selection

The material used for this design is mild steel. In Solidworks simulation, there is no specific mild steel material selection. Thus, a similar material properties with mild steel which is AISI 1020 material is chosen to build all of its components. The properties of AISI 1020 material is shown on table below.

Table 1: AISI 1020 properties

Property	Value	Units
Elastic Modulus	200	GPa
Poisson's Ratio	0.29	
Shear Modulus	77	GPa
Mass Density	7900	kg/m^3
Tensile Strength	420507000	MPa
Yield Strength	351571000	MPa

AISI 1020 is suitable to be used for the design because it is low cost compared to the other strong steel material. In addition, the yield strength is over 350 MPa which is suitable to be used for clamping tire. AISI 1020 is strong enough to withstand force given by a normal human with weight around 90 kg without any special tool. The mass density is not very high with the value of 7900 kg/m^3 or 7.9 kg/L compared to other materials like stainless steel.

2.4 Arm dimension

Before proceed to simulation, the critical component needs to be analysed manually to determine the dimension. In this paper, the critical component is the three arms. The arms feel the most force exerted because it is the longest component for this wheel clamp design. The dimension of the arms is calculated using solid mechanics.

Length arm = maximum radius size of wheel

Stress,

$$\sigma_{\text{tensile}} = \frac{F}{A} \quad (1)$$

Bending stress

$$\sigma_{\text{bending}} = \frac{My}{I} \quad (2)$$

where:

M = *bending moment*
y = *length from neural axis to top surface*
I = *second moment of inertia*

Safety factor, *k*

$$k = \frac{\text{Yield strength}}{\text{Maximum stress}} \quad (3)$$

2.5 Design modification

The modification used the same basic concept but is improved by changing some of its characteristics. The major modification made is that the three arms are changed to the telescopic arm as shown in Figure 3 and Figure 4. The modification makes the wheel clamp smaller when it is not utilized. It is easier to handle and to carry around as it is compact and can be fitted in a small space rather than before its modification.

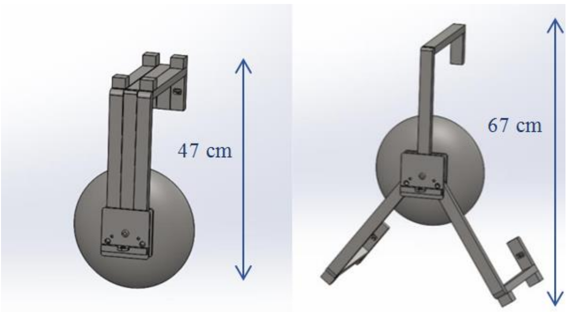


Figure 3: Before modification

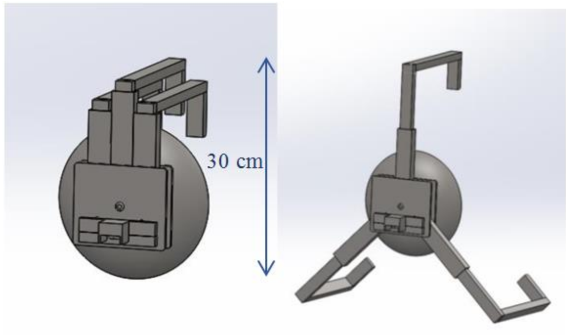


Figure 4: After modification

Apart from making the wheel clamp smaller, the telescopic arm also makes it adjustable. Both right and left arms must open to maximum length. The adjustable to fit a certain size of the tire was made at the center arm. The center arm has a push-button lock as in Figure 5 behind it to adjust the arm length according to the size of the tire. It is using a spring and a button to make it an automatic lock, and range of holes that had been specified to a certain size of the tire to be clamp.

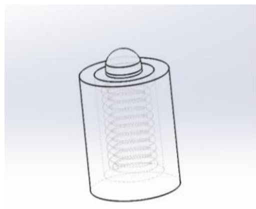


Figure 5: Push-button lock

2.6 Mass and costing

Mass estimation of this design is done using Solidworks mass properties by using simulation only. The estimation mass for the final design wheel clamp is 4806.81 grams or 4.81 kg. This weight is to follow the product design specification which is below 7 kg. For the costing, it is calculated based on the actual price by the manufacturer of the material used. The raw material to build one prototype of this wheel clamp design is around RM 77.20. The price is for the raw material only not including delivery and manufacturing. The material has to be cut and formed to look like the shape in Figure 4. Thus, the estimated price to build one prototype of this wheel clamp is about RM 150.00.

3.0 ENGINEERING ANALYSIS

This project used Finite Element Analysis (FEA) to do the engineering analysis. Finite Element Analysis [4] (FEA) is the process of simulating the behaviour of a part or assembly under given settings so that it can be evaluated using the Finite Element Method (FEM). Finite Element Analysis is used by engineers to help simulate physical phenomena, thus reduce the need for physical models. For this project, Solidworks simulation is used to run the Finite Element Analysis.

Before running the simulation, a Computer-Aided Design (CAD) model is prepared where it is conditioned with a combination of constrains and load set according to the real-life situation. The simulation condition will define the boundary condition and degree of freedom of the system and this will affect the overall result simulations. There are four situations that are set according to the real-life situations in this study. The situations are; someone pulling the centre arm (tension and bending moment), bending bolts and nuts cover, pulling padlock and driving while clamp is still clamped at the wheel.

3.1 Analysis

Analysis for the design is fully using Solidworks Simulation to find the maximum stress, strain, displacement, and its factor of safety in the critical area. To find the critical area based on the three criteria, the five situations were analysed according to the forces that act as in a real situation. Figure 6 presents the maximum stress distribution between the four situations. In this case, it is when someone is pulling the centre arm with a maximum stress of 0.115 GPa near the centre of the locking plate.

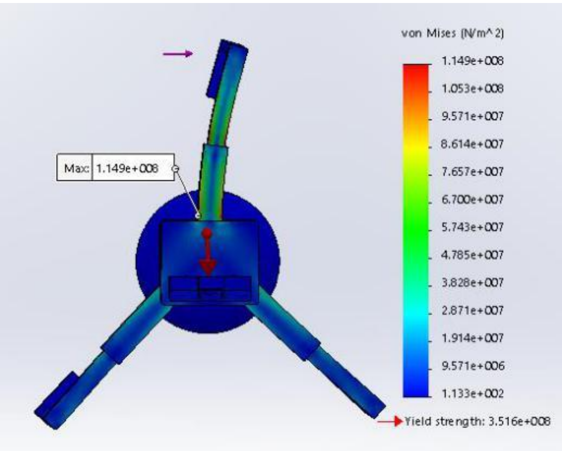


Figure 6: Stress distribution when someone is pulling the centre arm

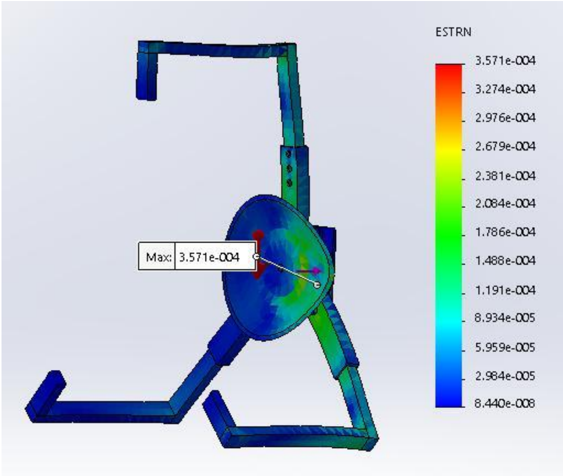


Figure 7: Strain result for situation two, when someone is bending the bolts and nuts cover

In Figure 7, it can be seen that the maximum strain is on the contact point and the side of structure where the force is applied. At this point, the maximum strain is 0.00036 which can be considered too small compared to the strain the material can stand.Factor of safety is defined as the ratio of the structure's absolute strength to the actual applied stress. In designing a mechanical structure, the factor of safety is one of the vital criteria that must be taken into account to make sure it does not fail during operation. As for this design, the factor of safety is calculated to make sure this wheel clamp design is safe to use and serve its purpose. Overall, the factor of safety for all situations is more than 2. Thus, this wheel clamp design is safe to use for a force generated by human with 90 kg of weight [6] or a medium size car with weight of 2000 kg [7].

4.0 CONCLUSION

In conclusion, the final design of the wheel clamp has been chosen using a systematic design process to ensure the best outcome. Apart from choosing the final concept, the modification of the chosen concept successfully makes the design compact and adjustable. Arms of the wheel clamp is modified from one solid component to sliding using telescopic mechanism resulting the maximum dimension when the clamp in a compact state is half than the original dimension. The engineering analysis for the wheel clamp design is done successfully on finding stresses, strains, displacement, and factor of safety. The critical situations for the engineering analysis are from situation 2, the force on the bolts, and nuts cover. This situation gives the highest stress resulting in the lowest factor of safety but it is still in the range of 2 to 2.5 which is the recommended value for this project [6]. Overall, the objective of this project is considered as successfully attained. The compact and portable clamp for medium-size tire-wheel is designed and it also has some improvement after modification by considering in detail the problems and suggestions. The engineering analysis is done successfully to make sure the design is safe to used and serve its purpose.

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REFERENCES

[1] Products. (n.d.) Wheel clamp and Parking Lock. Pancar Selamat Sdn Bhd. Retrieved from: http://www.pancarselamat.com.my/index.php?cat=98&page=929.

[2] Hotel service supervisor (October 2005). Policy for the clamping of vehicles. Page 2, definition of tire clamping.

[3] Hart S. (January 2011). Wheel and Tire Fitment Guide for Rear Wheel Drive Volvo Models. iPdUSA Technical Articles. Retrieved from: https://www.ipdusa.com/techtips/10011/wheel-and-tire-fitment-guide-for-1962-to-1995-rear-wheel-drive-volvo-models on August 12, 2020

[4] Harish A. (March 2020). Finite Element Method – What Is It? FEM and FEA Explained. SimScale Blod. Retrieved from: https://www.simscale.com/blog/2016/10/what-is-finite-element-method/ on August 10, 2020.

[5] TEC (n.d.). Finite Element Analysis Software Overview. Top Finite Element Analysis (FEA) Software. Retrieved from: https://www3.technologyevaluation.com/sd/category/finite-element-analysis-fea on August 10, 2020

[6] WorldData (n.d.). Body size by country. Average sizes of men and women. Retrieved from: https://www.worlddata.info/average-bodyheight.php on August 12, 2020

[7] Sellen M. (August 2019). How Much Does a Car Weigh? – List of Weights by Car Model. Mechanic Base website. Retrieved from: https://mechanicbase.com/cars/car-weight/ on August 12, 2020.

[8] Juvinall, R. C., & Marshek, kurt M. (2017). Fundamentals of machine component design

[9] McFadden C. (August 2020). What Are the Different Types of Welding and Which Is the Best? Interesting Engineering. Retrieved from: https://interestingengineering.com/what-are-the-different-types-of-welding-and-which-is-best on August 20, 2020

[10] Dassault Systemes (n.d.). Meshing. SOLIDWORKS Help. Retrieved from: http://help.solidworks.com/2017/english/solidworks/cworks/c_meshing.htm#:~:text=The%20process%20of%20subdividing%20the,solid%2C%20shell%20and%20beam%20elements on August 15, 2020.