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Innovative Foldable Tire Changer: Design and Fabrication

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Abstract

Changing a flat tire is a difficult and challenging task for vehicle owners, causing inconvenience, delays and benefits if mismanaged. This project addresses the need to help those who may be deficient in technical proficiency or physical strength when changing tires. This research is to design and fabricate a portable tool that facilitates the tire changing process to reduce the risk of injuries. The project methodology involves the process of developing a Foldable Tire Changer assistive device, a lightweight and ergonomic device suitable for tire sizes with a radius of 14-20 inches. The main features are its foldable nature for easy storage, minimal physical effort required and a fast and safe tire changing process. A stress analysis was conducted to assess the performance of the tool under the loads associated with tire weight. The Finite Element Analysis illustrates that the product design for tire size 175/65 R14 (small car), 185/55 R15 (sedan & MPV's car) and T115/70/D14 (SUV's car) with 6.5, 9.1 and 15 kg respectively shows the stress analysis result indicating that the design is predominantly stable and possesses the capability to endure the applied forces. Meanwhile, experiments demonstrate that with comparison of tire changing processes, the time taken is less in between 65-70% rather than traditional method. Therefore, in align with the United Nations Sustainable Development Goal (SDG) 9, this tool fosters innovation in accessible infrastructure as a versatile automotive accessory. This assistive device provides a pragmatic solution aimed at mitigating injuries and augmenting efficiency in tire-replacement activities.

Keywords: - Tire, automotive accessory, vehicle, simulation

1. Introduction

A tire is an adaptable construct composed of rubber, textile materials, and steel wiring that encircles the rim of a wheel. Its fundamental function is to furnish traction, mitigate shocks, and sustain the weight of the vehicle while ensuring a seamless and secure riding experience. Tires are of paramount importance because they represent the sole component of a vehicle that establishes direct contact with the roadway, thereby playing an essential role in safety, performance, and fuel efficiency. The performance guarantee adequate grip and braking efficacy, particularly under wet or slippery circumstances, and contribute to the maintenance of stability during acceleration, cornering, and abrupt halts. Furthermore, tires that are properly maintained enhance fuel economy by minimizing rolling resistance and avert unnecessary degradation of other vehicle components. In the absence of tires, vehicles would be devoid of control, comfort, and efficiency, thereby rendering them essential in contemporary transportation.

However, dealing with unexpected breakdowns while driving, such as a flat tire, is one of the most unpleasant problems (Adetunji et al., 2023 & Wang et al., 2016). While some drivers are skilled at handling it, others often need help for various reasons, including lack of expertise, inability to handle the necessary equipment, lack of lighting or aids needed to perform the task properly, loss of valuable time if unable to change the tire quickly, increased safety risks due to being on the side of the road or in busy areas and the risk of injury during the changing tire process. lack of emergency planning, or concerns about safety factors when stuck on the road (Mayer & Laux, 1990 & Raub & Schofer, 1997).

As a driver, it is necessary to understand how important it is to be able to change tires efficiently to ensure the safety and continuity of the car user's journey. The act of replacing a car tire may appear uncomplicated in principle; however, numerous individuals encounter difficulties during the actual execution of this task due to the necessity for physical strength, appropriate technique, and the ability to adapt to real-world circumstances.

In contrast to a regulated environment, instances of flat tires frequently occur in inconvenient or hazardous locations such as on an inclined roadway, amidst heavy traffic, or during inclement weather it thereby complicating the effort. Moreover, lug nuts may be excessively tight owing to over-torquing or corrosion, necessitating additional leverage or the application of penetrating oil to facilitate their loosening. The precise positioning of the jack is of paramount importance which as placing it on structurally weak points can result in damage to the vehicle or cause it to slip, thereby posing a risk of injury. Lifting and aligning the spare tire also requires significant effort, particularly with heavier vehicles such as sport utility vehicles and trucks. For example, even after the new tire is mounted, improperly tightened lug nuts (whether too loose or unevenly torqued) can pose a serious hazard, potentially resulting in the wheel detaching while in motion. Although many individuals understand the basics, they often feel inexperienced due to a lack of hands-on practice. To enhance proficiency, it is beneficial to conduct a trial run in a secure environment, utilize appropriate tools (such as a breaker bar or torque wrench), and adhere to safety measures, including parking on level ground and activating hazard lights. With increased hands-on experience, the process becomes less intimidating; however, until that point, many drivers remain apprehensive and may option to request roadside assistance in challenging scenarios.

Most drivers, especially women and the elderly require skill for many of a car owner where they find this process challenging due to the physical requirements, particularly the weight of the tire, which can cause muscle strain or physical injury. Many tire changing aids and tools aimed at facilitating tire installation and removal are discussed. Portable Manual Tire Changer operates on the principle of a second-class lever, aiming to facilitate the process of changing car tires (Wofuru-Nyenke, 2020). Heavy tires may be easily moved and raised or lowered using manually operated aids. The design of this aid is U-shaped, with wheels or tire support bases connected by parallel links. In contrast to traditional techniques, the tire changer that can be operated electrically, mechanically, and pneumatically, saving time and human labour have been proposed by previous researcher (Abebe et al., 2018). This development aims to increase productivity, reduce physical strain, and reduce the possibility of injury or damage to the tire during changing (Abebe et al., 2018 & Wofuru-Nyenke, 2020). For tire technicians and service stations, the design prioritizes portability, affordability, and user-friendliness. However, the resulting design focuses more on tire changing tasks at service stations.

The Foldable Tire Changer is proposed as an alternative in tire changing tasks. By emphasizing accessibility, safety, and ergonomics, this equipment aims to facilitate tire changing. For the benefit of women and the elderly in particular, the design places strong emphasis on portability, ease of use, and low physical effort. This equipment offers a safer and more effective way to deal with flat tires by reducing strain on the body muscles and the concern of physical injury to the user. Additionally, by promoting innovation and resilient infrastructure, the project supports the UN Sustainable Development Goal (SDG 9). The design is a user-friendly and useful solution for diverse demographics as it places high priority on lightweight construction, ergonomic considerations and compact foldability. The technology is expected to increase driver confidence, reduce reliance on outside assistance, and advance road safety by empowering users to handle flat tires safely and quickly. The size and portability of the tool allow it to be easily stored in the car for quick use in emergencies.

Innovation of Foldable Tire Changer aims to explore the design, fabrication and functional analysis. The novelty of this project is to facilitate the tire changing process, especially for individuals with physical or technical challenges an assistive device. The project discusses the ergonomic design and structure of the tool, ensuring portability, user-friendliness and minimal physical strain for diverse users, including women and the elderly. Next, it will examine the fabrication process focusing on lightweight, durable and compact construction for easy storage and emergency roadside use. Finally, the last step is to analyse the impact of tire weight on design functionality, ensuring stability and efficiency across different tire sizes while reducing user effort.

2. Methodology

Product design from the ground up requires a methodical strategy to guarantee that the final product is useful, practical, and ready for the market. Identifying the need or issue that the product is intended to address is the first step in the process. This includes identifying problems, studying user challenges, and creating a precise problem statement. The project's first phase was to overcome the problem statement at the design phase. A morphology chart was used to choose the final design, which is shown in Table 1, taking into account factors including cost, technical features, mobility and efficacy. Morphological charts are tools for exploring design solutions by listing functions and means to perform them (Mulders, 2019 & Smith et al., 2006)

Cost, ease of use, durability, portability, and safety are the five main criteria that the morphological chart uses to assess four design options for a Foldable Tire Changer assist tool. With a total score of 1, the Baseline option (Alternative A: Standard Tool) acts as the benchmark because it is portable (+1) and performs neutrally (0) in every other criterion. The Lightweight Tool, Alternative B, improves Cost (+1), Ease of Use (+1), and Safety (+1) to earn the maximum overall score of 3. Durability is somewhat jeopardized, but (-1). The Motorized Tool, Alternative C, receives a score of 2, prioritizing Durability (+1) at the expense of Cost (-1) and Portability (-1). Last but not least, Option D, the Compact Tool, maintains a mostly neutral score but lowers Safety (-1), yielding the lowest score of 0. In conclusion, despite a little durability trade-off, Alternative B is the best design because it strikes a better balance across important factors, making it safer, more affordable, and easier to use. Alternative C is less optimal because it provides a durable choice at the sacrifice of cost and portability. According to the investigation, designs that are ergonomic and lightweight offer the target users the most overall utility.

Table 1: Morphology chart of Foldable Tire Changer

Criteria	Baseline A: Standard Foldable Tire Changer Assist Tool	Alternative B: Lightweight Foldable Tire Changer Assist Tool	Alternative C: Motorized Foldable Tire Changer Assist Tool	Alternative D: Compact Foldable Tire Changer Assist Tool
Cost	0	+1	-1	0
Ease of use	0	+1	0	0
Durability	0	-1	+1	0
Portability	+1	0	-1	0
Safety	0	+1	0	-1
Total score	1	3	2	0

The design is improved to maximize utility, ergonomics, and manufacturability in response to the comments. In this step, dimensions and material selection are finalized. using tools like Finite Element Analysis (FEA) is a quantitative technique employed to model and forecast the dynamics of physical systems, especially in the realms of engineering and physics, by deconstructing intricate models into more manageable, interrelated components (Munoz et al., 2021 & Ceylan et al., 2021). In this research, the FEA is to verify adherence to industry standards and assess the design's performance in practical settings,

Next, several sketches were formed while considering the design from the other researcher. Then comprehensive design, engineering drawings, and specs is shaped which was completed using Autodesk Inventor.

2.1 Finalized Design

The development of a prototype for a Foldable Tire Changer went through several steps. The most important step was deciding on a design which was finalized using Autodesk Inventor Professional 2021. The next step was to obtain materials for the fabrication of the prototype. Next, a simulation was run using the same software to obtain the results. After the optimal results were obtained, the next process of developing a Foldable Tire Changer prototype was based on the flowchart in Fig 1.

Various sketches were developed, and the final design was selected based on material selection, ergonomics and cost as shown in Fig 2. The final materials and procedures were then used to build a functional prototype. To assess its usability, robustness and usability, this prototype was put through a comprehensive testing process. The design was ready for use after the necessary modifications were made based on the feedback from this phase.

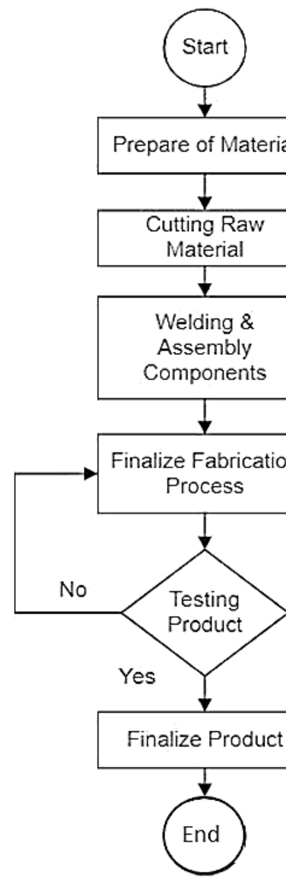

Fig. 1: Flowchart of fabrication Foldable Tire Changer

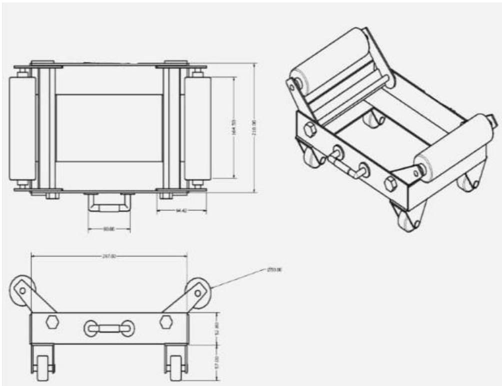

Fig. 2: Isometrix and orthographic drawing of Foldable Tire Changer using Autodesk Inventor

2.2 Fabrication Procedures

Fabrication is the process that occurs during the process of building the project. The following steps are involved in the production of the Foldable Tire Changer are explained in a coherent step. Prior to starting the fabrication process, all necessary materials have been acquired.

Here is the revised sentence in past tense: The project began by using a grinder to cut four mild steel angle bars, reducing their length from 30 cm to 20 cm, focusing on shaping the body of the product. After cut, position the angle bars in the manner. Spot weld the components in the desired arrangement, making sure that they are symmetrical by doing the same on the opposite side. To secure the structure, the completely all gaps were weld after finishing the spot welding.

Then, using a drill bit with a 10 mm radius and following the instructions in the accompanying picture, holes were drilled with a diameter of 4 cm from the structure's edge, as shown in Fig. 3. Next, four 1-inch flat bar pieces been cut into 18cm lengths. Following, as indicated by the provided design, a 2-inch flat bar are being cut into the necessary shape.

(a) (b) (c)

Fig. 3: Fabrication body steps (a) by selection of steel, (b) join part and (c) drill a hole

At the designated spot, drill a 10mm radius hole in the 2-inch flat bar. The product is weld into the 1-inch and 2-inch flat bars together, to make sure that they are aligned. Then apply an anti-rust priming spray to every manufactured component to stop corrosion. To complete the fabrication process, the chosen paint colour was applied to each component after the primer had dried, as shown in Fig. 4.

(a) (b) (c)

Fig. 4: Fabrication inner body steps (a) by cutting the steel, (b) drill the shape and (c) join with roller

3. Result and Discussion

The performance, usability and structural reliability of the Foldable Tire Changer were evaluated in various scenarios to ensure that it achieved the desired results. Choosing the right material is essential to obtain the expected performance. The main structure is made of mild steel for its strength, while the foldable parts are made of lightweight aluminium to increase portability. The ergonomic design pays special attention to older users or those with weaker bodies. In addition, the design of the tool reduces the physical strain experienced by those who use and operate it. The finalize result of fabrication is shown as in Fig. 5.

Fig. 5: Fabrication of Foldable Tire Changer

3.1 Simulation Result: Stress Analysis

Stress analysis aims to look at the structural strength, usability and safety of a product under various operating conditions. Finite Element Analysis (FEA) has been used by setting up an analysis in Autodesk Inventor Software which is commonly used to evaluate stress distribution, deformation and fatigue life under various loading conditions (Aryadi et al., 2021; Rahman et al., 2021 & Wang et al., 2018). By determining how a product responds to forces such as tension, compression and shear, stress analysis allows engineers to determine whether the design can sustain the expected load without failure. The procedure increases the reliability and life of the product by preventing structural defects or possible failure areas. In this design, there are three types of simulations that have been performed with the given stresses being equal to the weight of the different types of tire sizes. It is worth noting that the 6.5 kg tire is an R14 size tire, which is usually used for small cars, and the 9.1 kg tire is an R15 size tire suitable for sedan cars. On the other hand, the R20 size tire, which is often found on SUVs, weighs 15 kg. The force given is dependent on the weight of each type of tire.

a) Small Car

The graphic in Fig. 6, displays the results of a Von Mises stress study for a component, most likely a section of a folding tire changer or something comparable. The colour map displays areas of low to high tension, where blue indicates low stress and red indicates excessive stress. The blue patches show that most of the component is under very little stress, which is great because they are well within the material's safety limits. When external forces, such as the weight of a tire, exert influence on specific contact points, the material is compelled to resist deformation, resulting in localized peaks of stress. Furthermore, abrupt corners, sudden transitions in cross-sectional geometry, or regions characterized by thin walls disrupt the uniform flow of stress, functioning as stress concentrators that exacerbate tension (Leclerc & Pellegrino, 2019).

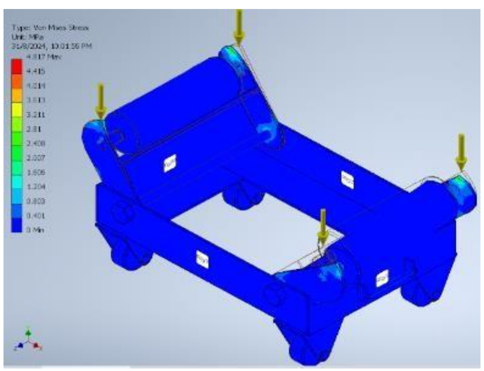

Fig. 6: Stress analysis for tire size 175/65 R14 with 6.5kg weight

The variations in material thickness and stiffness also significantly affect the distribution of stress, with thinner or more pliable sections typically exhibiting elevated stress levels (Liu et al., 2015 & Marcián et al., 2019). Interactions at contact points with adjacent components, such as hinges or clamps, may introduce secondary concentrations of stress due to frictional and pressure-related effects. Although the present analysis focuses on static loading conditions, the dynamic forces encountered in practical applications due to repetitive use or impact loads may intensify these stress concentrations over time, potentially precipitating fatigue failure.

The existence of these high-stress regions does not inherently signify an impending failure; rather, it underscores opportunities for design enhancement through the reinforcement of critical regions, the smoothing of geometries, the upgrading of materials, or the implementation of improved load distribution strategies to augment the durability and safety margins of the component under operational conditions (Lee et al., 1995 & MacKenzie, 2008). The force of tire is calculated using equation (1).

$$N = m \times 9.81 \frac{m}{s^2} \quad (1)$$

Where N represents force, m is mass and 9.81m/s^2 is the acceleration due to gravity. For a tire with a m of 6.5 kg, the F is calculated to be 63.765N.

b) Sedan & MPV Car

Von Mises stress analysis is shown in Fig. 7 with a force of 9.1 kg (89.271 N). With red indicating high stress and blue indicating low stress, the colour map shows areas of low to high stress. Since the blue spots are well within the material safety limits, it indicates that most of the component is under very little stress, which is excellent. In contrast, weak points that may fail under stress are shown by the red areas, which are areas of concentrated stress. These high stress areas may require design improvements, such as reinforcement or material changes, especially near the point of load application (shown by the yellow arrows).

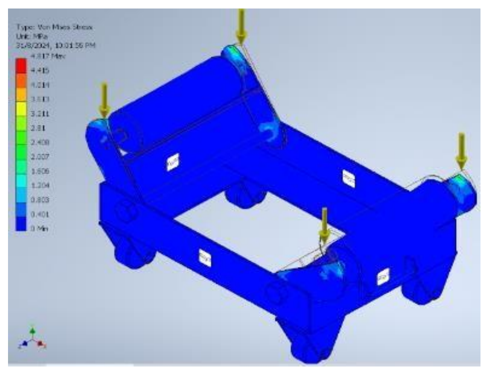

Fig. 7: Stress analysis for tire size 185/55 R15 with 9.1kg weight

The simulation outcomes of the foldable tire changer elucidate the spatial distribution of Von Mises stress under specified operational loading conditions. According to the analysis, a substantial portion of the structure exhibits minimal stress, as denoted by the prevailing blue hue in the model. This observation implies that the design is predominantly stable and possesses the capability to endure the applied forces. Nonetheless, stress concentrations are identified regions, especially around the joint areas and the curved surfaces adjacent to the upper corners of the frame, where the color transitions to green, yellow, and red. These regions signify zones of elevated stress, with the maximum Von Mises stress approximating 4.171 MPa. This value remains within a permissible threshold, provided that the material utilized possesses a yield strength exceeding the observed stress, which is generally applicable to structural steel or similar alloys. The analysis suggests that the existing design is structurally robust; however, consideration should be directed towards the high-stress regions for potential reinforcement or geometric optimization to enhance fatigue resistance and ensure prolonged durability during repeated utilization.

c) SUVs Car

The Von Mises stress analysis illustrated in Fig. 8 elucidates the stress distribution that transpires when a load of 15 kg (147.15 N) is imposed upon the design.

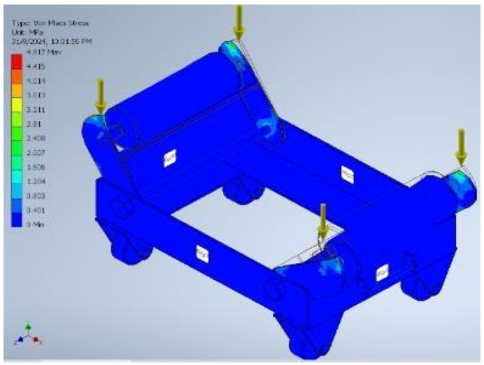

Fig. 8: Stress analysis for tire size T115/70/D14 with 15kg weight

The predominant portion of the component is depicted in blue, signifying minimal stress levels, which implies that these regions are not subjected to critical loading and the material remains well within its permissible limits. This observation indicates that the design exhibits efficiency, as it does not endure excessive stress throughout most of its structural framework. Nonetheless, elevated stress concentrations, indicated by yellow or red regions, manifest in proximity to the points where external forces are exerted, as delineated by the yellow arrows. These localized stress peaks are anticipated, given that forces inherently generate increased stresses at load-bearing junctures. Despite these concentrated stress areas, the design continues to maintain safety as the Von Mises stress does not surpass the yield strength of the material (Wheatley et al., 2020).

Furthermore, the component possesses the capability to endure even greater loads, such as those imposed by SUV tires, thereby further corroborating its structural integrity. This incorporation of low overall stress and localized, manageable high-stress regions substantiates that the design is both robust and reliable under the anticipated operating conditions (MacKenzie, 2008 & Winzer et al., 1989).

3.2 Experimental Result

This experiment was conducted to involve the time saving factor when using the Tire Folder Changer compared to completely using the traditional method in tire changing work. The respondents consisted of 30 samples of which focus to the 20–50-year-old of respondent to test the product. The time measured was from the process of removing the tire nut, removing the flat tire from the rim nut, installing the new tire on the rim nut and tying the tire nut to the rim nut.

The results indicated that the time taken when using the Folder Tire Changer as an assistance tool was significantly reduced. When compared to traditional methods, users reported a 65-70% reduction in the time and effort required to change tires, indicating a significant increase in efficiency as in Table 2. This is because the process of removing the tire from the rim nut and installing the tire back onto the rim nut is faster. More importantly, the process of inserting the tire into the screw slot does not hurt the back of the body and can be completed quickly.

Table 2: Comparison of Tire Changing Processes using tire size 185/55 R15

Age	**Fully Traditional**	**Using Tire Folder Changer**
Age 20-30 years old	12 minutes 30 seconds	8 minutes 10 seconds
Age 31-39 years old	8 minutes 10 seconds	6 minutes 20 seconds
Age 41-50 years old	10 minutes 15 seconds	7 minutes 05 seconds

4. Conclusion

Changing a flat tire is something that every driver dreads. It is a difficult job, especially for those who are not strong or have little experience. The Foldable Tire Changer solves this problem with a simple design as an assistance tool that makes changing a tire quick and easy for anyone. Unlike the heavy tools used in repair shops, this tool is portable, lightweight and can be folded small to fit in a tire storage bin. It is easy to use, does not require special skills or strength. It is safe to use and allows you to change the tire quickly. This means users do not have to wait for help or risk injury while trying to change a tire. This invention helps all drivers, especially women, the elderly or anyone who struggles with heavy tires.

Author Contributions: The research study was carried out successfully with contributions from all authors.

Conflicts of Interest: The authors declare no conflict of interest.

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