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Comparison of Standard, Tubular, and Banana Swing Arm Designs for Converting Scooter-Type Motorcycles into Electric Vehicles

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Abstract

The motorcycle population in Indonesia reaches 82% of the total number of motorized vehicles. Almost all these motorcycles are gasoline-powered vehicles, which consume a significant amount of fossil fuels and contribute to approximately 5% of greenhouse gas emissions. The government is promoting a motor vehicle electrification program to address this issue. Motorcycles are predominantly automatic scooter types, presenting a significant opportunity for the vehicle electrification program. This research aims to design a swing arm to convert automatic scooter-type motorcycles into electrically powered ones. This study created three different swing arm designs: standard type, tubular type, and banana type. In this research, stress analysis was conducted on these three swing arms under a load of 70kg. The results indicate that the banana-type swing arm is the best design due to its superior strength and lighter weight. The designed banana swing arm has a weight of only 4.37 kg, experiences von Mises stress of 43.93 MPa, displacement of 0.2469 mm, and a safety factor of 4.71

Keywords*:* *motorcycle; electrification; swing arm; stress analysis*

1. Introduction

According to the Indonesian National Police, the population of motorized vehicles in Indonesia as of December 31, 2022, was 152.51 million units. Among this total number of motorized vehicles, motorcycles dominated at 82%, approximately 126.99 million units (Sadya, 2023). Motorcycles remain a popular choice among many Indonesian people due to their simplicity, ease of navigating traffic congestion, as well as their lower purchase price and operational costs.

Nearly all motorcycles in Indonesia are gasoline-fueled, which is a fossil fuel. Transportation accounts for 42.72% of national energy consumption (Kusnandar, 2022). On the other hand, transportation also contributes about 5% of the total greenhouse gas emissions (Departemen Perhubungan, 2013). The substantial consumption of fossil fuels contrasts with Indonesia's limited oil reserves, estimated to last only about 15 years (Antara News, 2022). Therefore, efforts must be made to reduce the reliance on oil-based energy consumption. One approach is to replace oil-fueled vehicles with electric-powered vehicles.

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Currently, the population of electric motorcycles constitutes only 0.01% when compared to the total population of motorcycles (Bisnis Tempo, 2022). This situation has prompted the government to subsidize 7 million Indonesian Rupiah for 200 thousand new electric motorcycles and 5,000 units for converting gasoline motorcycles to electric ones (Bisnis Tempo, 2023). Several studies on electric vehicles have been conducted. Research by Khande et al. provides an overview of an electric scooter and its various components (Khande et al., 2020). In another study, converting 2-stroke engine scooters to electric ones incurred lower costs, approximately 17% of the price of a new electric scooter in India (Harris et al., 2021). Additionally, various studies have been carried out in designing the frame of electric motorcycles to achieve a chassis design with suitable strength (Konada & Suman, 2020; Nugraha et al., 2020; Rege et al., 2017). Research on swing arm design for electric sport-type motorcycles has also been conducted (Diogo & Ramos, 2016; Shinde & Nagargoje, 2022; Spanoudakis et al., 2020; Swathikrishnan et al., 2019).

The population of automatic scooter-type motorcycles in Indonesia holds the most significant percentage, as evidenced by the sales of automatic scooter-type motorcycles from January to May 2023, reaching 54.04% compared to other types of motorcycles (Kristianto, 2023). The substantial population of automatic scooter-type motorcycles presents an

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Table 1. Motorcycle specification

Brand / Type / Manufacturing Year	**Yamaha Mio Soul 2009**
Engine type	4 stroke 113.7 cc
Dimension (L×W×H)	1820×675×1050 mm
Wheelbase	1240 mm
Ground Clearance	130 mm
Weight	87 kg
Tire size	70/90-14 and 80/90-14

opportunity for conversion into electric-powered motorcycles. Unlike cub and sport-type motorcycles, automatic scooter-type motorcycles have an engine and wheel construction that forms a unified unit, which moves when the suspension system operates, commonly called the unit swing suspension system. Challenges arise when converting these scooters into electric-driven vehicles. By removing the engine, there is nothing to support the rear wheel, so a swing arm needs to be made.

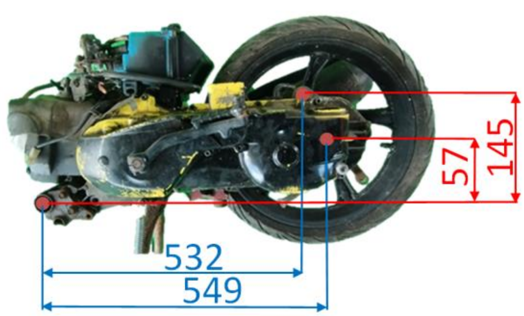
Various studies on swing arms have been conducted. A study has produced a design for a double-sided front swing arm for an electric motorcycle capable of withstanding loads while being lightweight (Shinde & Nagargoje, 2022). Other researchers also designed a swing arm for a prototype performance-geared electric motorcycle. The initial design (SA1) was modified into the second design (SA2) and further modified into the final design (SA3). The results showed that the final models demonstrated a better safety factor than the existing model (Swathikrishnan et al., 2019). In addition to two-wheeled motorcycles, research has also been conducted to design a front single-sided swing arm for three-wheeled electric motorcycles. Finite element analysis was performed to test the strength of the swing arm, which was then optimized using a topology optimization procedure. A direct comparison of the outcomes of the initial and final swing arm designs revealed a remarkable 23.2% reduction in weight (Spanoudakis et al., 2020).

Research on swing arms that has been conducted primarily designs swing arms for sport-type motorcycles and partly for three-wheeled vehicles. On the other hand, the process of converting scooter-type motorcycles into electric vehicles requires a swing arm to support the rear wheel. Based on this condition, research related to the design of scooter motorcycle swing arms is needed, where the designed swing arm is expected to be directly mounted without altering the frame construction of the scooter motorcycle. The Finite Element Method (FEM) will be used to analyze the strength of the design outcome.

2. Material and Method

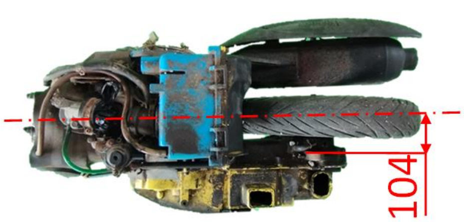
2.1. Material

The motorcycle to be converted into an electric vehicle is a 2009 Yamaha Mio Soul with specifications as outlined in Table 1. The motorcycle will be equipped with a brushless DC motor, precisely a hub drive type, rated at 48 volts and 1500 watts, fitted for a 14-inch wheel diameter.

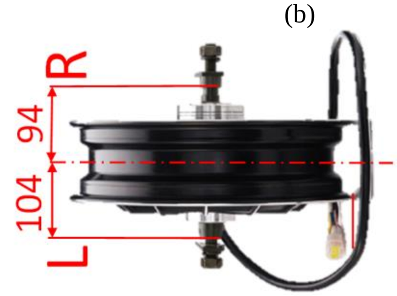


(a)

(b)



(c)



(d)

Figure 1. Main dimensions: a) Side view, b) Bottom view, c) Top view, d) BLDC motor

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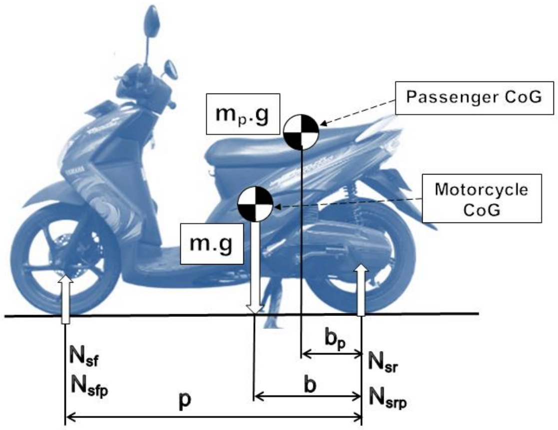

Figure 2. Load distribution on a scooter

2.2. The Measurement of The Vehicle's Main Dimensions

The research process commences with dimension measurements to determine the swing arm geometry to be produced, as depicted in Figure 1. Dimension measurements are taken on specific parts, such as the distance between the swing arm axis and the wheel axis, the swing arm axis position concerning the vehicle's centerline, and the swing arm mount position.

2.3. The Calculation of Load Distribution

Besides the main dimensions of the vehicle's parts, the vehicle's load distribution should also be measured to determine the load borne by each wheel. The vehicle's load distribution in a scooter-type motorcycle can be seen Figure 2.

The scooter intended for conversion to electric drive is weighed to determine the vehicle's mass supported by the front wheel (m_f) and rear wheel (m_r), So that the magnitude of the vehicle's mass (m) is obtained using equation 1.

Table 2. Material properties

Material	Steel
Mass Density	7.85 gr/cm3
Yield Strength	207 Mpa
Ultimate Tensile Strength	345 Mpa
Young’s Modulus	210 GPa
Poisson’s Ratio	0.3
Shear Modulus	80.7692 GPa

$$m = m_f + m_r \quad (1)$$

After obtaining the vehicle's mass, the percentage of load distribution on the front wheel $(\%\,N_{sf})$ and rear wheel $(\%\,N_{sr})$ is then calculated for the scooter using equation 2 and 3.

$$\%\,N_{sf} = \frac{m_f}{m} \times 100\% \quad (2)$$

$$\%\,N_{sr} = \frac{m_r}{m} \times 100\% \quad (3)$$

The next step is to measure the unsprung mass (m_u) of the scooter. Unsprung mass refers to the vehicle's mass that is not supported by the vehicle's suspension system. In the case of a scooter-type motorcycle, the suspension system uses a unit swing type, which includes the rear wheel, engine, and related components in the unsprung mass. Based on the percentage distribution of the vehicle's mass, unsprung mass, and gravitational force (g), the load borne by the front wheel (N_{sf}) and rear wheel (N_{sr}) can be calculated using equation 4 and 5.

$$N_{sf} = \%N_{sf} \times (m - m_u) \times g \quad (4)$$

$$N_{sr} = \%N_{sr} \times (m - m_u) \times g \quad (5)$$

Figure 1 shows that there is a different center of gravity between the motorcycle and the rider, causing a change in the load distribution on the wheels when the motorcycle is ridden. If measured from the rear wheel, (b) is the distance to the motorcycle's center of gravity,

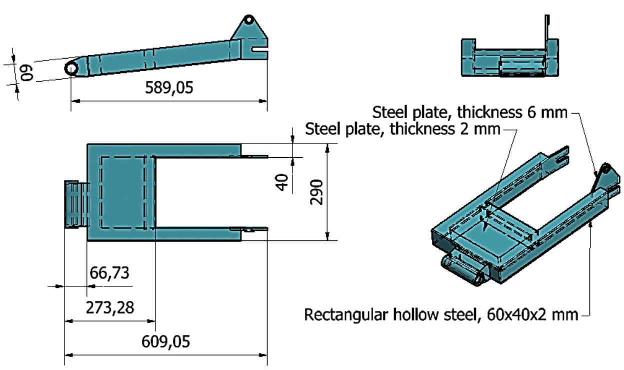

Figure 3. Standard Swing Arm

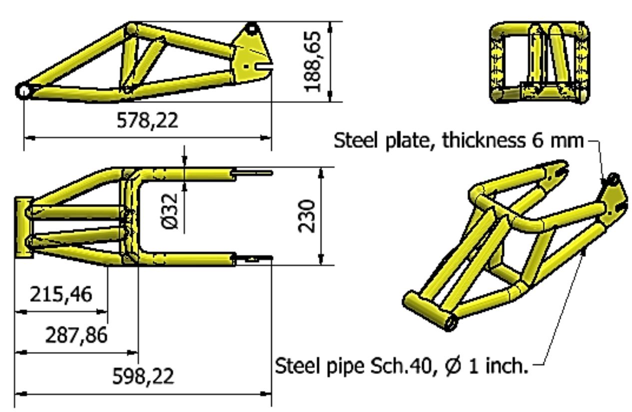

Figure 4. Tubular Swing Arm

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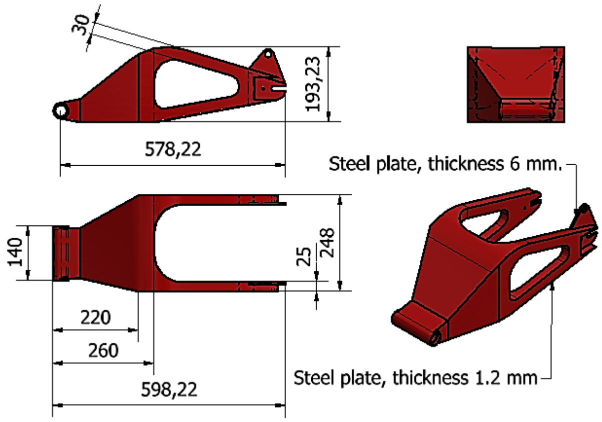

Figure 5. Banana Swing Arm

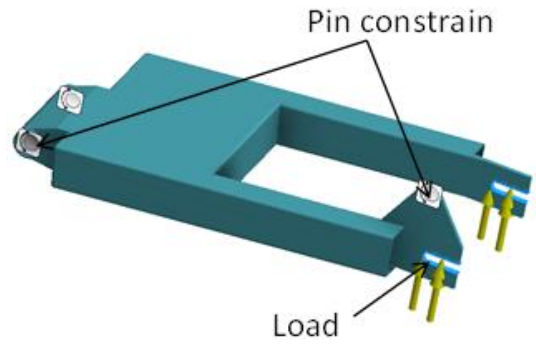

Figure 6. Load and constrain

while (b_p) is the distance to the passenger's center of gravity. The load distribution when the motorcycle is ridden on the front wheel (N_{sfp}) and rear wheel (N_{srp}) is calculated using equation 6 and 7.

$$N_{sfp} = N_{sf} + \left(\frac{b_p}{p} \times m_p x g\right) \quad (6)$$

$$N_{srp} = N_{sr} + \left(\frac{p-b_p}{p} \times m_p x g\right) \quad (7)$$

where (m_p) is the passenger's mass and (p) is the wheelbase. The load borne by the rear wheel when ridden will be used to load the designed swing arm analysis.

2.4. Design and Analysis of The Swing Arm

2.4.1. Tools

In this research, the design and analysis of the swing arm are conducted using Autodesk Inventor Professional 2022 installed on a Lenovo laptop equipped with an Intel(R) Core(TM) i7-4700MQ processor and 16 GB RAM.

2.4.2. Design Geometry

The swing arm design process begins with determining

the main dimensions obtained from measurements.

Subsequently, the creation of three designs for

comparison follows: the standard type (

Figure 3), the tubular type (Figure 4), and the banana type (Figure 5).

In the standard type design, the swing arm resembles those used in underbone and sports motorcycles, exhibiting a simple shape made of rectangular steel tubing. Following the desired construction and design, The tubular swing arm is formed from connected iron pipes. As the name suggests, the banana-type swing arm is inspired by the shape of a banana, featuring a curved form, typically made from joined sheet plates or solid materials that are machined. Banana swing arms are commonly used in high-performance motorcycles for motorsport purposes, such as in MotoGP, superbike, and supersport categories.

Figure 3 shows the construction of the standard-type swing arm, primarily composed of 60×40×2 mm rectangular hollow steel. Figure 4 illustrates the construction of the tubular-type swing arm, mainly made from Sch.40 steel pipes with a diameter of 1 inch. The banana-type swing arm is primarily constructed from steel sheet metal with a thickness of 1.2 mm, as depicted in Figure 5. These swing arms have wheel support components made of 6 mm thick steel plates.

2.4.3. Material

The material used in all swing arms is steel, with specifications outlined in Table 2.

2.4.4. Load and Constrain

Based on the vehicle's weighing results, it was found that the front wheel's load is 35.8 kg, and the rear wheel's load is 51.2 kg. Consequently, after calculating equation (1), the vehicle's mass was 87 kg. Using equations (2) and (3), the distribution percentage on the front wheel is 41.1%, while the rear wheel's load distribution percentage is 58.9%. For scooter-type vehicles, the rear wheel, engine, and related components are part of the unsprung mass, which was determined to be 43 kg through weighing. From equations (4) and (5) and the value of gravitational force (g) is 9.8 m/s^2, the loads received by the front and rear wheels are 177.6 N and 254 N, respectively. The swing arm's strength analysis is assumed under the condition of being ridden with a passenger, totaling a weight of 70 kg. The passenger's center of gravity is assumed to be 350 mm from the rear wheel. Thus, using equation (7), the load supported by the rear wheel when ridden is determined to be 740.9 N. This load will be applied to the swing arm during static analysis. In this test, the loading applied is in the form of static load on the wheel support, while the

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Table 3. Static analysis result

Properties	Swing arm type		
	Standard	Tubular	Banana
Mass (kg)	6.35	8.04	4.37
Von mises stress (MPa)	54.9	85.86	43.93
Displacement (mm)	0.421	0.5628	0.2469
Safety factor	3.77	2.41	4.71

constraints consist of pin constraints on the swing arm pivot and shock absorber pivot. The load and constraint scheme can be seen in Figure 6.

2.4.5. Meshing

In this research, the meshing settings follow the default settings of Autodesk Inventor 2022, as seen in the following Table 4.

2.5. Calculation Method

The strength of the designed swing arm is determined based on the safety factor value. The safety factor can be defined as the maximum allowable stress divided by the actual stress (Zaidani & Mas'ud, 2023). For steel material, yield strength represents the maximum allowable stress, and the stress observed is the von Mises stress. Therefore, mathematically, the safety factor can be calculated using the equation 8.

$$safety\ factor = \frac{yield\ strength}{on\ Mises\ stress} \qquad (8)$$

3. Result and Discussion

The static analysis results have revealed several vital parameters used in determining the strength of the swing arm. Parameters utilized to assess the strength of a construction include von Mises stress, displacement, and safety factors (Tayong et al., 2023). All designed swing arm variations use the same material, thereby possessing identical material properties such as mass density and yield strength. Mass density affects the weight of the designed swing arm, whereas yield strength influences its strength. With three different swing arm designs, variations in weight and strength are expected. The parameters derived from the static analysis, including mass, von Mises stress, displacement, and safety factor for the three designed swing arm types, are presented in Table 3. Table 3 shows that the standard swing arm weighs 6.35 kg, the tubular swing arm weighs 8.04 kg, and the banana swing arm weighs only 4.37 kg.

In Figure 7, Figure 8, and Figure 9, the distribution of von Mises stress is depicted. Figure 10, Figure 11, and Figure 12 display the displacement that occurs. Additionally, Figure 13, Figure 14, and Figure 15 illustrate the safety factor for the three designed types of swing arms.

The maximum von Mises stress on the standard swing arm was 54.9 MPa, on the tubular swing arm was 85.86 MPa, and on the banana swing arm was 43.93 MPa. The red color in the images indicates the maximum von Mises stress, which, for all three swing arms, is located in nearly the same area, namely, on the right-hand side connecting the left and right sides of the swing arm. This occurs because the load is applied to the wheel support area and is only supported by a shock absorber positioned on the left. The maximum von Mises stress observed in all three types of swing arms is still lower than the yield strength value of the material used.

The maximum displacement observed on the standard swing arm was 0.421 mm, on the tubular swing arm was 0.5628 mm, and on the banana swing arm was 0.2469 mm. The maximum displacement, indicated by the red color, is situated near the right-side wheel mount. This occurs because the right and left wheel mounts are

Table 4. Mesh properties

Properties		**Value**
Elements type		Solid Tetrahedral Elements
Avg. Element Size		0.1
Min. Element Size (fraction of avg. size)		0.2
Grading Factor		1.5
Max. Turn Angle		60 deg
Create Curved Mesh Elements		Yes
Number of nodes	Standard type	44029
	Tubular type	863720
	Banana type	41663
Number of elements	Standard type	21965
	Tubular type	460281
	Banana type	20917

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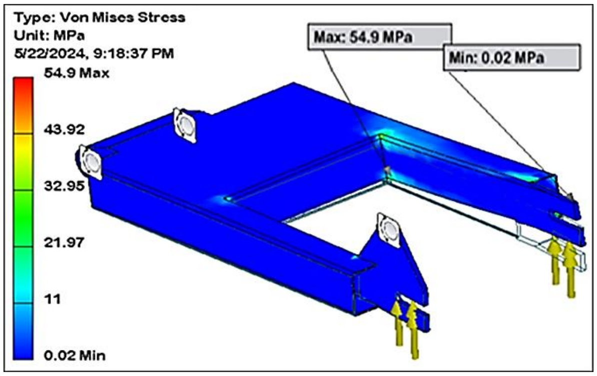

Figure 7. Von Mises stress on the standard swing arm

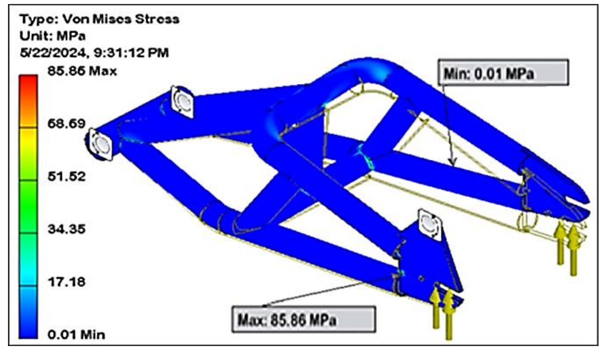

Figure 8. Von Mises stress on the tubular swing arm

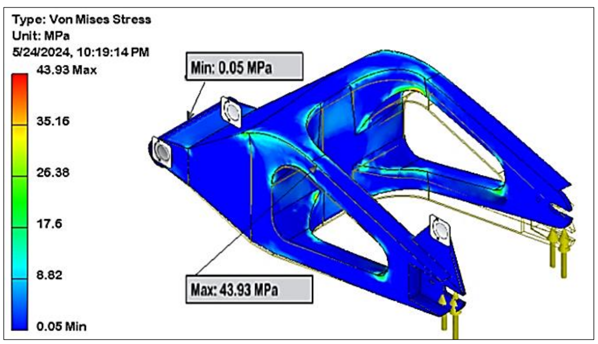

Figure 9. Von Mises stress on the banana swing arm

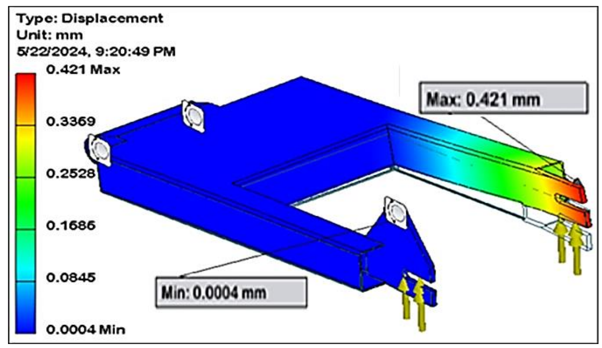

Figure 10. Displacement on the standard swing arm

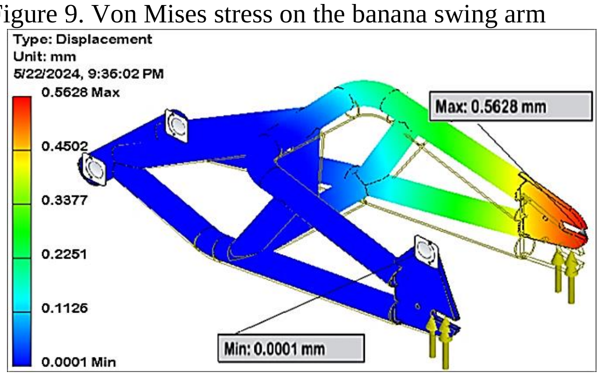

Figure 11. Displacement on the tubular swing arm

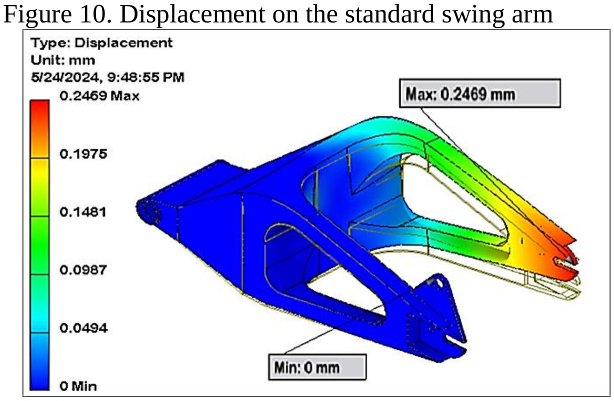

Figure 12. Displacement on the banana swing arm

the loading points, with support provided by the shock absorber on the left side only, while the right side is unsupported by a shock absorber, resulting in the maximum displacement.

The minimum safety factor observed on the standard swing arm was 3.77, on the tubular swing arm was 2.41, and on the banana swing arm was 4.71. Among the three types of swing arms designed, the banana type exhibits the highest minimum safety factor of 4.71. This indicates that the designed banana-type swing arm has the strongest structural integrity among the three variations.

Based on those factors, the banana-type swing arm was selected for the prototype to be manufactured and installed on the scooter, as depicted in Figure 16. The fabrication process of the banana-type swing arm prototype is relatively straightforward. The main part of the swing arm is made from 1.2 mm thick steel plate cut according to each section's pattern, the wheel mountings are made from 6 mm thick steel plate, and the swing arm pivot part is made from steel pipe. These parts are then joined together by welding.

4. Conclusion

Research on swing arm design for the electrification of scooter-type motorcycles has been

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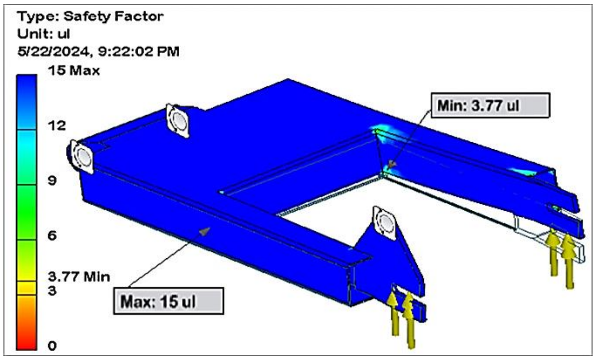

Figure 13. Safety factor on the standard swing arm

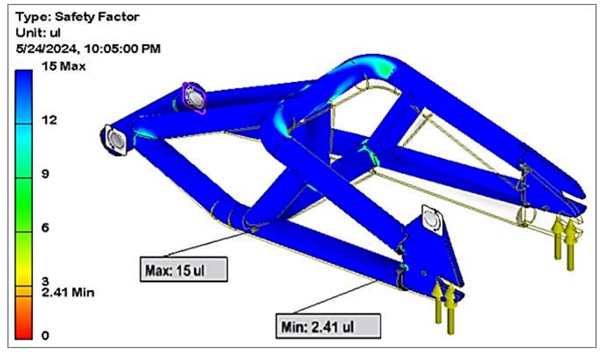

Figure 14. Safety factor on the tubular swing arm

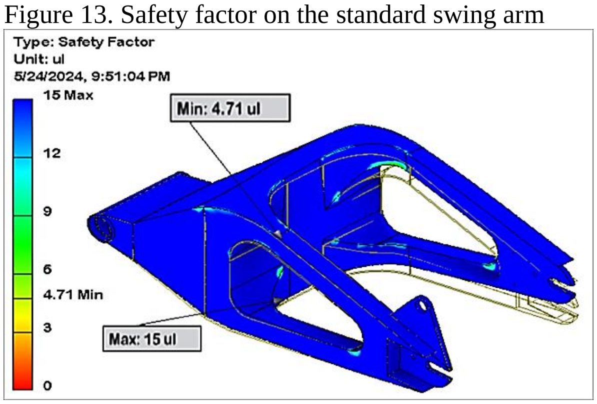

Figure 15. Safety factor on the banana swing arm

Figure 16. Banana swing arm installed on scooter

conducted. This study resulted in three different swing arm designs: the standard type, the tubular type, and the banana type. Through the comparison of these swing arm designs, it was found that the banana-type swing arm is the optimal choice as it exhibits the best safety factor of 4.71 and the lightest weight of 4.37 kg. In this banana-type swing arm, the von Mises stress observed is 43.93 MPa, and the displacement is 0.2469 mm. Based on this best design, a prototype of the swing arm has been developed for installation on the electrified motorcycle.

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