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TECHNICAL DESIGN OF ELECTRIC BICYCLES AS OPERATIONAL AIDS IN THE AIRPORT FACILITY MAINTENANCE

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Abstract

Airports, as the main gateway to air transportation in Indonesia, are increasingly expected to implement environmentally friendly practices, one of which includes the use of electric vehicles to support operational activities. This research aims to design the technical specifications of an electric bicycle as a tool for operational maintenance at airport facilities. The method employed is Research and Development (R&D) using the ADDIE model, supported by a literature review and simulation using SolidWorks 2021. The bicycle is designed with a simple, mild steel frame, a 350-watt BLDC motor, and a 48V 15Ah lithium-ion battery, with a payload capacity of up to 100 kg. Structural analysis using the Finite Element Method (FEM) shows that the design is structurally safe, with Von Mises stress and strain values remaining below the material's yield strength. The safety factor also indicates high structural reliability. The novelty of this study lies in the integration of FEM-based structural design with airport-specific operational requirements, thereby filling a gap in prior research that has primarily focused on general e-bike performance without consideration for the specific context of airport maintenance. With an estimated construction cost of IDR 8 million, the design presents a low-emission, cost-effective solution to support sustainable airport operations.

***Keywords**: electric bicycle, FEM, airport maintenance, design, sustainability*

Introduction

The growing demand for environmentally friendly transportation in airport operations has prompted the adoption of electric vehicles, including electric bicycles, as viable alternatives for operational and maintenance tasks. Compared to conventional fossil-fuelled vehicles, electric bicycles offer advantages such as zero emissions, high manoeuvrability, and lower operational costs (Elliot et al., 2018). However, adapting these bicycles to airport environments presents specific technical challenges, particularly concerning electrical reliability under intensive usage and structural durability under high operational loads.

Several airports in Indonesia have begun to embrace the concept of eco-airports, integrating renewable energy and sustainable operations (Suryan et al., 2024)for instance, Ngurah Rai International Airport has installed solar panels to power its airport facilities (Yasa Pastika & Ery Suardana, 2021) These developments align with global efforts to promote low-carbon airport operations (Sheikholeslami et al., 2023), including through the use of electric vehicles for internal logistics and infrastructure inspections (Taylor et al., 2020). Post-COVID-19 recovery efforts have further driven innovation, requiring airports to optimize resources while maintaining safety and environmental sustainability (Martadinata et al., 2021).

Routine inspections of airside facilities such as runway lighting, signage, and obstacle clearance are essential for ensuring operational safety, as mandated in the CASR Part 139 Manual of Standards. Currently, these tasks are often performed using fuel-powered vehicles, which contribute to noise and carbon emissions. A potential solution is the use of electric bicycles equipped with airport-specific adaptations, such as tool storage, front baskets, and high-load frames that can support technicians and inspection equipment.

The basic operation of an electric bicycle in this context involves activating the battery system through an ignition key, which powers the controller as the central hub of the electrical circuit. A digital display panel provides real-time information on battery status, speed, and travel distance. The pedal assist sensor (PAS) detects rider input and regulates motor assistance accordingly. If the rider ceases pedalling, the system maintains motion using stored electrical energy, ensuring uninterrupted operation. This configuration is particularly beneficial in wide-area facilities, such as airports, where mobility and operational continuity are crucial.

Prior research on electric bicycles has predominantly focused on motor and battery performance. Developed a handlebar-mounted speed controller, achieving a top speed of 27.1 km/h under a 100 kg load. Designed an electric bike using a brushless direct current (BLDC) motor and found that increasing rider weight reduced travel range due to battery strain. Meanwhile, Gilbert et al (2023) applied Finite Element Method (FEM) analysis to assess structural safety, confirming the elastic behaviour of the frame under load.

Despite these advancements, limited studies have examined the structural design of electric bicycles for specific airport maintenance applications. Therefore, this study aims to fill that gap by designing an electric bicycle using FEM analysis and technical simulation with SolidWorks. The research focuses on evaluating the frame strength, component configuration, and cost feasibility to determine whether such a design can meet the operational demands of airport facility maintenance efficiently and sustainably.

Methods

This study employs a Research and Development (R&D) approach, structured according to the ADDIE model, which comprises five key stages: Analysis, Design, Development, Implementation, and Evaluation. This model is selected due to its systematic and iterative nature, making it suitable for the design and validation of technical products, such as electric bicycles, for airport maintenance purposes. The research began with the **Analyze stage**, where a literature review and field observation were conducted to identify the operational needs of airport maintenance staff. Observations focused on mobility challenges, load requirements, inspection frequency, and the spatial characteristics of airport facilities. Relevant regulatory standards, such as CASR

Part 139, were also reviewed to ensure compliance with civil aviation maintenance protocols. In the **Design stage**, technical specifications were developed based on operational requirements. The bicycle was planned to support a payload of approximately 100 kg, utilizing a 350-watt brushless direct current (BLDC) motor, powered by a 48V 15Ah lithium-ion battery. The frame structure was made of mild steel due to its favorable strength-to-weight ratio and ease of fabrication. Two-dimensional drafting was conducted using AutoCAD 2016, followed by 3D modeling and finite element analysis (FEA) using SolidWorks 2021 to simulate mechanical stress and strain distributions under load conditions.

The **Develop stage** involved refining the design based on simulation results. The frame's stress points, deformation tendencies, and safety factors were analyzed using the Finite Element Method (FEM) (Hafeez & Krawczuk, 2024). This method enables the segmentation of the frame into discrete elements, allowing for the accurate simulation of physical loads, material behavior, and potential failure points. Boundary conditions were applied to the front and rear axle joints and bottom bracket, as these represent critical structural attachment point (Puspitasari & Nugraha, 2021; Setyoadi & Annanto, 2018).

During the implementation stage, the research proposed a prototype construction plan, which included material cost estimation, component sourcing, and assembly procedures. However, due to the scope limitation of this study, physical fabrication was not performed; instead, the focus remained on virtual validation and design optimization. Finally, the **Evaluation stage** involved interpreting the simulation outputs to determine whether the bicycle design met the required strength, durability, and safety criteria. Performance indicators, including Von Mises stress, maximum displacement, strain distribution, and factor of safety (FOS), were analyzed in detail. This methodological framework enables a rigorous and iterative development cycle, ensuring that the final product design is both technically sound and practically applicable within the context of sustainable airport operations.

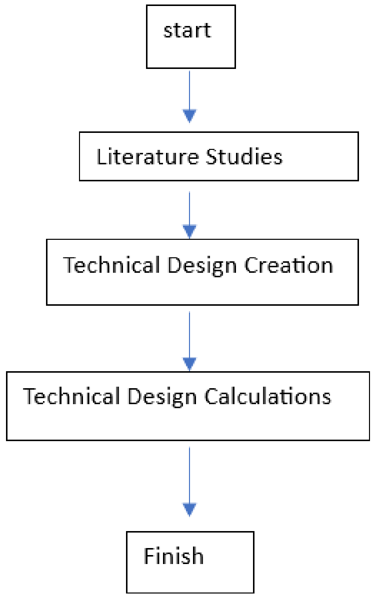

Figure 1. Research Frame Work

As illustrated in the figure above, the design process involves a comprehensive literature review and the utilization of SolidWorks software to support technical design computations.

Results And Discussions

This research uses the concept of design research and analysis using the finite element method where to create a design using data taken from the bicycle design plan taken, namely a simple commuter bicycle with a lady bike type material structure with the following dimensions:

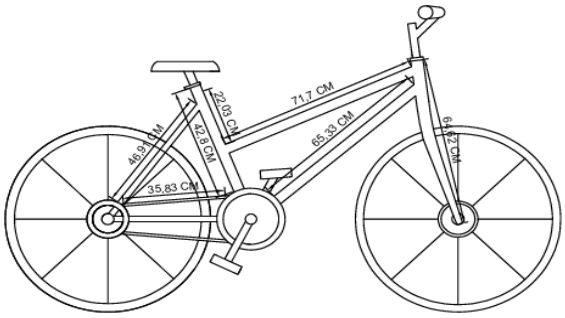

Figure 2. Bicycle Design

The 2D design drawing of this bicycle was created using AutoCAD 2016, which is based on the design of most existing bicycles on the market (Hosseini et al., 2024). With a mild steel base, which is considered a lightweight material. The design of the electric bicycle to be made is intended for use as a means of transportation in maintaining equipment on airport airside facilities. The frame is designed to carry a load of approximately 100 kg.

Based on references obtained from journals and articles related to the theme of writing, a drawing is made in the form of a design using the SolidWorks 2021 application. Then the design drawings are as follows:

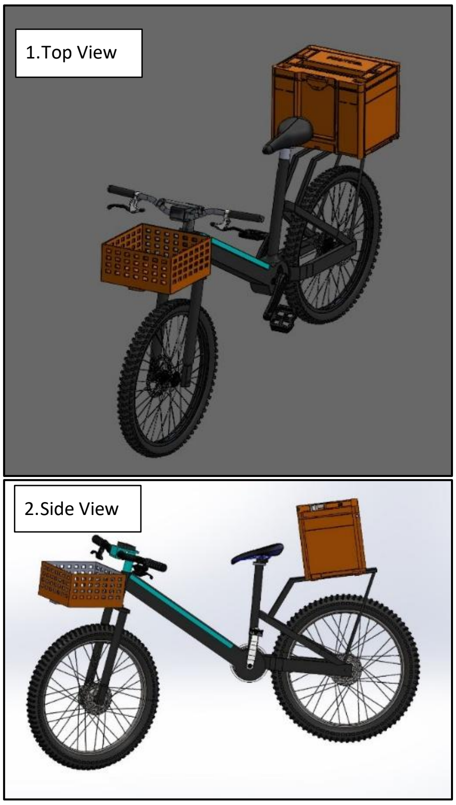

Figure 3. Top View Design

This electric bicycle design will use a BLDC motor mounted on the front wheel. The goal is that if the bicycle battery runs out, the bicycle can still be pedaled easily (Setiadanu et al., 2021). Researchers assume that an electric bicycle with a front-wheel drive will have several advantages, including being more stable on the road, easier to install, easier to control during the rainy season, and more affordable in maintenance costs (Gupta et al., 2023). The design of the electric bicycle is made as minimalist as possible, with specifications and costs that are considered cheap. With this design, it has technical specifications: a) Type of Bike: Simple MTB Bike, b) Motor: 350 Watt BLDC, c) Battery: Lithium-ion 48V 15Ah (With a range of 30-40km), d) Front Basket: For carrying light equipment, e) Brakes: Linked to the Jengki bike design. With an estimated cost of around Rp 8 million, some simple calculations used in this design aim to provide a safety value in driving. To note that the above design has the following data, material: mild steel, mass: 75958.07 gr = 76 kg, volume: 9928.89 cm^3 = 0.992889 m^3, surface Area = 9570.07 cm^2 = 0957007 m^2. From here it can be determined, density: m: v, then 76 kg : 0.992889 m^3 = 76 kg /m^3. Center of mass (cm), X = - 1.89, Y = 1.70, Z = 129.8.

Then the axis of inertia and moment of inertia can be determined:

Ix = (0.00, 0.12, 0.99) Px = 16716446.84
Iy = (0.00, -0.99, 0.12) Py = 88789067.07
Iz = (1.00, 0.00, 0.00) Pz = 102789087.04

Momen inersia where is (grams * square centimeters). Taken at the center of mass and aligned with the output coordinate system.

Lxx = 102788883.82 Lxy = 37994.67 Lxz = -70249.08
Lyx = 37994.67 Lyy = 87667514.89 Lyz = 8921110.39
Lzx = -70249.08 Lzy = 8921110.39 Lzz = 17838202.25

Moment of inertia I = Total mass x square distance from the axis of location : (grams * square centimetres). Taken at the output coordinate system.

Ixx = 1370628639.87 Ixy = -206423.09 Ixz = -18627921.05
Iyx = -206423.09 Iyy = 1355559060.06 Iyz = 25616566.86
Izx = -18627921.05 Izy = 25616566.86 Izz = 18329773.48.

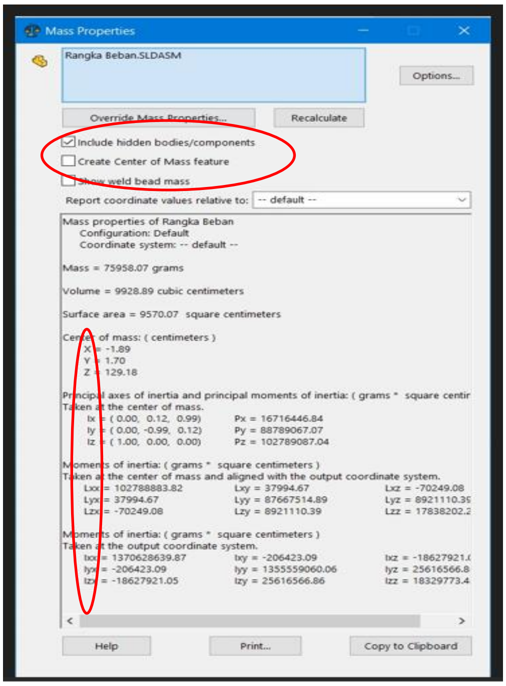

Figure 4. Solidworks Analysis Result

Based on the analysis carried out using the SolidWorks 2021 application on the design of an electric bicycle, the following data is obtained:

Table 1. Data Analysis Material Design

Name	Minimum	Maximum
Mass	75958.07 gr	75958.07 gr
Force	0	900 Newton
Mass Density	76 Kg/m^3	
Von Misses Stress	3.742e+06 N/m^2	4.210e+06 N/m^2
Yield Strength		6.204e+08
Elastic Modulus	100 x 10^9 N/m	100 x 10^9 N/m
Deformation scale		16.202,8

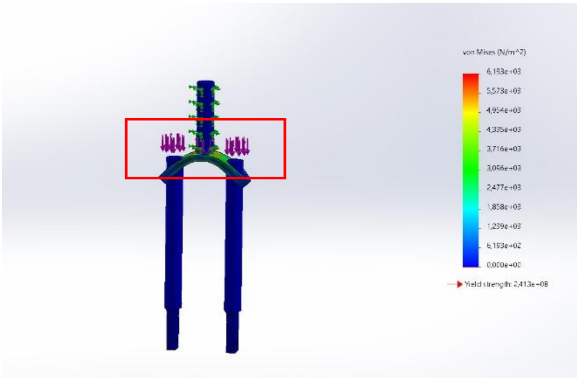

Figure 5. Shock Breaker Design Under Simulated Load

In Figure 5, the von Mises condition indicates that the yield does not depend on the normal stress or a particular shear stress, but on a third function of the principal shear stress. The largest von Mises stress occurs in the forward storage platform construction section of the bicycle shock absorber when the bicycle is stationary. The yield strength in Figure 6 is the largest at 2.413 x 10^8 N/m^2 when a load of 900 N is applied. As a result, the shock design value still meets an acceptable value, namely 615.44 cm^2, when the shock breaker is subjected to a load. It can be said that the material still retains elastic properties, as the value is below the yield strength, similarly with the frame design in Figure 7.

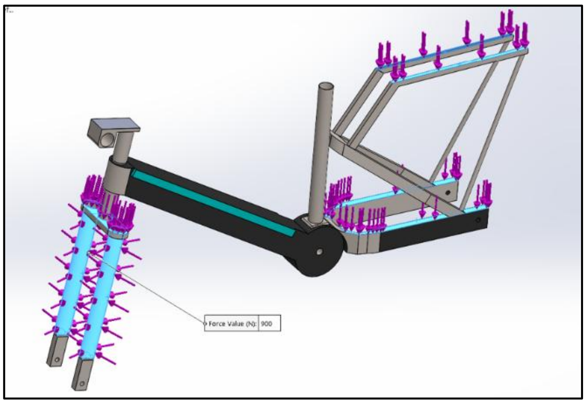

Figure 6. Simulation of Force Application on the Design Frame

The frame's loading at rest. This static loading is fixed but considered equal and divided throughout the frame. The frame structure remains capable of accommodating all the distributed loads.

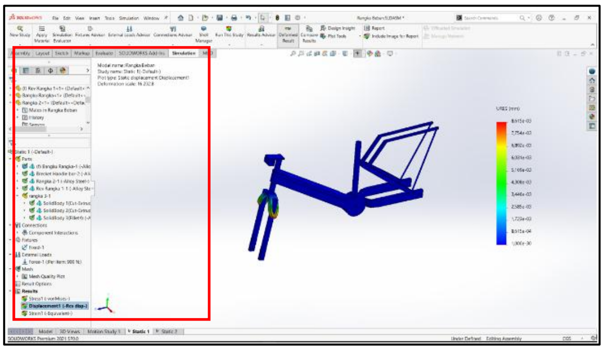

Figure 7. Strain Simulation

The results of the analysis using the finite element method are shown. The maximum displacement is 0.006892 mm. The given load causes a very large displacement, so the minimum displacement is 0.0005169 mm. The figure shows the results of the analysis where the largest von misses stress in the frame area is 9.355x10^5 N/m^2 while the minimum stress is 4.21× 10^6 N/m^2. Judging from the yield strength number for steel material, it can be said to be safe because the value is still below 6,204 x 10^8 N/m^2. The figure illustrates that the maximum strain is 1.211 × 10^{-5} N/m^2, while the minimum strain is 1.211 × 10^{-6}. In the figure, there is a deflection in the bicycle shock breaker connection design, so a more detailed design needs to be done; this happens if the bicycle is given a load. As shown in Figure 4.10, the factor of safety (FOS) value ranges from a maximum of 4,678 x 10^6 N/m^2 to a minimum of 4,678 x 10^5 N/m^2. Therefore, the higher the FOS value, the better the level of structural safety; however, if the FOS is at a minimum or low level, the level of structural safety becomes unsafe for use.

The simulation results confirm that the proposed electric bicycle design is structurally feasible for use in airport facility maintenance operations. The maximum Von Mises stress observed was 9.355×10^5 N/m², which remains significantly below the yield strength of the mild steel material (6.204×10^8 N/m²). This indicates that the frame remains in the elastic region under the intended loading conditions, confirming the safety and structural integrity of the design (Hastuti et al., 2022).

The **maximum displacement of 0.00689 mm** and **strain value of 1.211×10^{-5} N/m²** suggest that deformation is minimal and within acceptable tolerances for operational stability. These findings are consistent with Gilbert et al (2023), who demonstrated through FEM that electric bicycle frames can maintain performance under repeated operational loads and dynamic stress conditions. The conservative results further support the design's suitability for daily airport operations, particularly those involving repeated inspections and the transportation of equipment.

Additionally, the **factor of safety (FOS)** values ranging from 4.678×10^5 N/m² to 4.678×10^6 N/m² reflect a structurally safe design with a margin that accommodates unanticipated dynamic loads. According to Hotma et al (2024), a design with such safety margins is appropriate for electric vehicles that operate in variable terrain and load conditions, such as airport environments where reliability is essential. From a functional perspective, the installation of the **BLDC motor on the front wheel** offers several practical advantages: it simplifies drivetrain configuration, enhances road grip, and ensures the bicycle remains pedalable even when battery power is depleted (Setiadanu et al., 2021). The selected **48V 15Ah lithium-ion battery**, with a projected range of 30–40 km, corresponds with the performance reported by Li et al (2024), who concluded that this battery configuration can effectively support airport-level operational mobility under a 100 kg load.

Moreover, the design's estimated construction cost of **approximately IDR 8 million** provides an economically viable alternative to fossil-fueled motorcycles, which are commonly used in airport maintenance operations. With lower operational costs, minimal maintenance requirements, and zero emissions, electric bicycles such as the one proposed in this study align with the eco-airport concept promoted at facilities like Ngurah Rai International Airport (Yasa Pastika & Ery Suardana, 2021) and reflect broader green energy goals in Indonesian aviation (Ainou et al., 2023).

Nevertheless, this study has limitations. The analysis was conducted through virtual simulations only and did not include prototype fabrication or field testing. Furthermore, ergonomics, component durability, and battery degradation under long-term use were not thoroughly explored. Future research should incorporate **physical prototyping**, **user-centered evaluations**, and **lifecycle cost analysis** to ensure practical feasibility in real operational settings (Bagus Arya Dwipa et al., 2024; Pareza et al., 2020).

In summary, this study demonstrates that an electric bicycle designed with FEM-based structural validation and appropriate electrical configuration can serve as a safe, efficient, and environmentally friendly alternative for airport facility maintenance (Das et al., 2022). The model supports Indonesia's transition toward low-emission infrastructure and contributes to sustainable aviation practices in line with the Civil Aviation Safety Regulation standards (Morozov & Fedotova, 2020).

Conclusion

This study confirms that electric bicycles hold significant potential as an environmentally friendly and efficient transportation alternative for airport facility maintenance. Through the application of the Finite Element Method (FEM) and technical modeling using SolidWorks, the designed frame structure demonstrated structural feasibility, with all critical stress and deformation parameters remaining below the material's yield strength (Zdraveski et al., 2016). The maximum von Mises stress value of

9.355×10^5 N/m² and a low displacement value indicate that the structure operates safely within its elastic range under a simulated operational load of 900 N. The factor of safety (FOS), ranging from 4.678×10^5 to 4.678×10^6 N/m², further validates the robustness of the frame design, ensuring reliability for daily airport operations. Functionally, the use of a 350W BLDC front-wheel motor and a 48V 15Ah lithium-ion battery provides sufficient power and range (30–40 km) for routine maintenance activities. At the same time, the total construction cost remains economically viable at approximately IDR 8 million. In alignment with Indonesia's eco-airport initiatives and civil aviation safety regulations, the proposed design can contribute to operational efficiency and reduced emissions in airport environments. Nonetheless, further research is recommended to include physical prototyping, ergonomic assessment, and long-term durability testing to evaluate real-world performance and user acceptability comprehensively.

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