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Strength Analysis of Rollers and Supports of a Hydraulic Dynamometer Chassis Using Finite Element Method

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Abstract

The measuring performance tool of electric motorcycle in Indonesia is limited, which in contrast to the rapid development of motorcycle technology. Therefore, this study aims to develop a chassis hydraulic dynamometer as a tool to measure the mechanical parameters of electric motorcycles This research was conducted using an experimental method based on simulations with SolidWorks 2022 software as the simulation tool for roller and support strength. Simulation was performed on variations 35 mm, 40 mm, and 45 mm shaft diameter roller, using AISI 1045 steel material. Based on calculations and simulation results, a roller with a 35 mm shaft diameter can withstand the applied external load with a maximum von Mises stress of 2,394 x 108 N/m2², a maximum strain of 7,283 x 10-4, a maximum displacement of 6,275 x 10-2 mm, and a minimum safety factor of 2.2. Based on calculations and simulation results, the roller with a 35 mm shaft diameter is safe, optimal, and efficient in terms of material usage. Therefore, a roller with a 35 mm shaft diameter and SKF UCP 207 support was selected for use on the chassis hydraulic dynamometer.

1 Introduction

A dynamometer is a tool used to test the performance of a machine by measuring its rotational speed and torque, thereby determining the machine's power [1]. Dynamometers are used to test vehicle products to identify and define their specifications before being marketed, ensuring product accountability [2]. Vehicles must undergo various tests to experimentally evaluate their performance before entering the market [3]. A chassis dynamometer enables analyses such as durability, fuel consumption, emissions, engine performance, global and component efficiency, standardized cycle emulation, and external conditions [4]. Compared to direct on- road vehicle testing, chassis dynamometers offer advantages such as lower costs and higher precision in obtaining characteristic data [5]. The chassis hydraulic dynamometer serves not only as a tool for engine performance testing but also as a simulator for forces experienced by vehicles on the road,such as wind resistance, acceleration, and inertia deceleration [6].

It also has advantages over other absorption dynamometers, such as eddy current dynamometers, DC/AC dynamometers, inertia dynamometers, and hydraulic dynamometers. These advantages include modern instrumentation and control systems, low maintenance costs, and more affordable hydraulic servo-controllers compared to eddy-current dynamometers of the same capacity [7]. The chassis hydraulic dynamometer combines high power capacity with low inertia and serves as a suitable alternative for braking systems [8].

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In line with the increasingly complex needs of the industry, dynamometers are now used not only to test internal combustion engine (gasoline) performance but also to assess the performance of electric motorcycle engines. The growing demand for dynamometer testing amidst the rapid development of electric motorcycles contrasts with the limited availability of dynamometers. Therefore, a chassis hydraulic dynamometer was designed to meet the need for testing mechanical parameters. The roller is a critical component of the chassis hydraulic dynamometer, acting as a support for the vehicle's rear wheels during testing and as an absorber of the power output from the tested electric vehicle, transferring it to the differential axle shaft. During performance testing, the roller and its support endure various loads from the tested vehicle. Thus, validation is necessary to analyze the conditions and impacts on the roller and its support to establish safety standards for using the chassis hydraulic dynamometer. With advanced design tools and computational engineering techniques using CAE software, analyses can be conducted quickly, accurately, and precisely.

2 Research Methods

This study is an experimental, simulation-based research project where the design was created using Autodesk Inventor 2022 software and then simulated using SolidWorks 2022 to analyze von Mises stress, strain, displacement, and the resulting safety factor from the rotation of the roller and its support. Three roller and support designs were modeled using Autodesk Inventor 2022: a roller shaft diameter with SKF UCP 207 support, a roller shaft diameter of 40 mm with SKF UCP 208 support, and a roller shaft diameter of 45 mm with SKF UCP 209 support. The roller material used is AISI 1045 steel, which consists of 0.42–0.50% carbon (C), 0.17–0.37% silicon (Si), 0.50–0.80% manganese (Mn), ≤0.25% copper (Cu), ≤0.25% chromium (Cr), ≤0.30% nickel (Ni), and the remainder iron (Fe) (Zhao et al., 2023). AISI 1045 steel has a yield strength of 530 MPa (Iski et al., 2022). The roller features two designs: Design 1 is based on the dimensional measurements of a prototype with a shaft diameter of 35 mm, while Design 2 is derived from mathematical calculation to determine a safe, optimal, and efficient shaft diameter, building upon Design 1. The format is the same as previous section. In this section, you can write methods you use in your research. If it is not experimental (numerical or simulation) you can change the section name corresponding to your methods. If you use a specific material in your research, you should explain clearly the materials such as the specification, where you get it and important information. In terms of figure, this should be presented as shown below.

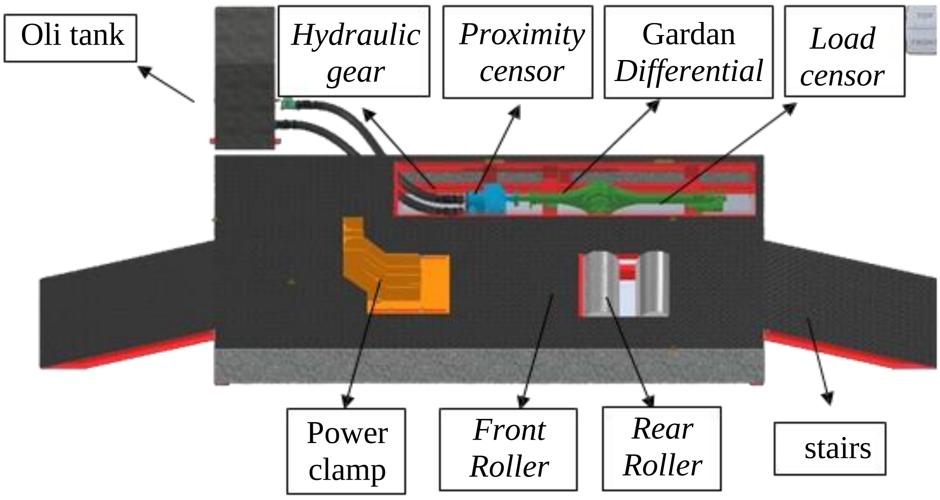

Figure 1. Prototype Chassis Hydraulic Dynamometer

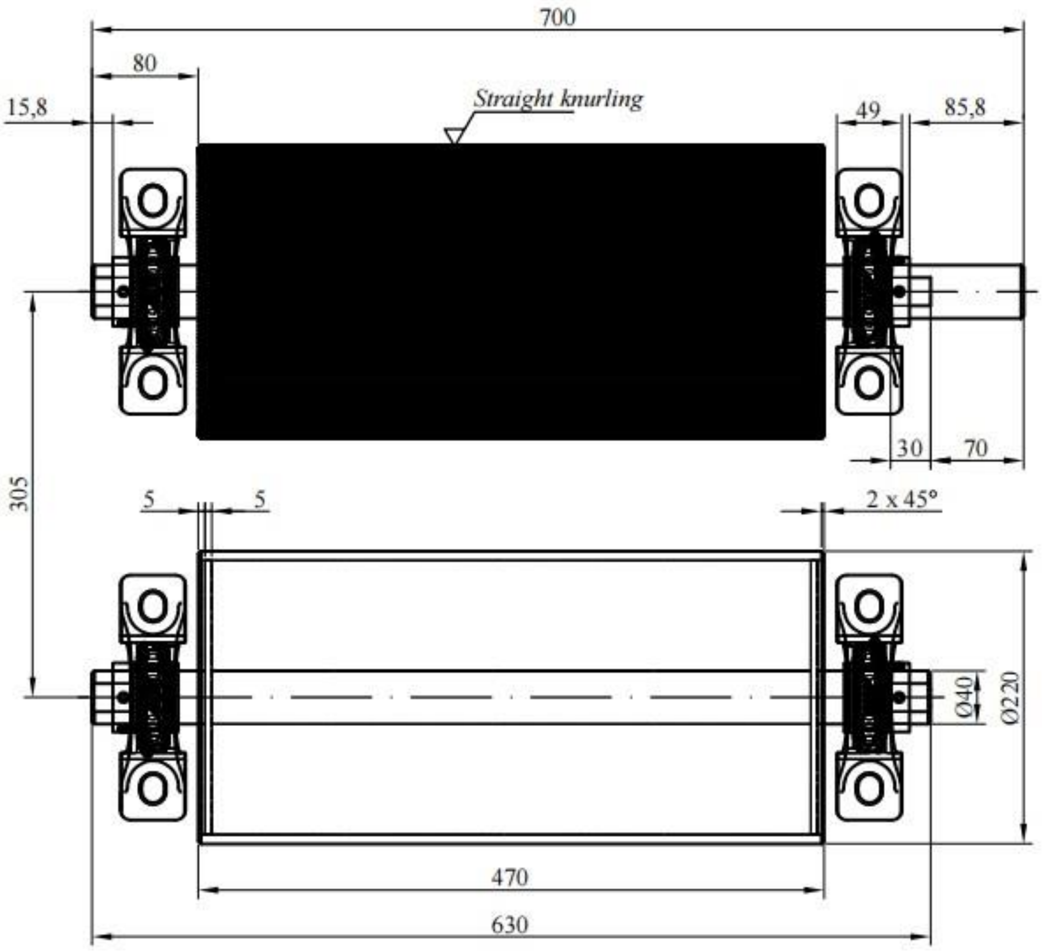

Figure 2. Design roller and support chassis hydraulic dynamometer

The research began with measurements of the chassis hydraulic dynamometer prototype, followed by the design process using Autodesk Inventor 2022 software. Subsequently, simulations were conducted using SolidWorks 2022 software. The loading parameters were derived from the Savart S1 electric motorcycle, with a total force load of 586.8 N on each roller, a torque load of 250 Nm, a centrifugal load of 3025 rpm, and a gravitational load of 9.81 m/s^2. The research results were used as a reference to obtain the best design and dimensions, aiming to develop rollers and supports for the chassis hydraulic dynamometer that meet safety, reliability, and comfort standards in transmitting power generated by the electric motorcycle engine under testing. The study also emphasizes the importance of selecting the most optimal and safe design and material for practical use.

3 Result and Discussion

Meshing is the process of subdividing a geometric model into smaller, interconnected parts called cells or nodes [6]. The more numerous or smaller the cells in the simulated area, the higher the precision of the simulation results [9]. Mesh convergence analysis is performed iteratively to select the most appropriate mesh size for finite element simulations, ensuring that the results are accurate and reliable while minimizing the number of elements used [10]. The mesh convergence study in this research refers to the study conducted by Iski et al. [11]. Mesh validation aims to achieve the best and most accurate results, with the validated mesh serving as a reference for simulations. According to numerical standards, a good mesh has an error value of less than 5% [12]. The error can be calculated using the following formula in Equation (1).

$$Error = \left(\frac{Simulation\ Data - Reference\ Data}{Reference\ Data}\right) x100\% \quad (1)$$

$$Error_{mesh\ 4} = \left(\frac{48,1 - 47,77}{47,77}\right) x100\%$$

$$Error_{mesh\ 4} = 0,7\%$$

Table 1. The simulation results of the crankshaft of the Honda GL Neotech for each mesh

***Mesh Size* (mm)**	***Max Von mises Stress* (MPa)**		***Displacement* (mm)**		***Safety factor***	
	Value	***GAP***	**Value**	***GAP***	**Value**	***GAP***
8	29,84	-37,5%	0,001845	-27,4%	1,78	-84%
4	48,1	0,7%	0,002471	-2,8%	11,02	-1%
2	60,05	25,7%	0,002022	-20,5%	8,26	-26%
1	115,1	140,9%	0,002062	-18,9%	4,6	-59%
Desain (Iski *et al.*, 2022)	47,77	0,0	0,002543	0,0	11,11	0,0

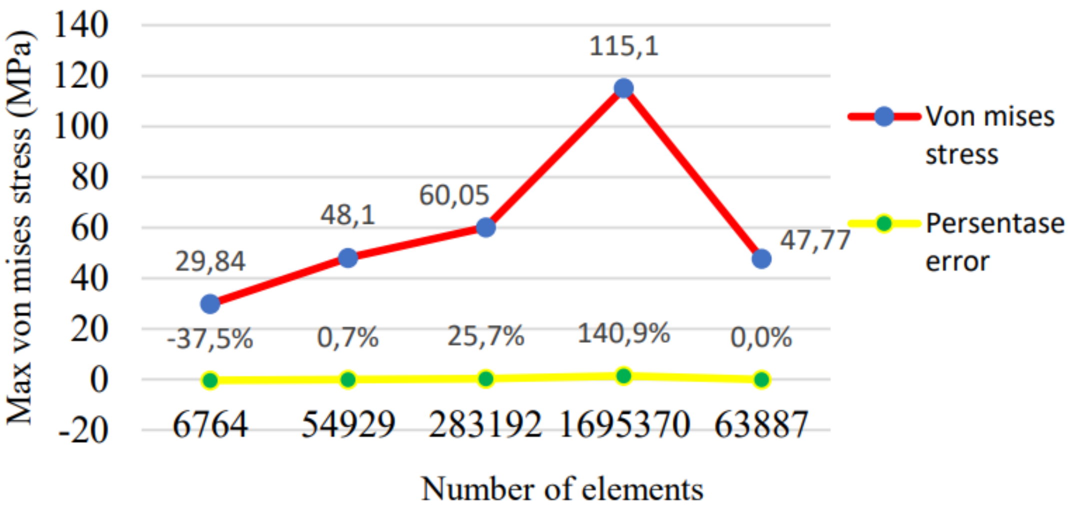

Figure 3. Convergence mesh graph

Based on the table and graph, the mesh size that most closely matches the results of the study conducted by [12], or where the error or deviation in von Mises stress, displacement, and safety factor is ≤ 5%, is the 4 mm mesh. Therefore, it can be concluded that the 4 mm mesh is valid and convergent. Consequently, in this study, a 4 mm mesh is used to analyze the strength of the roller and support of the chassis hydraulic dynamometer test.

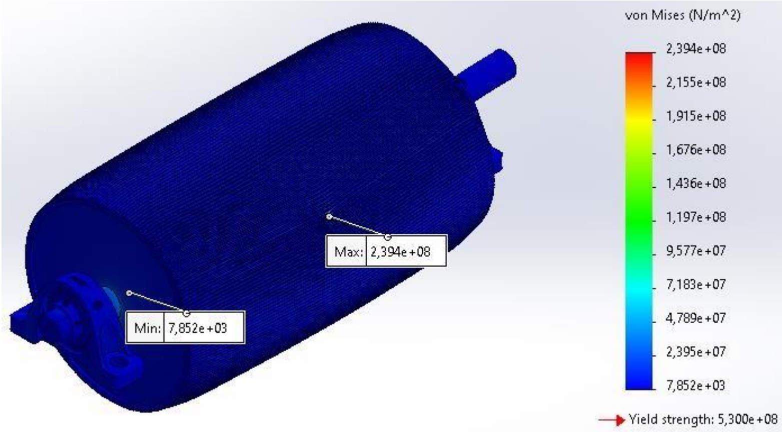

Figure 4. Von mises Von Mises Stress of the front roller and support with a shaft diameter of 35 mm

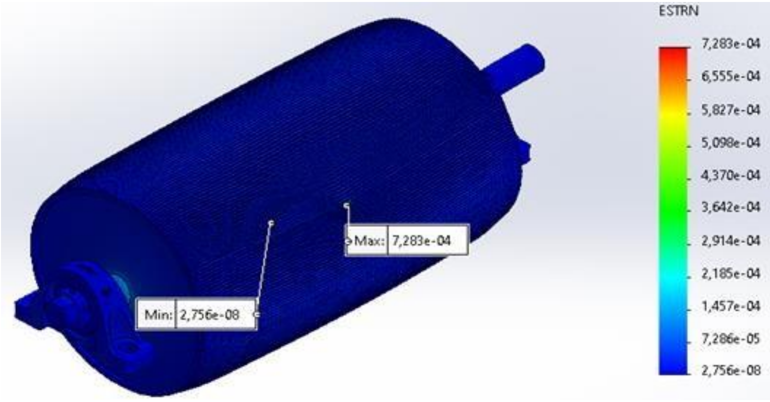

Figure 5. Strain of the front roller and support with a shaft diameter of 35 mm

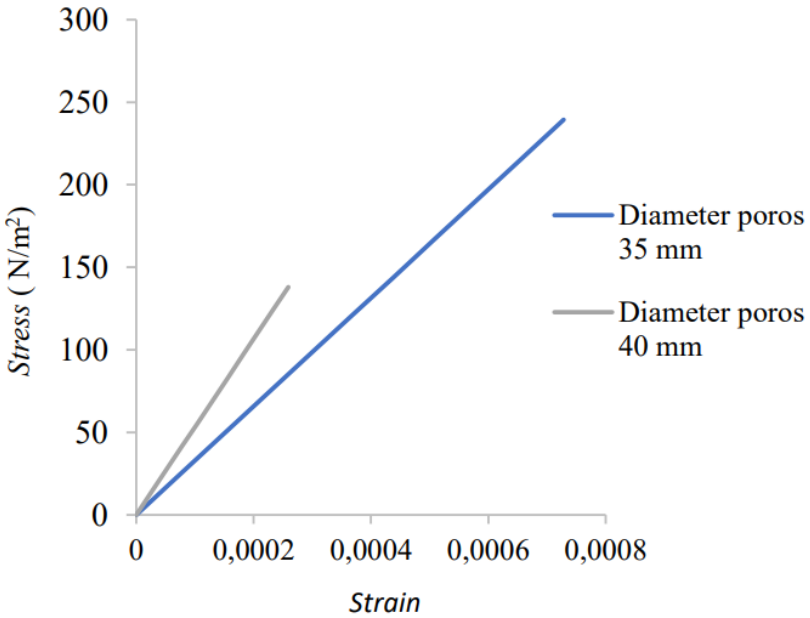

Figure 6. Comparison of stress and strain on the front roller

Based on the graph, the rollers and supports with shaft diameters of 35 mm, 40 mm, and 45 mm undergo elastic deformation because the maximum stress experienced is below the yield strength of the roller material, which is AISI 1045 steel with a yield strength of 530 MPa. As a result, the rollers and supports experience a temporary change in shape. Once the load is removed, the front roller will return to its original shape.

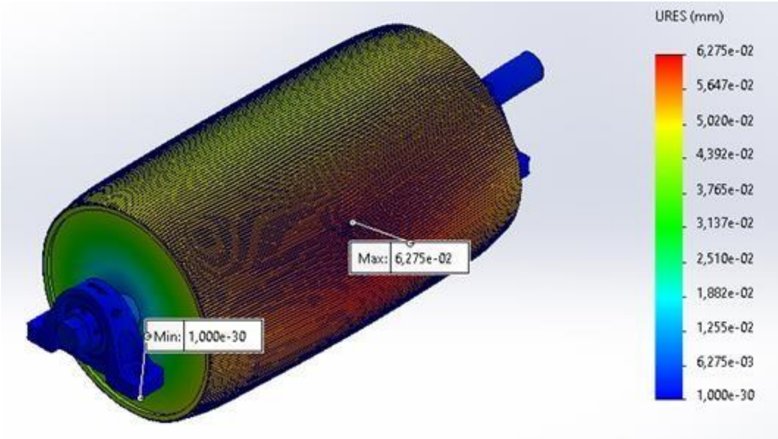

Figure 7. Displacement of the front roller and support with a shaft diameter of 35 mm

The largest displacement occurring in the three shaft diameter sizes of the front roller will not have a significant impact on the performance measurement results. This is because the maximum displacement value is extremely small, only 0.005282 mm. Therefore, it can be concluded that the displacement in all three roller and support designs is considered safe.

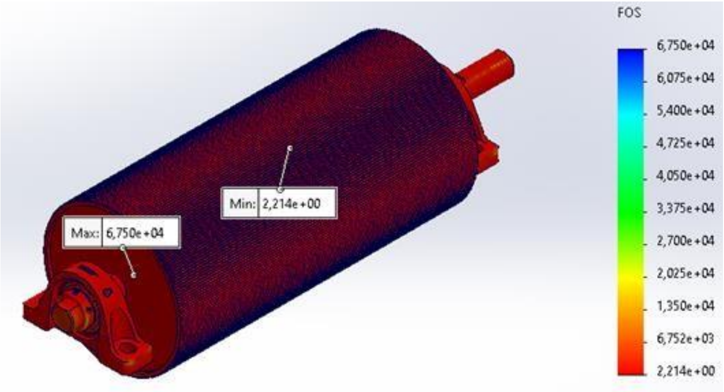

Figure 8. Fctor of safety the front roller and support with a shaft diameter of 35 mm

Structures subjected to dynamic loads must have a safety factor of 2–3 [13]. The safety factor of the front roller with a 35 mm shaft diameter and SKF UCP 208 support yields a minimum safety factor of 2.2, indicating that the roller with a 35 mm shaft diameter and SKF UCP 208 support meets the applicable safety standards.

Table 2. Simulation results of the front roller and support

Roller and support		Von Mises Stress (N/m^2)	Strain	Displacement (mm)	Safety Factor
Diameter 35 mm	Max	2,394 x 10^8	7,283 x 10^{-4}	6,275 x 10^{-2}	2,2
	Min	7,852 x 10^3	2,756 x 10^{-8}	1,000 x 10^{-30}	
Diameter 40 mm	Max	1,38 x 10^8	2,952 x 10^{-4}	3,487 x 10^{-2}	3,8
	Min	3,669 x 10^3	2,352 x 10^{-8}	1,000 x 10^{-30}	

The simulation results indicate that the maximum values of von Mises stress, strain, displacement, and safety factor decrease as the shaft diameter of the roller increases. Rollers with larger shaft diameters demonstrate better mechanical performance and a higher safety margin. Based on the simulation results and calculations, the roller design with a 35 mm shaft diameter and SKF UCP 207 support was chosen because it has been proven to be safe and sufficiently strong to withstand the load of the tested electric motorcycle. Additionally, it is more material-efficient due to its smaller size and mass.

4 Conclusion

The simulation results show that the maximum values of von Mises stress, strain, displacement, and safety factor decrease as the roller shaft diameter increases. Rollers with larger shaft diameters show better mechanical performance and higher safety margins. Based on the simulation results and calculations, the roller design with a shaft diameter of 35 mm and SKF UCP 207 support was chosen because it has been proven to be safe and strong enough to withstand the load of the electric motorcycle being tested, and is more efficient in the use of materials because it has a smaller size and mass.

5 Acknowledgement

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