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A Generative Approach to Mass Optimization of Wheel Assembly

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Abstract. Generative design in CAD software, driven by cloud computing and AI, optimises 3D models for various industries. It focuses on improving manufacturability and reducing mass within design and cost constraints. This research targets minimising the mass of the wheel assembly, including A-Arms, Upright, Wheel Hub, Brake caliper, and Rims. Mass minimization is essential as a lighter wheel assembly contributes in improving fuel efficiency, braking performance and promotes sustainability as it reduces carbon emissions. The components designed in Solid Works are optimised using Fusion 360, considering input parameters, materials, design constraints, and manufacturing requirements. Finite Element Analysis (FEA) in ANSYS under Static Structural conditions evaluates the feasibility of the design. On comparing the initial and final models respectively based on parameters like Factor of Safety, and Von Mises stress with the prime objective being mass optimization, a 27.94% mass reduction of the assembly is achieved as a result of generative design while maintaining the structural integrity and improving the performance characteristics of the vehicle witnessed a remarkable change.

Keywords. Generative design, mass optimization, wheel assembly, factor of safety, Von Mises stress, deformation, finite element analysis, Fusion 360

1. Introduction

The designing phase is of paramount importance to any product that is being developed [1]. It plays a huge role in the reduction of costs, improving quality, providing a competitive advantage, and providing room for innovation, thereby serving as one of the major processes involved in product development [2]. CAD software possesses the capability of sketching, modeling, and the subsequent analysis of various shapes and components used in real-world applications [3]. The Generative design integrated into the conventional CAD software brings about the possibility of making amendments in the early stages of the design process rather than being employed only in making a final product [4]. Generative design enables the designer to conceptually design the product and subsequently develop it, thereby enabling a wide range of design options based on the (i) functioning of the component (ii) user-defined constraints (iii) cost (iv) performance, etc. [5]. A generative engineering design based on mass reduction aims at achieving the desired outcome without compromising on the functionality,

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effectiveness, and safety of the component (i.e.) reduction in mass without any reduction in strength [6]. This paper aims to optimize the mass of a wheel assembly by utilizing generative design and thereby analyzing the model obtained based on various parameters concerning the strength and functionality of the component.

2. Materials and Methods

In this work, we are making use of Solid Works, CAD design software, to design five distinct components namely A-Arms, Upright, Wheel Hub, Brake caliper, and Rims (figure 1). We employ the robust features of Solid Works to model each part with minute detailing while adhering to industry standards. The software handles complex assemblies, thereby allowing effortlessly bringing together multiple components of the wheel assembly thus allowing an easy check for any possible interference between them.

Fusion 360 utilizes advanced algorithms to perform Generative Design (figure 1). It tends to explore various design possibilities based on specified constraints and objectives, resulting in structures that are optimized for strength, weight, and other performance criteria. It ensures that the designs are optimized for performance thereby reducing the need for extensive modifications during the later stages of product development without letting go of the structural integrity of the initial design.

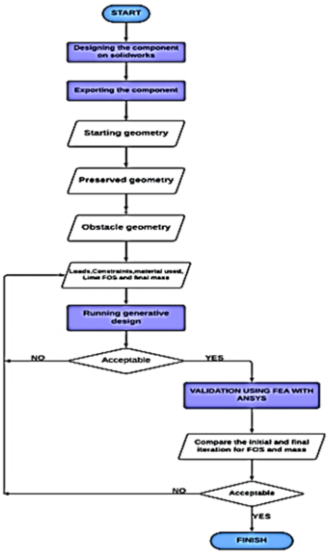

Figure 1. Flowchart.

A-arms:

A-Arms are essential components that connect the wheel assembly to the chassis. The design of the A-arms plays a pivotal role in determining the suspension characteristics of the automobile.

One preserved geometry is the area where the apex of the A-arm connects to the up- right, and the other preserved geometry is the region where it pivots about the chassis (figure 2). A cylinder-shaped region is designated as excluded geometry wherever a bolt is intended to pass through.

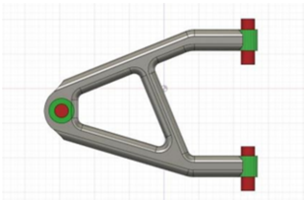

Figure 2. A-arm on Fusion 360.

Figure 3. Brake caliper on Fusion 360.

Brake Calipers:

The brake caliper is an integral part of the assembly consisting of brake pads that help in slowing the vehicle down and finally bringing it to a halt by applying pressure on the rotor. Brake calipers are instrumental in the controlled application and release of braking force within the wheel assembly. Obstacle geometry includes the cylindrical part which is present on the mounting holes for the caliper to be mounted on the wheel hub and for the brake pads to be mounted on the brake caliper and the center part of the caliper where the rotor will rotate. The brake pad is the preserve geometry (figure 3).

Rims:

Wheel Rims serve as a support structure for the tire of the vehicle, thereby playing an important role in housing the wheel assembly. Wheel rims tend to serve functional purposes related to tire support and heat dissipation. Preserved regions for the rim include the mounting holes on which the wheel hub will be attached and the outer circumference of the rim which will help in maintaining the shape of the rim. Obstacle geometry includes the cylindrical part which passes through the mounting holes (figure 4).

Upright:

The upright is a support structure that connects the caliper, A-Arms, and wheel hub. The caster angle that helps the steering to recenter, is defined by the design of the up- right. The preserved regions include the upper and lower areas where the A-arms attach to the upright, which can be further optimized. Another preserved geometry is the central region housing the wheel hub and bearing. Additionally, the mounting points for the caliper and tie rod are considered preserved (figure 5). The excluded geometry comprises a cylindrical zone at the upright center for the wheel hub, a rectangular area between the A-arm mounts, and the space behind the caliper mounting region. Optimization can be performed based on these defined regions.

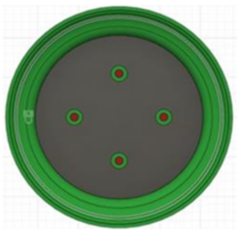

Figure 4. Rims on fusion 360.

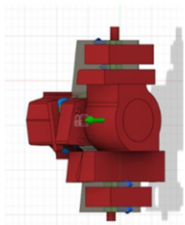

Figure 5. Upright on Fusion 360.

Wheel Hub:

The Wheel Hub connects the gap between the wheel and drive shaft and houses the Up- right and Brake rotor. It minimizes friction and facilitates smooth wheel movement.

The red cylindrical part is the obstacle geometry it was given such that those parts are used to mount the wheels and rotor to the wheel hub and the central cylinder is where the axle passes. The green parts are the preserved geometry to ensure the object appears as intended. The yellow signifies the starting geometry that allows fusion to understand the initial and base geometry and helps to create complex shapes and designs with accuracy.

3. Static Structural Analysis on ANSYS

ANSYS is powerful and user-friendly software suitable for performing engineering simulations that incorporate structural analysis, fluid dynamics, heat transfer, electromagnetics, and various other fields. The software provides advanced meshing solutions using different tools and algorithms thereby generating meshes of good quality which ensures the accuracy of the results obtained. In this project, we are using ANSYS as a tool to compare the parameters namely Factor of Safety and Von-Mises Stress with the initially designed model in Solid Works and analyses the effectiveness of the Generative Design model (figure 1).

The force on the A-arms acts parallel to the direction of the rod. Hence the force will always be in either compression or tension. The chassis mounting point is given as the fixed support. The force acts from the apex point. Hydraulic force which is transmitted by the brake fluid acts on the brake pads which push them towards each other thereby clamping on the rotor. The mounting point for the caliper is present on the upright. The radial force from the ground acts on the “curved part of the rim”. The bolts that are used to connect the rims to the wheel hubs produce a clamping force on the face of the rims. The rim mounting points are chosen as the fixed support. The force from the tire while accelerating is transmitted to the A-arms through the A-arm mounting points on the uprights. The circular slot where the bearing sits is chosen as fixed support and the bearing pressure acts on the circular wall. Since the caliper is mounted on the upright, it produces a moment at the mounting point. The force from the tie rod causes a bending moment at the steering arm. The major forces acting on the wheel hubs are the forces due to the rotor and the force to rotate the wheel. A moment is applied where the brake rotor is mounted on the wheel hub and force is applied on the location where the rims are mounted to the wheel hubs. The location where the wheel hubs fit in the upright is chosen as fixed support.

4. Results & Discussion

Minimizing mass in an automobile is crucial as mass directly influences the (i) performance characteristics of a vehicle. Reduction in mass results in better handling and performance of the vehicle. Acceleration, Deceleration, and changing of directions are much easier and quicker in mass-optimized vehicles when compared with their heavier counterparts. This enhances the overall driving experience thereby enabling the vehicle to be more responsive and maneuverable. The overall safety of the vehicle is improved since the likelihood of accidents and collisions is drastically minimized since stopping distance is reduced because of the lowered mass. (ii) Fuel efficiency. A mass-optimized car can achieve better fuel efficiency thereby contributing to lesser greenhouse gas emissions and a reduced operating cost for the user. Owing to environmental norms and concerns, it is mandatory for automobile manufacturers to design vehicles that are environmentally friendly, fuel-efficient, and also have lower emissions. (iii) Sustainability Electric vehicles contribute to sustainability by reducing carbon footprint, extending vehicle lifespan on account of having fewer moving parts when compared to their traditional counter- parts, etc. In this context minimizing mass is crucial for extending the vehicle's range on a single charge.

Traditional methods of mass reduction include (i) Material selection. Using a light-weight material like Aluminum, Aluminum Alloys, and Carbon Fiber composites in place of conventional metal components like steel, cast iron, etc., or using high-strength steel parts for the creation of a lighter component without compromising the structural integrity. (ii) Component Integration combining functions within a single component can reduce the overall number of parts and, consequently, the weight of the vehicle. Integrating functions within a single component will result in the reduction of the overall number of parts in the vehicle thereby leading to the ultimate goal of mass reduction. For example, Monocoque chassis a unitary construction is a structural design for automobiles where the body and chassis form a single integrated structure. It integrates the function of the car's chassis and its frame into a single component thereby leading to a reduction in mass subsequently leading to better performance and optimised fuel consumption.

Generative design involves the use of artificial intelligence, machine learning algorithms, computational methods, and iterative processes. This methodology enables users to generate and explore a variety of design options. It facilitates product design to create innovative and optimized solutions. This approach is especially beneficial in industries such as automotive and aerospace, where lightweight structures and optimal performance are critical. It allows accelerating the design process thereby facilitating the creation of solutions that are tuned to meet specific performance criteria, leading to more sustainable, efficient, and aesthetically pleasing designs. These tools enable the designers to make use of the capabilities of artificial intelligence to augment their creativity and problem-solving skills. Through the automation of parts, generative design allows the users to focus on high-level, intricate conceptualization and overall project goals.

Generative design tools explore a vast design space efficiently and provide a wide variety of design options by considering various input parameters thereby helping the designers to discover innovative solutions that comply with the industry standards which prove to be much easier and quicker than traditional design processes. (i) Iterative and Rapid Prototyping: quicker iterations and prototyping of designs are facilitated by this method. Designers can evaluate and refine multiple iterations, much faster in a short amount of time, which in turn speeds up the overall design process as opposed to Traditional methods that may involve time-consuming, laborious manual adjustments and re- designs. (ii) Integration of Simulation and Analysis: The integration of advanced simulations and analysis tools can seamlessly be performed by using this method. Real-time evaluation of designs with the considerations of factors like stress, strain, and factor of safety under various conditions whereas traditional methods may require individual steps to analyses and optimize. (iii)Automation and AI: Generative design leverages automation and artificial intelligence (AI) to assist designers in the design process. Thereby the designers can focus on advanced schematization and analytical reasoning, while the algorithm takes care of the exploration of design options. (iv) Adaptability to Constraints: A large variety of design constraints and requirements can be accommodated in this pro- cess, such as manufacturing constraints, material properties, etc. This adaptability makes it well-suited and one of the best and most reliable options for a wide range of applications ranging from architecture to aerospace.

In this study, five components such as A-arms, brake caliper, upright, rims, and wheel hubs from the wheel assembly in an FSAE car are taken into consideration and after generative design parameters such as von-mises stress, factors of safety and mass are compared with their initial models The initial mass of the A-Arm is 150 grams. The initial factor of safety is 3.3, which serves as a measure of the component's load-bearing capacity relative to its design requirements. Meanwhile, the initial von Mises stress, 75 MPa, provides insight into the material's ability to withstand deformation and failure under applied loads. These parameters undergo changes when Generative design is performed. The updated mass being 99 grams (figure 6) suggests alterations to the geometry, affecting the overall weight with a reduction of 34%. The factor of safety, now 1.6, indicates whether the A- Arm can still withstand anticipated loads with the same margin of safety. Similarly, the von Mises stress is increased to 161 Mpa after mass optimization signifies potential changes in the structural resilience of the A-Arm material.These modifications to the A-Arm's initial parameters reflect a comprehensive approach to enhance its performance, durability, or efficiency in the given application, taking into account factors such as weight optimization, load-carrying capacity, and structural integrity within the context of the dynamic forces experienced by an A-Arm.

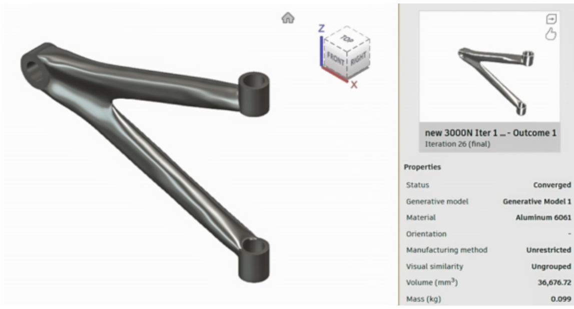

Figure 6. A- Arm after Generative Design.

In the context of a brake caliper, the mass, factor of safety, and von Mises stress are crucial parameters that directly impact the performance and safety of the braking system. The initial mass of the caliper, 505 grams, represents the weight and material distribution of the component. Meanwhile, the initial factor of safety, 3.11, serves as a measure of the caliper's structural integrity, indicating the margin of safety against failure. The initial von Mises stress, denoted as 83.5 MPa, reflects the maximum shear stress experienced by the caliper under applied loads. Subsequently, these parameters undergo changes after Generative Design transitioning to 346 grams, 2.6, and 105 MPa respectively. These refinements underscore a commitment to precision with a mass reduction of 31.48% addressing nuances in the brake caliper's design, and manufacturing methodologies. These changes aim to optimize the caliper's performance and are instrumental in elevating the braking efficiency while ensuring the caliper's durability, and enhancing the overall safety of automotive braking systems.

The wheel rim undergoes adjustments in its fundamental characteristics during its operational lifespan. Initially characterized by a mass of 2960 grams, the factor of safety is 6, and an initial von Mises stress level of 30 MPa, the rim's performance changes as it en- counters the demands of usage. Over time, the mass transitions to 2160 grams with a reduction of 27.02 %, the factor of safety adapts to 1.73, and the von Mises stress is refined to 109 MPa. These alterations in parameters underscore the dynamic nature of the wheel rim's response to various operational conditions. Whether influenced by wear and tear, fluctuations in loads, or environmental factors, these modifications play a pivotal role in evaluating the overall structural robustness and safety of the wheel rim throughout its active service.

Upon scrutinizing the structural integrity of an upright component, the initial mass is denoted as 450 grams which serves as a crucial metric for understanding load distribution. The factor of safety that establishes a vital buffer against unexpected stresses initially is 6 ensuring robustness in the structure. Simultaneously, the von Mises stress is 140 MPa. These parameters undergo modification to 289 grams, 1.55, and 169 MPa respectively. The mass is reduced by 35.78 %. The adjustments carefully balance the enhancement of performance without compromising the structural integrity. This nuanced engineering trade-off is especially critical for upright components, where changes must not only maintain but also improve safety, stability, and reliability.

When examining the characteristics of a wheel hub, its initial specifications, including the mass being 430 g, the initial factor of safety being 3.8, and the initial von Mises stress measured as 64 MPa. Over time, modifications have been introduced; leading to a shift in these parameters to 345 grams, 1.5, and 85MPa respectively and the mass is reduced by 19.76%. Such alterations are pivotal in the continuous refinement and adaptation of the wheel hub's design as they serve as fundamental indicators of its structural integrity and load-bearing capacity and are intrinsic to the dynamic nature of engineering. This iterative process underscores the commitment to enhancing the wheel hub's overall functionality and longevity

5. Conclusions

In conclusion, the application of generative design for the comprehensive optimization of a wheel assembly, consisting of A-arms, brake calipers, uprights, rims, and wheel hubs, has brought into light significant technological advancements in engineering design. By means of the iterative processes, the algorithmic design approach has paved the way for the achieving mass reduction of structures while taking into account the required strength and safety margins. With the assembly, commencing with an initial mass of 4495 grams, the meticulous application of generative design and subsequently mass optimisation led to a remarkable transformation. The final mass, now reduced to 3239 grams, represents a significant percentage reduction of 27.94%. This achievement not only contributes to the vehicle's over- all weight efficiency but also has far-reaching implications for fuel economy, emissions, and overall environmental impact. This breakthrough in mass reduction promises the consumers a future of vehicles that are not only technologically advanced but also environmentally conscious. Through this study, the integration of generative design techniques into wheel assembly development has been demonstrated with the aim of highlighting the adaptability of this methodology and its potential to redefine traditional design methodologies.

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