Design and Optimization of Wheel Hub with Different Number of Holes using CFD

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Abstract

The wheel assembly used in automobiles usually includes hubs, steering knuckles, bearings and wheels, which are all or part of the product. The wheel assembly connects the wheel and chassis through the suspension system. Improving safety standards is important because a defect in the wheel assembly can affect people's lives. The main purpose of the project is to design, manufacture and produce wheel assemblies, focusing on improving previous designs. When measuring and using this design, the various forces acting on the entire wheel assembly during various conditions such as braking, acceleration and cornering must be taken into account. The light hub and wheel combination will reduce inertia when trying to move the vehicle forward or stop it. There are many types of designs regarding the hub bore diameter in this study. Three, four and five holes with different fillet and pad radii were examined in this research.

Introduction

Understanding the basic geometrical aspects of road surfaces and suspensions, such as roll, roll types, various roll centers, and their relationships, is essential to understanding vehicle performance and cornering. One of the earliest examples of wheeled vehicles was probably single axle handcarts, in which the wheels rotate without the need for a steering mechanism. Thousands of years ago, this was the basis for the light horse drawn carriage, which had significant military uses. Despite lacking special spring members, the suspension was necessary for rough terrain and to provide comfort while also mitigating stress on the structure. Additionally, it relied on general conformity rather than additional support. The axle can be bent vertically and longitudinally to ride over bumps by being made long. The use of large wheels is a crucial aspect to consider when riding on rough roads.

The wheel hub, or other rotational components, is often the center of a wheel. The wheel can revolve around an axle thanks to the hub's primary function of attaching a bearing. The Wheel Hub includes the bolt and connection for the wheel. Torque is transferred from the drive line to the wheels by wheel hubs, which are situated at the car's driving axle.

In most vehicles, whether they are heavy-duty trucks, light commercial vehicles, or passenger automobiles, the wheel hub is an essential component. It is mounted on the wheel set and serves as the attachment point for the wheel, as well as housing the wheel bearing, brake components, and fasteners. The rear wheel hub is directly connected to four other vehicle systems – the brake disc, wheel, wheel bearing, and rear axle for vehicles with rear-wheel drive. Typically, the hub consists of two sections, known as petals, with one attached to the wheel and the other to the brake disc . The rear wheel hub is composed of four main sections: (1) a region for coupling with the transmission system in vehicles with rear or all-wheel drive; (2) a section for attaching the brake disc using mounting buttons; (3) a sector for attaching the vehicle's wheel; and (4) a part connected to the inner race of the wheel bearing to support the hub.

The most common methods for coupling the vehicle transmission and wheel hub are the constant-velocity (CV) joint or the tripod joint. In the case of the Formula CEM team's 2021 vehicle, shown in Fig -2, the wheel hub currently utilizes a CV joint, but the team plans to change it to a tripod joint. Before beginning the model of the wheel hub, certain design requirements must be met, such as the diameter of the driveline shaft, dimensions of the bearing, and pattern of the wheel fasteners.

Smith et al. provides a comprehensive overview of recent advancements in wheel hub design for ATVs, focusing on the integration of different materials. The paper discusses the advantages and limitations of materials such as aluminum alloys, steel, and composite materials in enhancing performance, durability, and weight reduction.

Johnson, A. et al. (2019) explore innovative wheel hub designs for ATVs, emphasizing the importance of material selection. The paper presents case studies and experimental results comparing the performance of steel, aluminum, and composite wheel hubs in various terrain conditions, highlighting the influence of material properties on traction, stability, and durability.

Brown, M. (2018) et al discusses the criteria and considerations involved in selecting materials for off-road vehicle components, including wheel hubs. The paper evaluates the mechanical properties, cost-effectiveness, and environmental impact of different materials, providing insights into optimal material choices for wheel hub design in ATVs.

Robinson, S. (2017) et al examines the potential of composite materials in light weighting off-road vehicle components, including wheel hubs. The paper reviews the mechanical properties, manufacturing processes, and applications of composite materials in ATVs, highlighting their role in improving fuel efficiency, performance, and corrosion resistance.

Gonzalez et al. present a detailed analysis of aluminum alloy wheel hub design for ATVs, focusing on structural optimization and material selection. The paper discusses finite element analysis (FEA) simulations, experimental testing, and field trials to validate the performance and reliability of aluminum alloy wheel hubs in off-road conditions.

These literature sources offer valuable insights into wheel hub design for all-terrain vehicles, with a particular emphasis on the role of different materials in enhancing performance.

Methods

FEA, a computational tool for engineering analysis, is facilitated by software programs utilizing Finite Element Method (FEM) algorithms. FEA involves dividing complex problems into smaller elements and solving them numerically. This approach is suitable for analyzing problems across complicated domains, varying precision requirements, or when smoothness is lacking, such as in structural analysis, heat transfer, and fluid flow simulations.

In practical applications, such as wheel hub design for all-terrain vehicles (ATVs), Computational Fluid Dynamics (CFD) plays a significant role in optimizing aerodynamic performance and thermal management. CFD enables engineers to study airflow patterns, heat transfer mechanisms, and component interactions. The workflow typically

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involves geometry creation, mesh generation, defining boundary conditions, solver setup, and post-processing to interpret results and guide design decisions.

Challenges in wheel hub design using CFD include the complexity of turbulent flow phenomena, the need for validation against experimental data, and the requirement for a multidisciplinary approach involving aerodynamicists, mechanical engineers, and vehicle dynamics specialists.

During the phase of design, the team utilized SolidWorks to complete the design and conducted simulations using Ansys. Additionally, calculations were performed to ensure that overall stresses remained low, considering various load transfers in dynamic conditions.

In the manufacturing phase, the team considered various materials by conducting market surveys to assess availability and cost. Based on these factors, a suitable material was chosen for the wheel hub. In order to obtain the required accuracy for producing parts like the upright, hub, and brackets, the team then researched several manufacturing techniques and decided on CNC turning and water jet machining.

For the analysis of the wheel hub design, boundary conditions were set based on practical considerations and the load-bearing capacity of the wheel hub. The wheel mounting holes were supported with fixed points, and the disc mounting holes were oriented tangentially with the brake rotor.

Results

The analysis focused on three parameters: equivalent stress, strain, and total deformation. The performance and structural soundness of the wheel hub design under the specified circumstances were assessed using these metrics. The results of this analysis provided insights into areas of improvement and optimization for the design. The component was analyzed for Equivalent stress Total Deformation and Elastic strain.

Three Hole Geometry

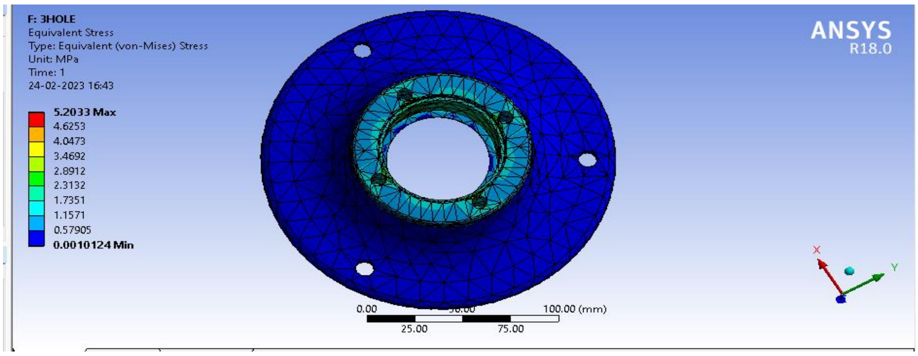

Figure 1 Equivalent Stress (von Misses Stress) for 3 Hole Geometry

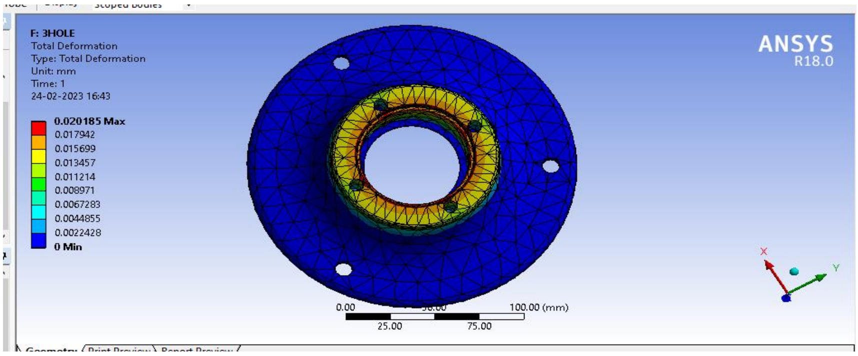

Figure 2 Total deformation of 3 Hole geometry while different load condition

Five Hole Geometry of Wheel hub

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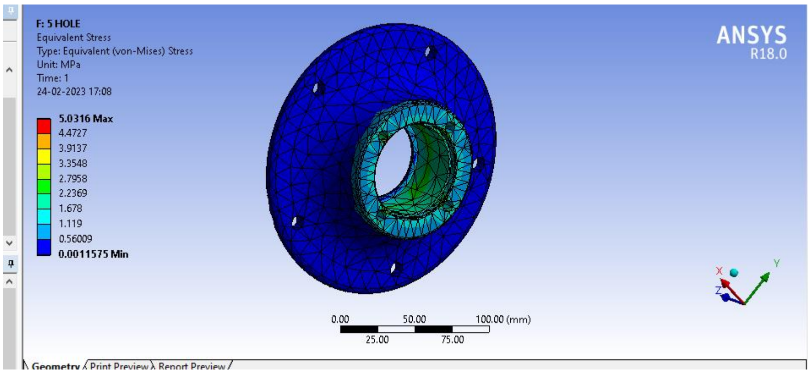

Figure 3 Equivalent Stress (von Misses Stress) for 5 Hole Geometry

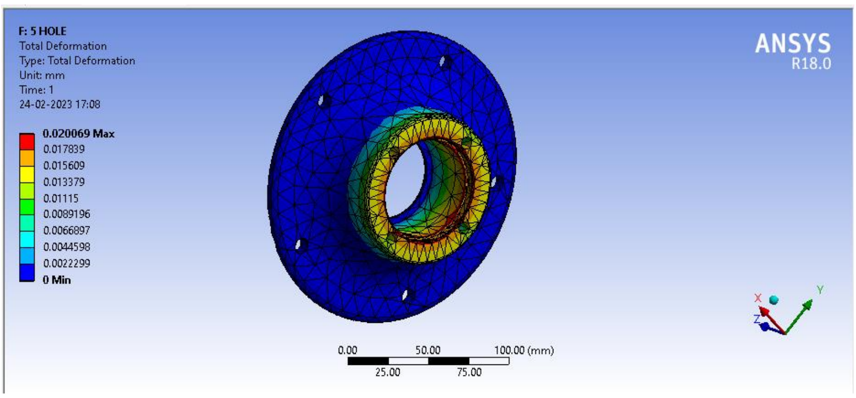

Figure 4 Total deformation of 5 Hole geometry while different load condition

4.4 Six hole Geometry for Wheel Hub Design

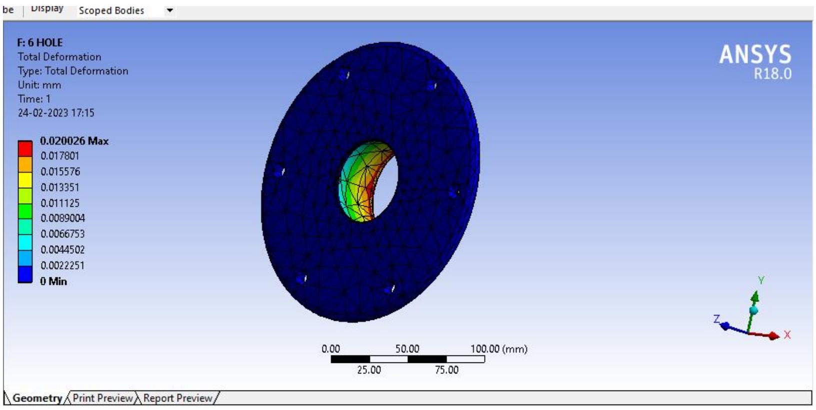

Figure 5 Total deformation of 6 Hole geometry while different load condition

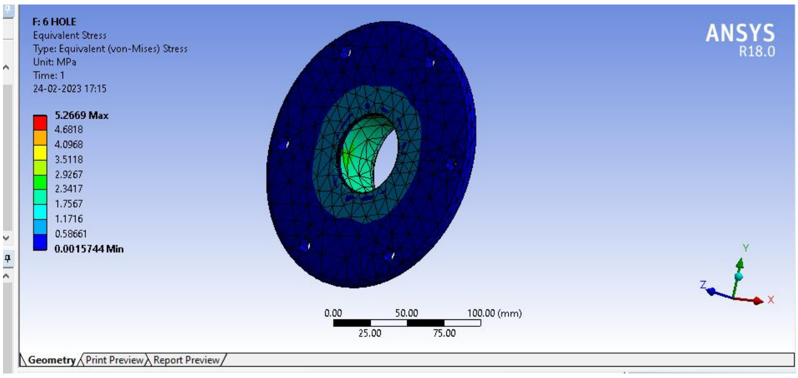

Figure 6 Equivalent Stress (von Misses Stress) for 6 Hole Geometry

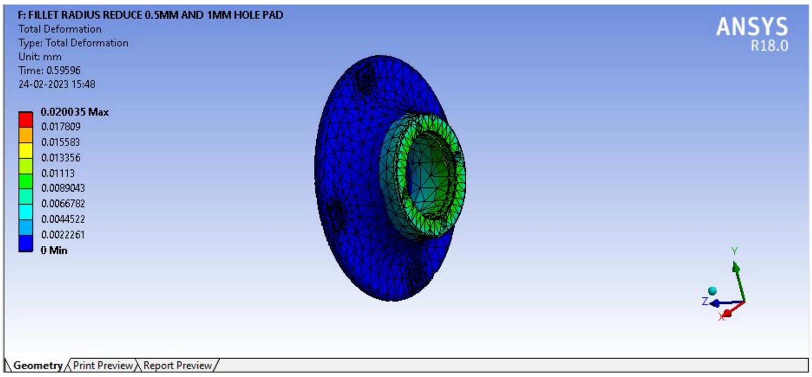

Figure 7 Total deformation of fillet radius reduced to 0.5mm and 1 mm pad hole

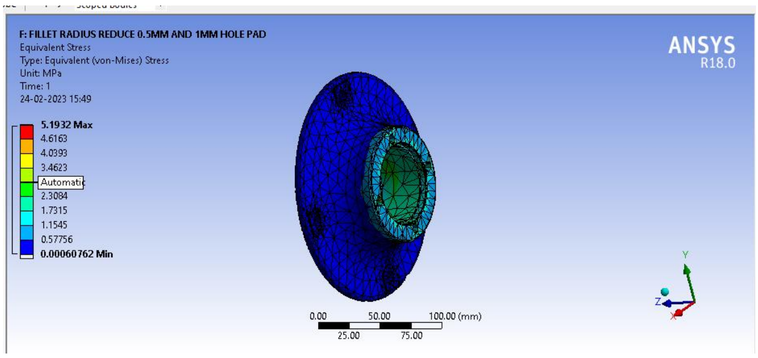

Figure 8 Equivalent stress (von Misses) stress of fillet radius reduced to 0.5mm and 1 mm pad hole

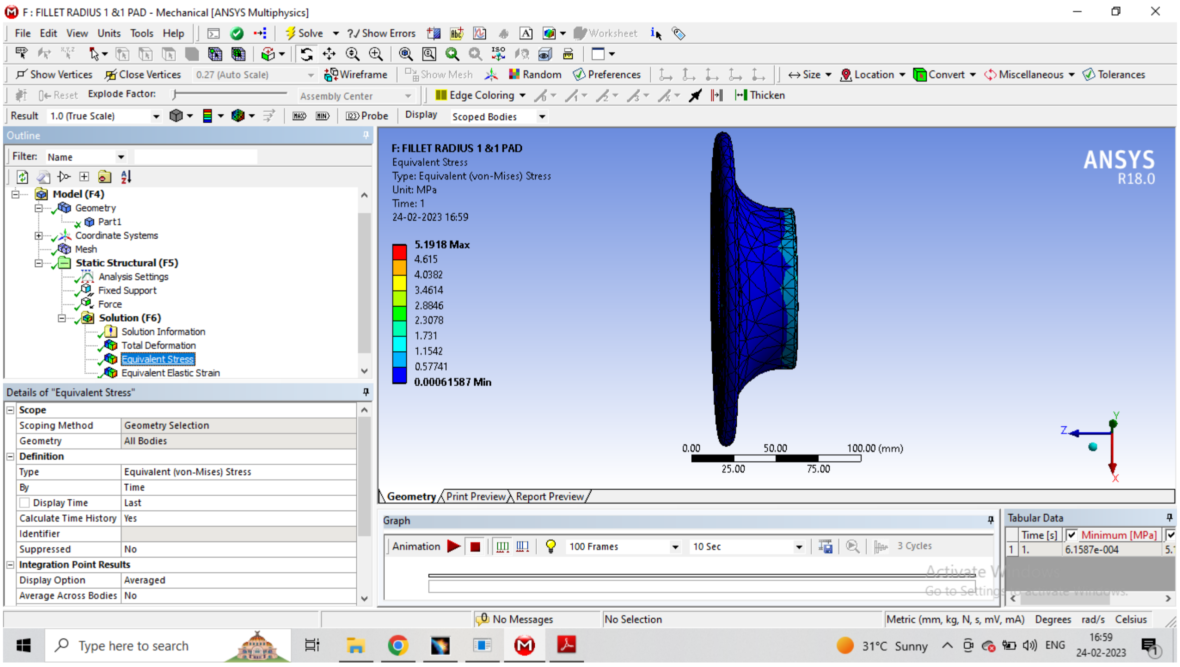

Figure 9 Equivalent Stress of wheel hub with 1mm fillet radius and 1 mm Pad hole

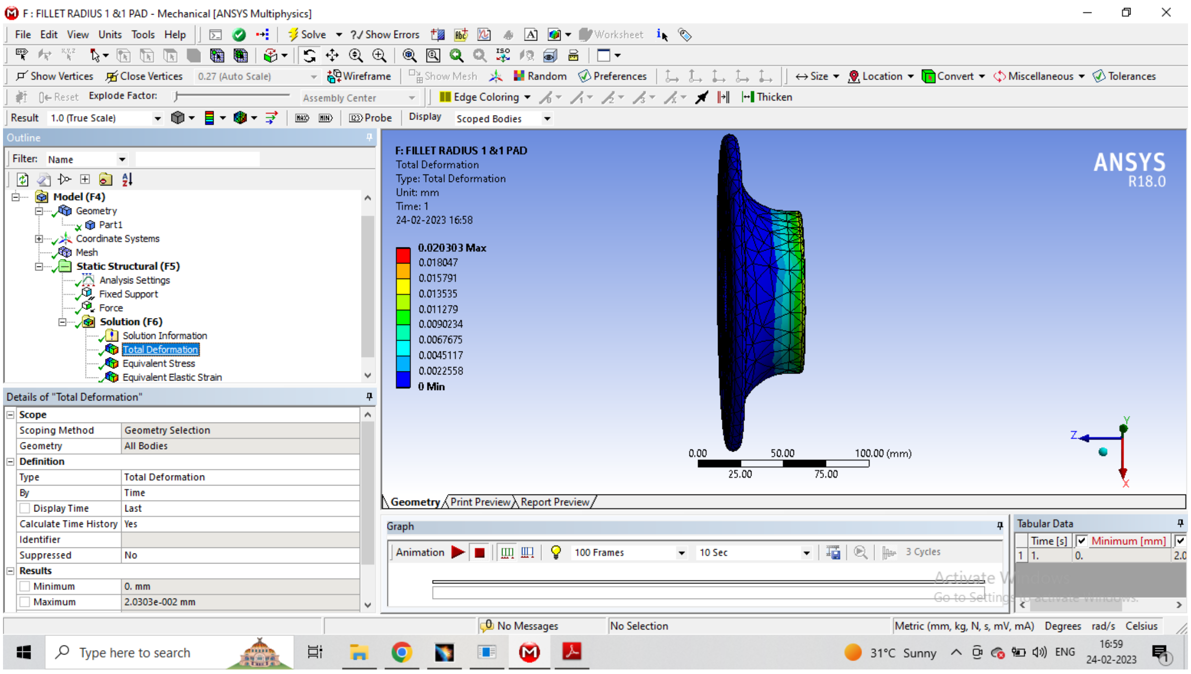

Figure 10 Total deformation of 1mm fillet radius with 1 mm Pad hole

Discussion

Figure 1 shows the Equivalent Stress (von Misses Stress) for 3 Hole Geometry, where the maximum stress given by 5.1 MPa and range for hub is given by 0.5 MPa To simulate the actual loading situation, the previously described Force was applied to the design in Ansys.and Figure 2 The wheel hub mountings hole with 3 hole geometry having total maximum deformation of 0.02

mm and 0.17 mm diameter deformation in centre hole area , which is clearly visible in analysis part of wheel hub assembly.

Figure 3 where the component with 5 hole was analyzed for Equivalent stress Total Deformation and Elastic strain. Figure 4.4 shows the Equivalent Stress (von Misses Stress) for 5 Hole Geometry, where the maximum stress given by 5.03 MPa and range for hub is given by 1.19 MPa The design was subjected to the previously stated Force in Ansys in order to simulate the actual loading situation. This analysis made it easier to comprehend how the component behaved with the material. Figure 4gives analysis regarding given wheel hub mountings hole with 5 hole geometry having total maximum deformation of 0.02 mm and 0.013 mm diameter

Figure 5 shows the overall deformation of the six-hole wheel hub geometry, with the plate side of the wheel hub experiencing the least amount of distortion and the center of the wheel hub experiencing the largest displacement of 0.020 mm. The deformation could be seen at inner cavity of the wheel hub where the 0.011125 mm value is shown at the joint of disc and shaft cavity.

Figure 6 which shows the corresponding stress of the component—also referred to as von Misses stress in the research of part failure—clearly illustrates the maximum value of 5.2669MPa in the wheel hub design.

Figure 7 depicts the design results of wheel hub condition of total deformation with 0.5 mm reduced fillet radius and 1 mm pad hole where the maximum value for given design is 2.0×10^{-2} mm where the component having major value of deformation under the 8.9 x 10-4 mm in the face of the wheel hub shaft hole collar. In this condition clearly mentioned here by diagram there is no stress and no deformation condition for the wheel hub condition and safe design for rest of the wheel hub design.

Figure 8 the equivalent stress of fillet radius reduced to 0.5 mm and 1 mm pad hole design diagram under the software analysis, the maximum value 5.19 MPa. The component shaft hole collar varies the values between 2.3 MPa to 1.17 MPa. There is minimum stress found in the other parts of wheel hub with minimum variation and shows the clearly that entire hub is considered as a safe component.

Figure 9 depicts total deformation of the filet radius 1mm and 1mm pad hole consideration where the maximum value 0.020 mm during the load condition of wheel hub. 0.011 mm values associated with outer periphery of the shaft hole whereas the other value at collar are 0.009 mm and 0.006 mm which less and considered as safe design of the shaft wheel hub.

Figure 10 equivalent stress of 2mm fillet radius with 1mm pad hole shows the design of the wheel hub at load condition. Maximum stress as per the diagram is 5.336 MPa and component value varies in between 2.3 MPa and 1.1 MPa.

Conclusion

From vehicle dynamic requisites, several load situations were identified, which component may be requested during its operation. It was found that a drive condition in acceleration, simultaneous with turning movement, results in higher vertical load on the wheel bearing. This condition with drive torque on the tripod joint was applied for the topological optimization to design a product model that aim for a minimum mass, but keeping its structural stiffness. The results of the failure analyses made by FEM calculations can be considered satisfactory This level of factor is in accordance with the standard adopted by the team. Thus, the component has an infinite lifespan that ensures the wheel hub may be applied for the future vehicle prototypes.

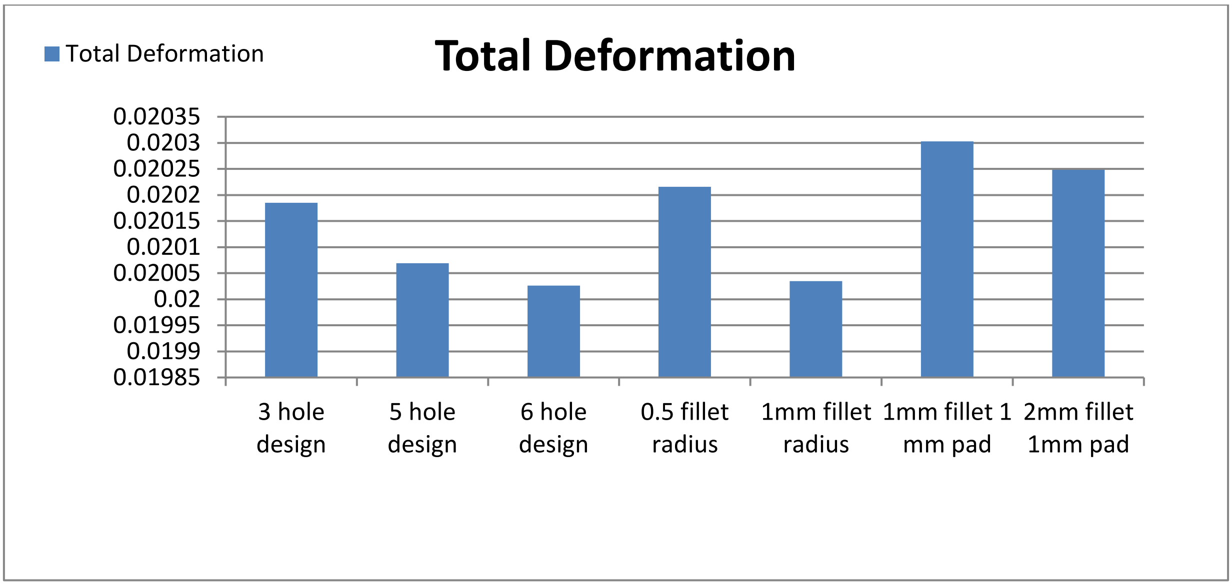

Figure 11 Total deformation graphs for all proposed design

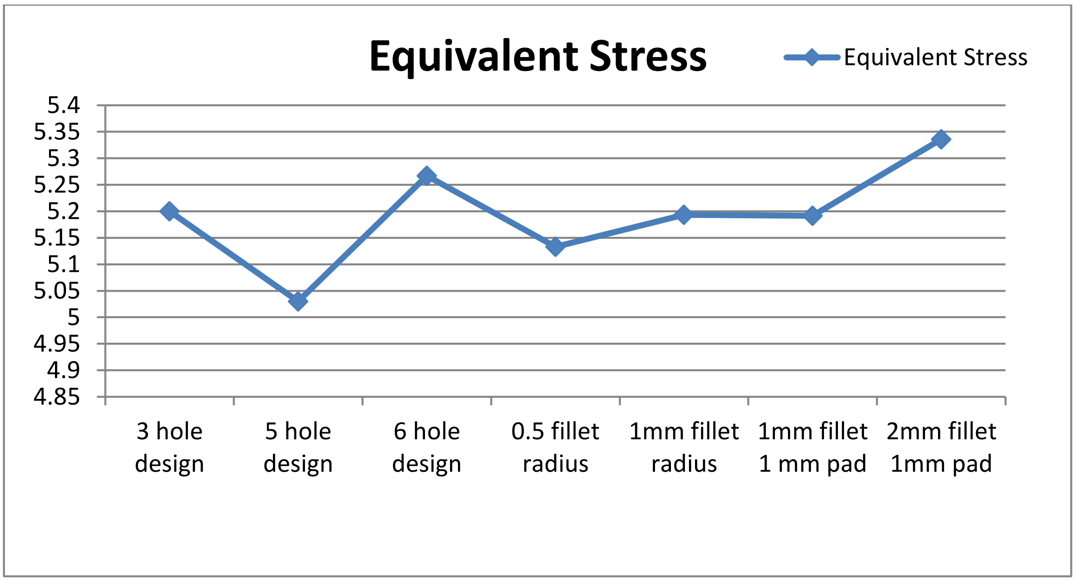

Figure 12 Equivalent Stress for all design wheel hubs

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