ANALYSIS OF THE CRITICAL STRESS POINT OF A MOTORCYCLE WHEEL

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Abstract - Software programs find their application in almost every field of science. In Engineering, CAD software such as solid works have been used to model, analyse and optimize assemblies, structures and processes to ensure efficient systems. In this study, the base dimensions of the front wheel of a Bajaj CT 125X were used to design 12 variants of the motorcycle wheel. The modified wheels were assigned an aluminum material with all its properties and subjected to a pressure load of 1Mpa while constraining the hub.
To ensure for consistency of the results with realistic characteristics of wheels, Si units, appropriate material properties, proper mesh, loading and analysis settings were programmed into the software and the results read and analysed using basic principles of physics. The results showed that under same conditions of loading and constrains, the reactions, stresses, strains, and displacement of the wheel variants differed in magnitude and direction. It was also observed that the wheel with 5 curved spokes had the highest weight of 39.1974 N but was only able to withstand 146.6MPa. The wheel variant with 5 inclined spokes could withstand stress of about 783.1 MPa and the critical point of failure was observed to be at the air hole. Displacements of the magnitude of 0.2 mm to 0.4 mm were observed at the regions furthest from the spokes. In conclusion, it is inferred that reinforcements should be made to resist the shear forces at the air hole region and bending stresses at the regions furthest away from the spokes.

Index Terms - CAD software, Motorcycle Wheel, Stress analysis, Material properties, Finite element analysis (FEA).

I. INTRODUCTION

The wheel is a device that enables efficient movement of an object across a surface where there is a force pressing the object to the surface. Early wheels were simple wooden disks with a hole for the axle. However, due to the structure of wood a horizontal slice of a trunk is not suitable, as it does not have the structural strength to support weight without collapsing. Hence, rounded pieces of longitudinal boards are required [1]. More recently, the spoke wheel was invented, and gave room for the construction of lighter and swifter motorcycle and vehicles. The spoke wheels are usually made from alloy wheels. Alloy wheels are automobile wheels which are made from an alloy of aluminum or magnesium metals (or sometimes a mixture of both). These wheels differ from normal steel wheels because of their lighter weight, which improves the steering and the speed of the motorcycle and vehicle, however some alloy wheels are heavier than the equivalent size steel wheel. In addition, some alloy wheels are also better heat conductors than steel wheels, improving heat dissipation from the brakes, which reduces the chance of brake failure when there is a more demanding driving conditions [2]. Over the years, there has been a consistent effort in mechanical design, coupled with rigorous field-testing to keep improving the wheels used by motorcycles and vehicles alike. Recently, the procedures to achieve this, have significantly improved with the coming of innovative methods like experimental and analytical analysis [2].
In recent times, modeling has become a major process in the quest for determining, improving, and optimizing the characteristics of engineering systems. Model creation and analysis of a particular stress system involve using CAD software like Solid Works, ANSYS Fluent, Pro E, CATIA, COSMOL, etc. to design the part or assembly which is to be studied and applying virtual conditions of force, temperature, and flow to the design. Since movement is a fundamental necessity and characteristic of living organisms, there have been commensurate efforts in the advancement of transport-related technologies. The invention of the wheel was a game-changer in transportation technologies. Its development though was not as rapid as other technologies. With the help of software and present computational methods, better and more efficient wheels are now designed to meet specific stress, thermal, fatigue, and vibration conditions. The advantages of the development of transportation technologies cannot be overemphasized. From saving lives to helping to build businesses, ordering goods, transforming entire cultures, and promoting tourist activities, recent technological trends in transportation have helped to make life easier for man. Unlike in ancient times when journeys of a few hundred kilometers lasted days on foot, recent technologies make it possible for safe and commercial travels at half the speed of sound [3]. Since its invention in the 4th century, the wheel has gone through hundreds of modifications all aimed at making travels on land safer, faster and cheaper [4].
Modeling and analyzing machine components and assemblies with CAD software work based on mathematical models which compute physical properties using known laws of physics. Modeling a mechanical system begins with the creation of a physical model on which physics laws and mathematical operations are applied to develop the mathematical model. To make the analysis, certain assumptions and boundary conditions are applied to the model to create a framework for the analysis of the model.
The study aims to determine the critical point of failure in motorcycle wheels, with specific objectives being to design and simulate the behavior of a motorcycle wheel using different variation of the wheel under loading. Additionally, the point of failure of the wheel will be determined.

Justification for the Study

The study focuses on analyzing the critical stress point of a motorcycle wheel through Finite Element Analysis (FEA) of different wheel variants. This focus is crucial since motorcycle wheels, as an integral part of the vehicle, affect its overall safety, performance, and durability. The significance of this study is justified based on several important reasons.
First, by subjecting different wheel variants to a comprehensive FEA analysis, this study addresses the critical concern of ensuring the safety and reliability of motorcycle wheels. This evaluation of stress distribution, displacement, and strain characteristics offers valuable insights into potential failure points and deformations under varying loading conditions. These findings can be used to optimize wheel

designs, ultimately enhancing the safety of motorcycle riders [5], [6].

Secondly, FEA analysis provides an effective means to assess the structural integrity and mechanical behavior of different wheel designs. Hence, by comparing the stress, displacement, and strain contours across various configurations, engineers can identify the most optimal design that can withstand the highest stress loads and exhibit minimal deflections, which offers a systematic approach to design optimization, allowing manufacturers to produce wheels that strike a balance between performance, durability, and cost-effectiveness [7], [8].

Also, the FEA analysis of the critical stress point of a motorcycle wheel done in this study not only evaluates existing wheel designs but also enables the exploration of innovative materials and manufacturing techniques. By simulating the behavior of different materials under varying loads, engineers can make informed decisions regarding material selection, hence fostering the development of lightweight yet robust wheel structures that contribute to fuel efficiency and overall vehicle performance [6].

Additionally, the comprehensive analysis of stress and displacement not only provides insights into the static loading scenarios but also lays the foundation for subsequent dynamic analysis. Therefore, an opportunity is left open for future research to extend this study and consider the impact of dynamic forces such as vibrations, impacts, and varying road conditions. This holistic approach will lead to a more accurate representation of wheel behavior in real-world scenarios. Lastly, this study is justified because the investigation of stress-strain relationships and design parameters conducted in this study contributes to the existing body of knowledge in mechanical engineering, serving as a valuable academic resource that can be referenced by researchers, students, and professionals in the field of structural mechanics and vehicle design [8].

II. LITERATURE REVIEW

Archaeologists and historians of today see the introduction of the wheel as the real genesis of any old civilization. The wheel is perhaps the most important discovery of old times. This discovery brought commerce to heights unknown before. Over the years, automotive wheels have evolved, it has developed from nothing more than an oversized bearing to a fully integral part of any modern transportation vehicle. In fact, modern automotive today is designed with fashion in view to complement people's individual tastes [1]. However, like its commonly emphasized in engineering, safety first. For this reason, automotive vehicles (cars and motorcycles) are produced according to very strict rules to ensure the safety of the passengers. Every component is therefore designed according to the criticality of the component, and as wheels are classified as a safety critical component, international codes and criteria are used for its design [9]. Furthermore, beyond the International codes followed, materials to produce wheels have become more sophisticated as these materials can range from steel to non-ferrous alloys like magnesium and aluminum [10].

Historically, successful designs arrived after years of experience and extensive field testing. Since the 1970's several innovative methods of testing, well supported with experimental stress measurements have been initiated. In recent years, the procedures have been improved by different experimental and analytical methods for structural analysis like the Finite element analysis, etc. Within the past 10years, durability analysis (fatigue life predication) and reliability method for dealing with variations inherent in engineering structure have been applied to the automotive wheel [10].

Types of Wheels

There are so many types of wheels still in use in the automobile industry today. They vary significantly in size, shape, and materials used, but all follow the same basic principles [11].

1. Wire Spoke Wheel

Wire spoke wheel is a structural wheel where the outside edge part of the wheel (rim) and the axle mounting part are connected by numerous wires called spokes. Today's vehicles with their high horsepower have made this type of wheel construction obsolete. This type of wheel is still used on classic vehicles. Light alloy wheels have developed in recent years, as a design that emphasize the spoke-effect to satisfy users fashion requirements.

2. Steel Disc Wheel

This is a wheel rim which processes the steel-made rim and the wheel into one by welding, and it is used mainly for mopeds vehicle especially original equipment tires.

3. Light Alloy Wheel

These wheels based on the use of light metals such as aluminum and magnesium has become popular in the market. These wheels rapidly became popular for the original equipment vehicle in Europe in 1960's and for the replacement tire in United States in 1970's. The features of each light alloy wheel are explained as below:

i. Aluminium Alloy Wheel

Aluminum is a metal with features of excellent lightness, thermal conductivity, corrosion resistance, characteristics of casting, low temperature, machine processing and recycling, etc. The main advantage of this metal, is reduced weight, high accuracy and design choices of the wheel. This metal is also useful for energy conservation, and this is due to the fact that, it is possible to re-cycle aluminum easily.

ii. Magnesium Alloy Wheel

Magnesium is about 30% lighter than aluminum, and also, excellent as for size stability and impact resistance. Recently, the technology for casting and forging is improved, and the corrosion resistance of magnesium is also improving. It's right to say that, this material is receiving special attention due to the renewed interest of organizations in energy conservation.

iii. Composite Material Wheel

The composite materials wheel, is a different kind of light alloy wheel, and it (Generally, it is thermoplastic resin which contains the glass fiber reinforcement material) is developed mainly for low weight. Again the second composite material, i.e., Carbon fiber which is been used more recently also has similar properties of thermoplastic resin, and its use is restricted to only sports vehicles because of their high cost of manufacturing process.

The Motorcycle Alloy Wheel

The alloy used in the finest road wheels today is a blend of aluminum and other elements. The term "magnesium wheel" is sometimes incorrectly used to describe alloy wheels. Magnesium is generally considered to be an unsuitable alloy for road usage due to its brittle nature and susceptibility to corrosion. Hence, in market, most times aluminum alloy wheel is used, and the reason is that, pure aluminum is soft, ductile, corrosion resistant and has a high electrical conductivity [6]. As a result of these characteristics also, it is widely used for foil and conductor cables. But alloying with other elements is necessary to provide the higher strengths needed for other applications. The making process of Aluminum alloy wheels is such that, they are cast into a mold in a hot liquid state and cooled, which makes them more accurate in both the heavier and lighter areas. So that the end result is balanced, having less weight on the wheel and less stress on the tire. Aluminum alloy wheels also provide a lighter weight for the racing enthusiast, and can be machined for a brilliant appearance [12].

Furthermore, it's important to note that, steel wheels are a great way to provide basic transportation for a basic car, but for those who want to extend the life of their tires and have a smoother ride, alloy wheels are the way to go. The reason is because, alloy metals provide superior strength and dramatic weight reductions over ferrous metals such as steel, and as such they represent the ideal material from which to create a high performance wheel. In fact, today it is hard to imagine a world class racing car or high performance road vehicle that doesn't utilize the benefits of alloy wheels. Hence, aluminum alloy is widely used in transport, packaging, building and architecture and machine component [12], [13].

Finite Element Analysis of Engineering Components

Finite element analysis (FEA) has become very common in recent days, and is now the source of income in the Engineering industry. Numerical solutions to even very complicated stress problems can now be obtained using FEA. The method is so important that even introductory treatments of Mechanics of Materials, as Finite element codes are less complicated than many of the word processing and spreadsheet packages found on modern microcomputers. Nevertheless, they are complex enough that most users do not find it effective to program their own code. A number of prewritten commercial codes are available, representing a broad price range and compatible with machines from microcomputers to supercomputers. However, users with specialized needs should not necessarily shy away from code development, and may find the code sources available in such texts as that by Zienkiewicz to be a useful starting point [14].

In practice, a finite element analysis usually consists of three principal steps [9], [14] & [15].

a) Preprocessing:

The user constructs a model of the part to be analyzed in which the geometry is divided into a number of discrete sub-regions, or elements, connected at discrete points called nodes. Certain of these nodes will have fixed displacements, and others will have prescribed loads. These models can be extremely time consuming to prepare, and commercial codes vie with one another to have the most user-friendly graphical \preprocessor" to assist in this rather tedious chore. Some of these preprocessors can overlay a mesh on a pre-existing CAD file, so that finite element analysis can be done conveniently as part of the computerized drafting-and-design process.

b) Analysis:

The dataset prepared by the preprocessor is used as input to the finite element code itself, which constructs and solves a system of linear or nonlinear algebraic equations, with ''u and f'' being the displacements and externally applied forces at the nodal points. The formation of the K matrix is dependent on the type of problem being attacked. Commercial codes may have very large element libraries, with elements appropriate to a wide range of problem types. One of FEA's principal advantages is that many problem types can be addressed with the same code, merely by specifying the appropriate element types from the library.

c) Design:

The final principal stress of FEA, involves the actual design and drawing of the profile diagram of the required component (in this case, a wheel rim). The basic steps involve, revolving the profile body with respect to y-axis. After which, you obtain the wheel rim body 3, and by selecting the face of wheel, the required design is drawn on the surface.

III. MATERIALS AND METHODOLOGY

Since motorcycles are used every day, a real life motorcycle wheel will be used to design and simulate the characteristics of the design under real life loading conditions. This study will reveal the stress, displacement and strain characteristics of the motorcycle wheel under realistic loading conditions. The material used for the model and simulation of the wheel in this study is made of an aluminum alloy called **33.0205 (EN-AW 1200)**. This alloy is comprised of Copper, Magnesium, Manganese, Silicon, Tin and Zinc. Aluminum alloys have found more use in wheels recently due to its low weight to strength ratio when compared to iron or steel. **3.0205 (EN-AW 1200)** was used in the model and analysis of this study because of its cost and machinability.

The dimension from the front wheel of a Bajaj CT 125X motorcycle (Fig.1) are used to create the base cross-section for the models with SolidWorks. The motorcycle wheel for this study is made of a cross section as shown in Fig.2.

Fig. 1 Bajaj CT 125X motorcycle

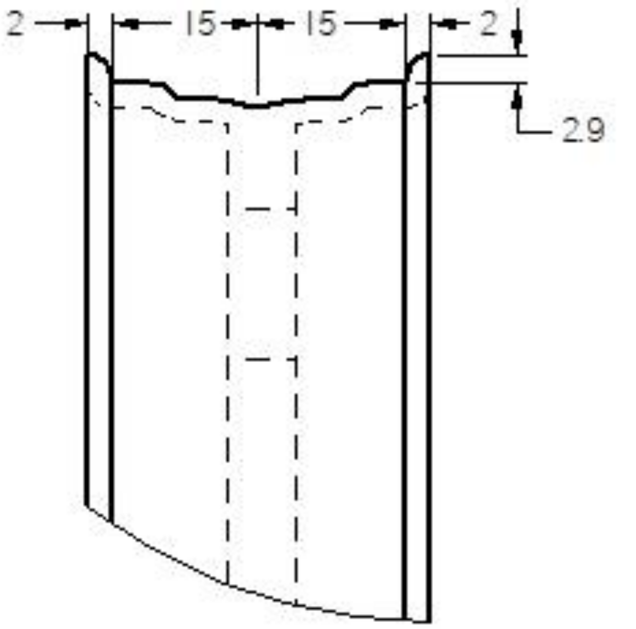

Fig. 2 Cross-sectional dimensions of the wheel

Methodology

The cross-sectional dimensions of the wheel of a Bajaj CT 125X were measured with the meter rule, a measuring tape and a Vernier caliper and compared with the product dimensions on the Bajaj product catalog for consistency. Next, SolidWorks 2021 Professional Software was used to model the wheel to the dimensions obtained. Variation of the number and type of wheel spokes were then modeled to suit the cross-sectional dimensions obtained.

The properties of the aluminum alloy material, **3.0205 (EN-AW 1200,** was then applied for the simulation. To meet up with the objectives of the study, the Hub cycle was constrained and a pressure of $1N/mm^2$ (1 MPa) was applied to the internal surface of the wheel.

The simulation was then run and the stress, strain and displacement results recorded in the deformed and undeformed states. The values of yield strength, Tensile strength, mass density, maximum loading, moment, forces in the wheel and their resultant, mesh information, and load information recorded and tabulated. The von Mises Stress contour, displacement and strain results were then documented and used to obtain the wheel variant that withstands the highest pressure. Lastly, a stress probe was also carried out to determine the stress-strain characteristics in the critical stress region. The results were then analysed and conclusions made from the information processed.

Designs obtained

Twelve variants of the designs modelled are shown in fig. 3 to fig. 8.

Fig. 3 Design with 3 and 5 Inclined shaped spokes

Fig. 4 Design with 3 and 5 Linear spokes

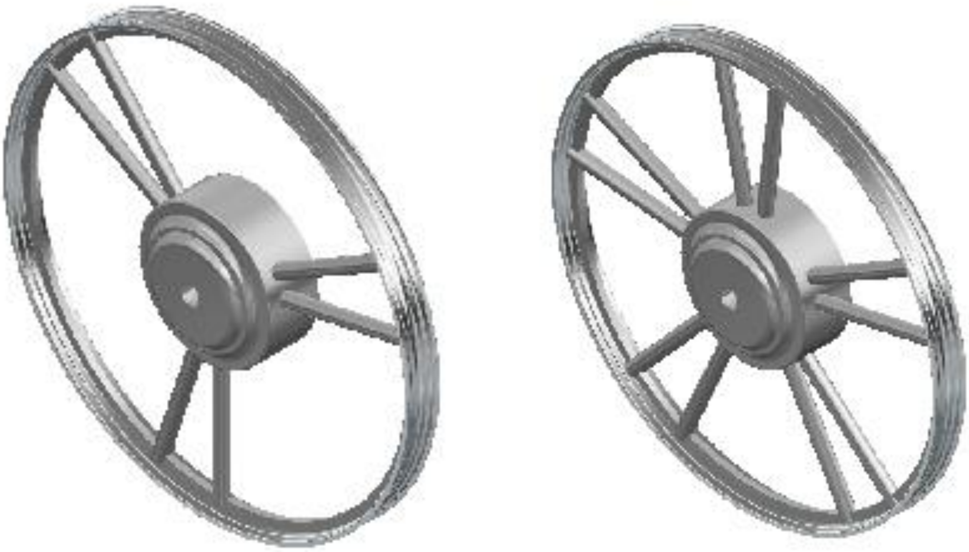

Fig. 5 Design with three and five diverging rods spokes (triangle)

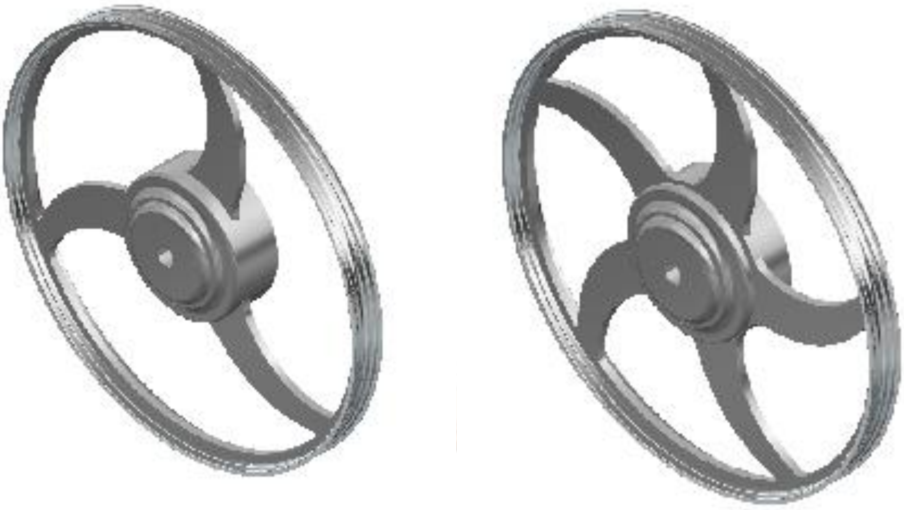

Fig. 6 Design with of three and five curved spokes

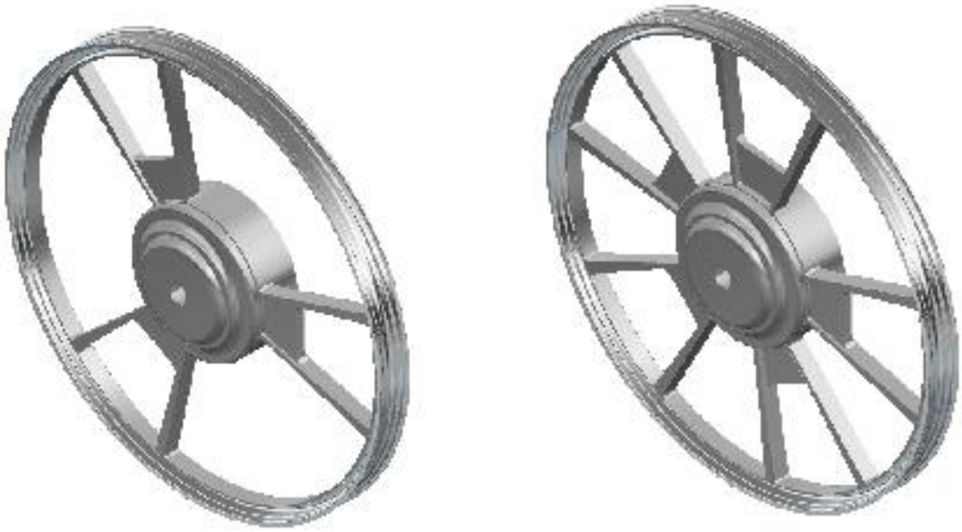

Fig. 7 Design with three and five V shape spokes with pad

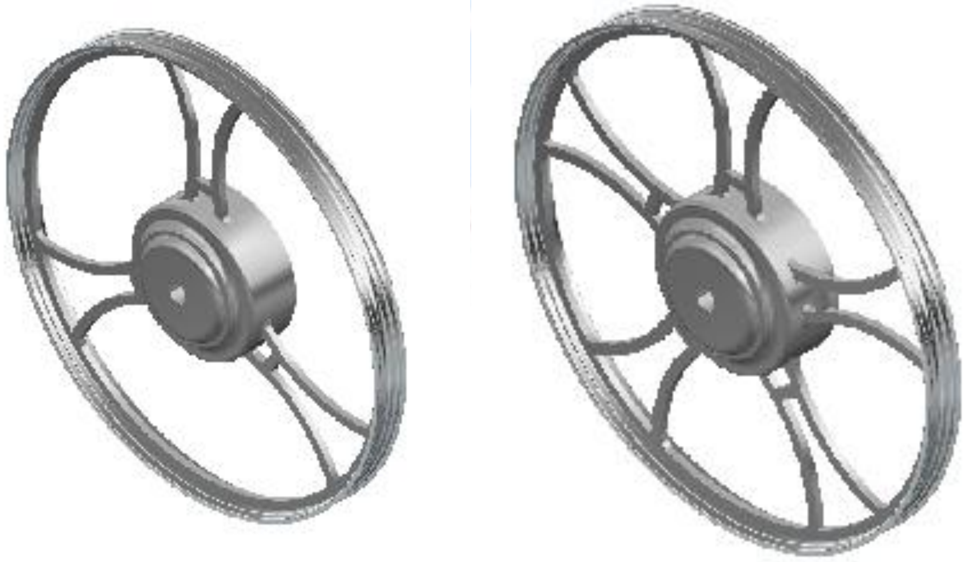

Fig. 8 Design with three and five curved V shape spokes

Validity of the instruments used in the study

FEA simulation in Solid works, an industry standard for modelling and analysing design parts and components was used to design and analyse the 12 variants of the motorcycle wheel.

To assure validity of the results obtained with realistic conditions, Si units, appropriate material properties, proper mesh, loading and analysis settings were used to make the result near accuracy as much as possible. Table 3.1 shows the settings used.

A. Analysis settings

Analysis type	Static
Mesh type	Solid Tetrahedral Mesh
Thermal Effect:	Off
Thermal option	exclude temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	Automatic
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (C:\Users\Omophuneh\Desktop\Project Work\2022\Project\Kelvin\Design\DONE)

B. Mesh Information

To ensure the validity of the tests, the mesh sizes and loading conditions were predetermined and the assumptions of static equilibrium made and programmed into the software

Mesh type	Solid Mesh
Mesher Used:	Curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	21.1675 mm
Minimum element size	4.2335 mm
Mesh Quality	High

C. Loading characteristics

Pressure load of 1MPa and equivalent of about 5 times the operating stress of the wheel was applied to the surface of the wheel while the hole in the hub was held fixed as shown in fig. 9.

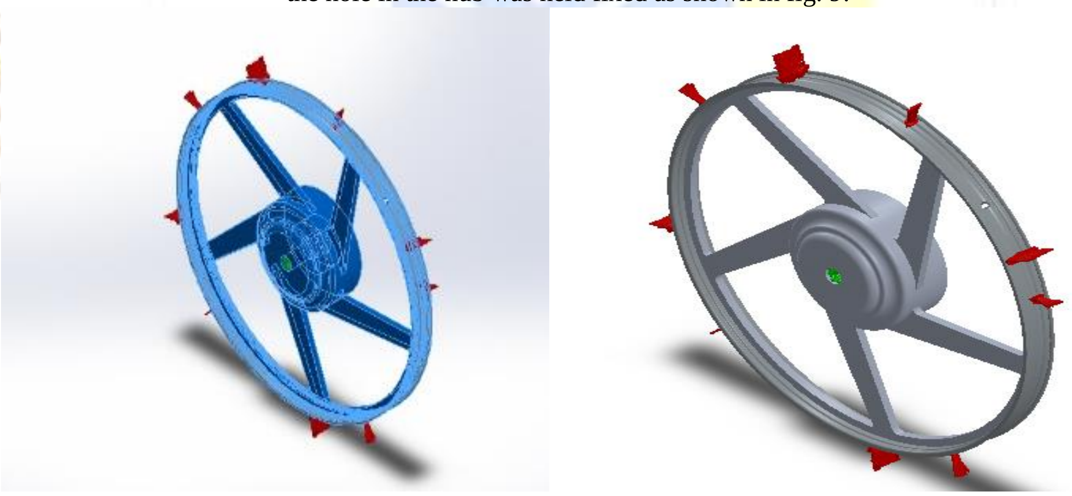

Fig. 9 Fixture and loading conditions of the wheels

IV. RESULTS

The following results were obtained from the analysis carried out using Solid works software on the motorcycle wheel models designed in the methodology section. In view of the aim and objectives of this study, results describing the physical properties, stress, displacement and strain characteristics of the model variations are represented and discussed.

Results of design characteristics

Table 1 Physical properties of the designed models

SN	Model	Volumetric Properties
1	Curved Shaped with 3 Spokes	Mass:3.86746 kg Volume:0.00138121 m^3 Density:2,800.04 kg/m^3 Weight:37.9011 N
2	Curved Shaped with 5 Spokes	Mass:3.99974 kg Volume:0.00148135 m^3 Density:2,700.07 kg/m^3 Weight:39.1974 N
3	Inclined Shape with 3 Spokes	Mass:3.56221 kg Volume:0.00131934 m^3 Density:2,700 kg/m^3 Weight:34.9097 N
4	Inclined Shape with 5 Spokes	Mass:3.76884 kg Volume:0.00139587 m^3 Density:2,700 kg/m^3 Weight:36.9346 N
5	Linear Bar Shaped with 3 Spokes	Mass:3.53875 kg Volume:0.00131065 m^3 Density:2,700 kg/m^3 Weight:34.6798 N
6	Linear Bar Shaped with 5 Spokes	Mass:4.62262 kg Volume:0.00171208 m^3 Density:2,700 kg/m^3 Weight:45.3017 N
7	Triangle Shape with 3 Spokes	Mass:3.61158 kg Volume:0.00133762 m^3 Density:2,700 kg/m^3 Weight:35.3934 N
8	Triangle Shape with 5 Spokes	Mass:3.8785 kg Volume:0.00143648 m^3 Density:2,700 kg/m^3 Weight:38.0093 N

9	V curved shape with pad with 3 Spokes	Mass:3.45128 kg Volume:0.00127825 m^3 Density:2,700 kg/m^3 Weight:33.8226 N
10	V curved shape with pad with 5 Spokes	Mass:3.56769 kg Volume:0.00132137 m^3 Density:2,700 kg/m^3 Weight:34.9633 N
11	V Shape with 3 Spokes	Mass:3.82495 kg Volume:0.00141665 m^3 Density:2,700 kg/m^3 Weight:37.4845 N
12	V Shape with 5 Spokes	Mass:4.04922 kg Volume:0.00149971 m^3 Density:2,700 kg/m^3 Weight:39.6823 N

Loading characteristics

Table 2 Force interaction due to the 1N/mm2 pressure loading in the internal surface of the wheels.

SN	Wheel Shape and type	Reaction Force Component			
		X	Y	Z	Resultant
1	Curved Shaped with 3 Spokes	-9.20333	-19.032	-0.509528	21.1465
2	Curved Shaped with 5 Spokes	-44.7582	-45.048	-6.17717	63.8027
3	Inclined Shape with 3 Spokes	-43.771	-43.9401	101.58	119.018
4	Inclined Shape with 5 Spokes	-44.3055	-44.4023	0.268934	62.7265
5	Linear Bar Shaped with 3 Spokes	-44.7271	-44.5458	0.468408	63.1273
6	Linear Bar Shaped with 5 Spokes	-44.6616	0.10348	44.8522	63.296
7	Triangle Shape with 3 Spokes	-44.6403	-44.595	-0.0870679	63.0989
8	Triangle Shape with 5 Spokes	-44.5602	-44.458	-0.423745	62.9468
9	V curved shape with pad with 3 Spokes	-44.3453	-44.4348	0.50748	62.7791
10	V curved shape with pad with 5 Spokes	-44.6819	-44.6136	0.337728	63.1424
11	V Shape with 3 Spokes	-44.0618	-44.4794	-0.184608	62.6091
12	V Shape with 5 Spokes	-44.2071	-45.2116	-0.151035	63.2327

Reactions at the hub and the resultants

Table 3 Reaction at the hub for the different wheel variations

SN	Wheel Shape and type	Reaction forces			
		X	Y	Z	Resultant
1	**Curved Shaped with 3 Spokes**	-9.20333	-19.032	-0.509528	21.1465
2	**Curved Shaped with 5 Spokes**	-44.7582	-45.048	-6.17717	63.8027
3	**Inclined Shape with 3 Spokes**	-43.771	-43.9401	101.58	119.018
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Stress contours
The following are the stress contours for the Curved, inclined and v curved shape spokes.

Analysis type	Failure criterion	Min Stress	Max Stress
Stress	VON: von Mises Stress	0.0N/mm^2 (MPa) Node: 25539	329.7N/mm^2 (MPa) Node: 16148

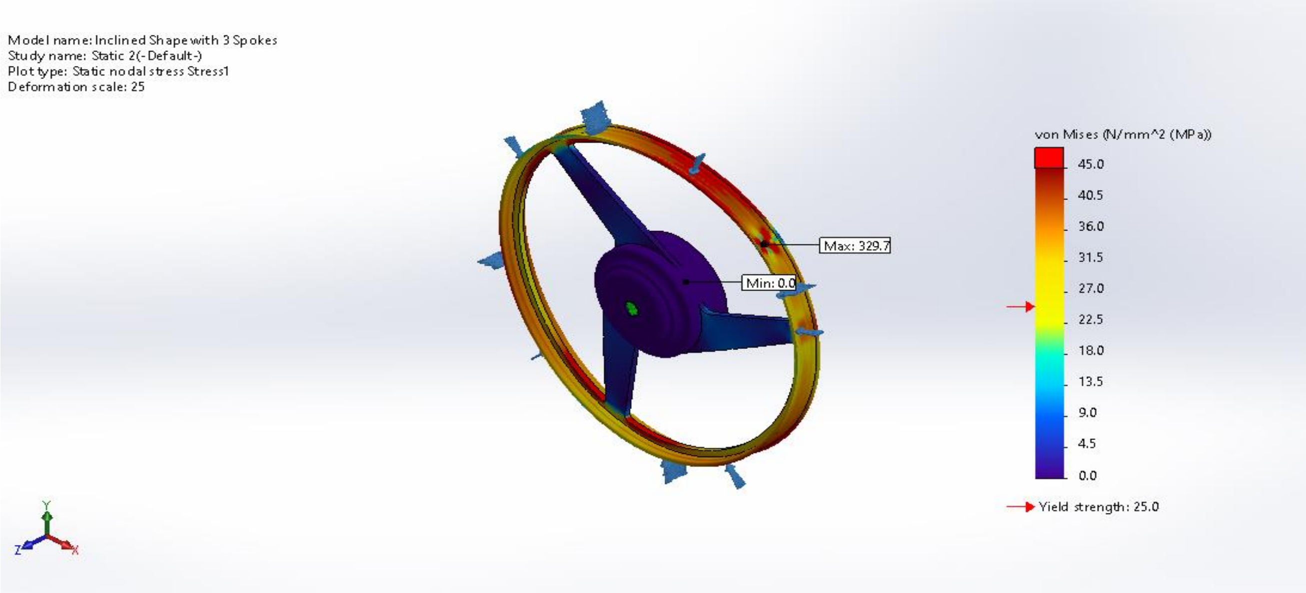

Fig. 10 Stress contour for Inclined Shape with 3 Spokes

Analysis type	Failure criterion	Min Stress	Max Stress
Stress	VON: von Mises Stress	0.0N/mm^2 (MPa) Node: 27154	781.3N/mm^2 (MPa) Node: 28360

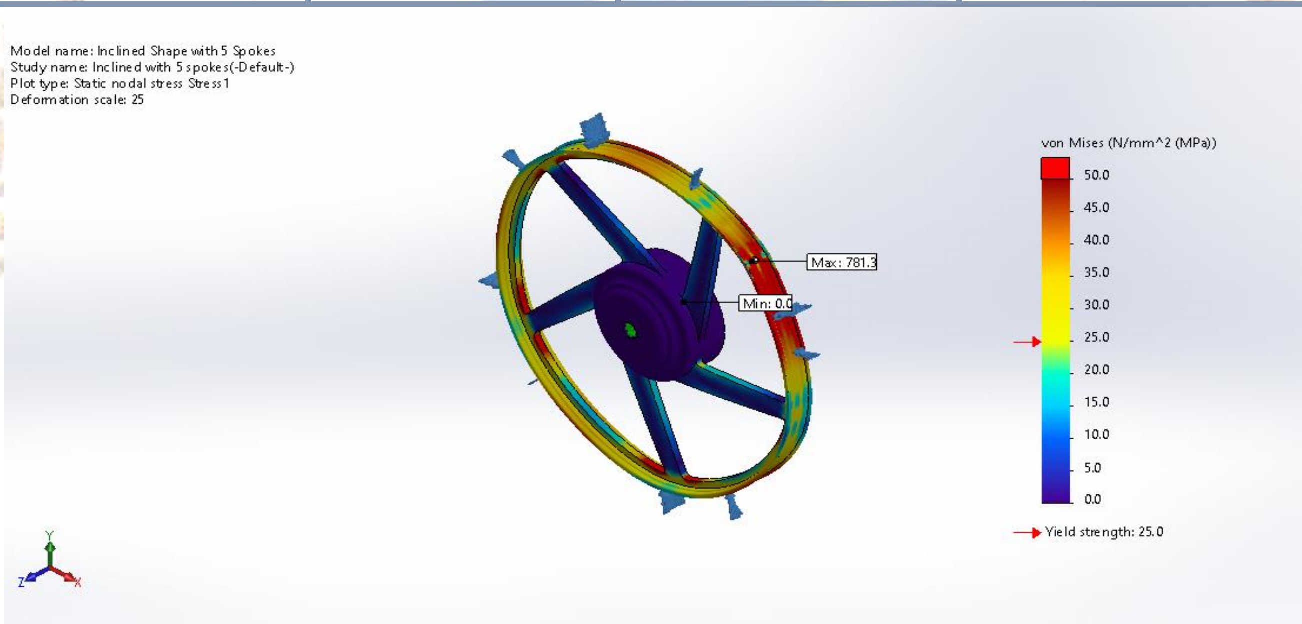

Fig. 11 Stress contour for Inclined Shape with 5 Spokes

Stress	VON: von Mises Stress	0.0N/mm^2 (MPa) Node: 24467	165.4N/mm^2 (MPa) Node: 9839

Analysis type	Failure criterion	Min Stress	Max Stress

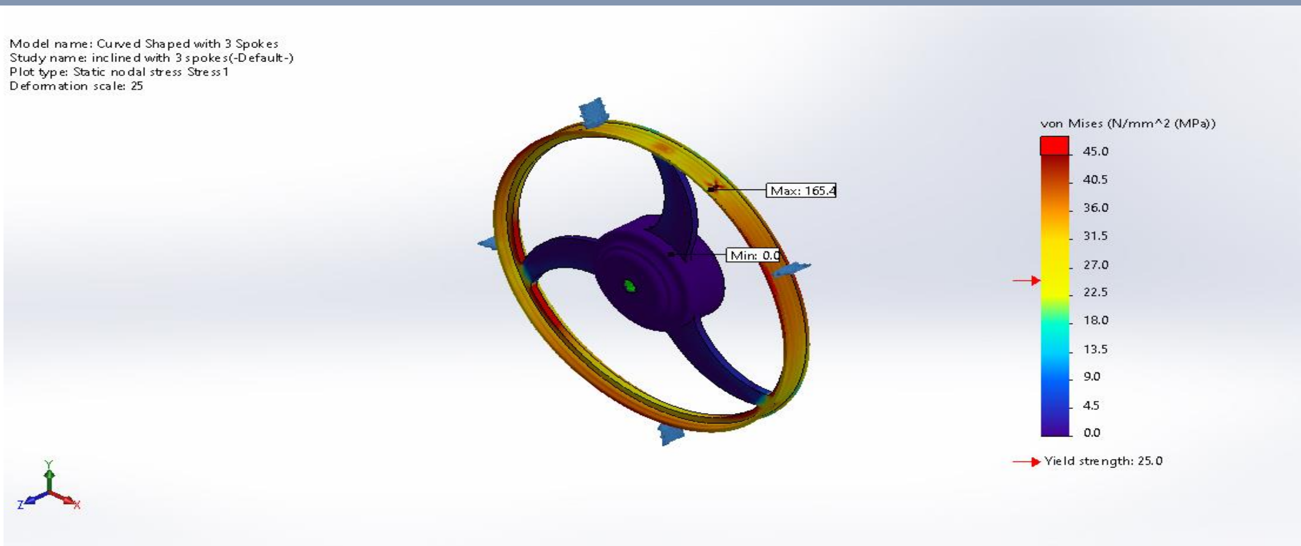

Fig. 12 Stress contour for Curved Shaped with 3 Spokes

Analysis type	Failure criterion	Min Stress	Max Stress
Stress	VON: von Mises Stress	0.003066N/mm^2 (MPa) Node: 24245	146.6N/mm^2 (MPa) Node: 51393

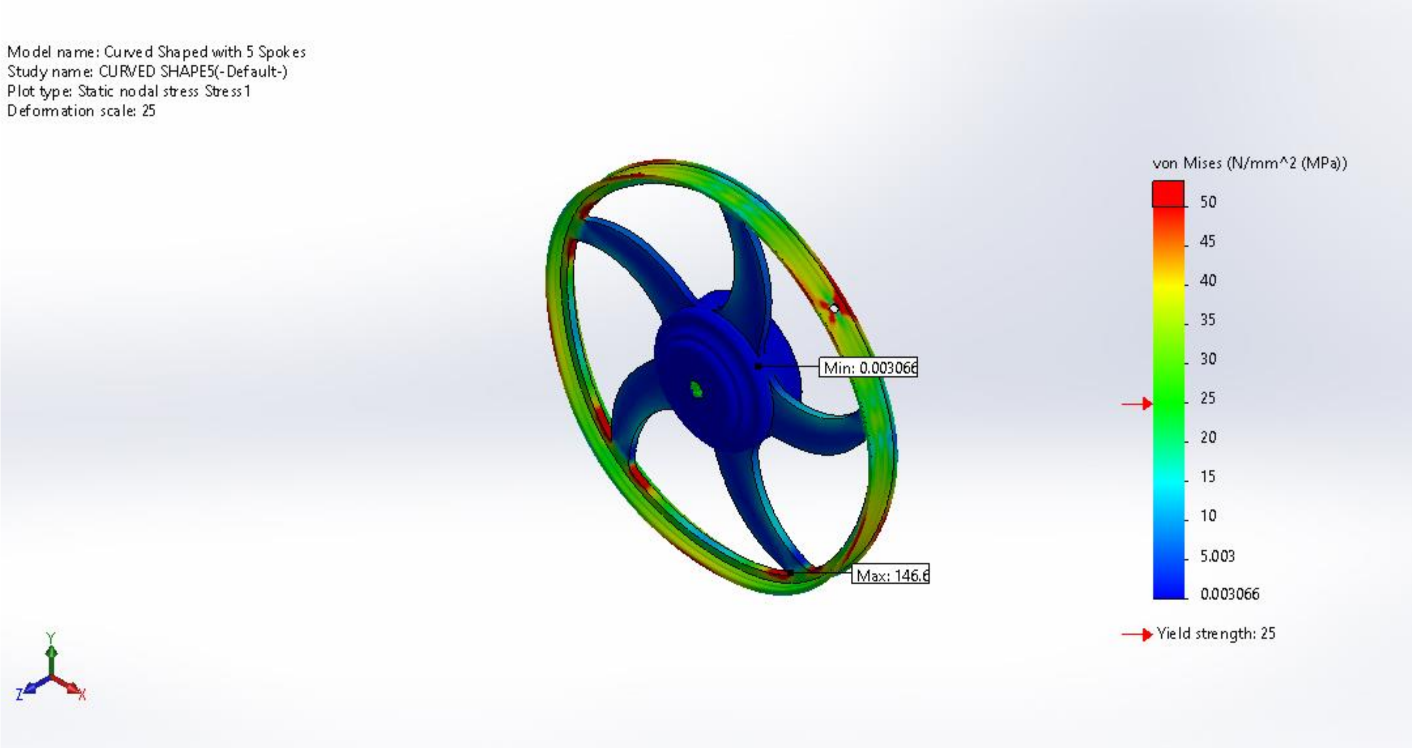

Fig. 13 Stress contour for Curved Shaped with 5 Spokes

Analysis type	Failure criterion	Min Stress	Max Stress
Stress	VON: von Mises Stress	0.00N/mm^2 (MPa) Node: 57817	534.11N/mm^2 (MPa) Node: 26940

Analysis type	Failure criterion	Min Stress	Max Stress

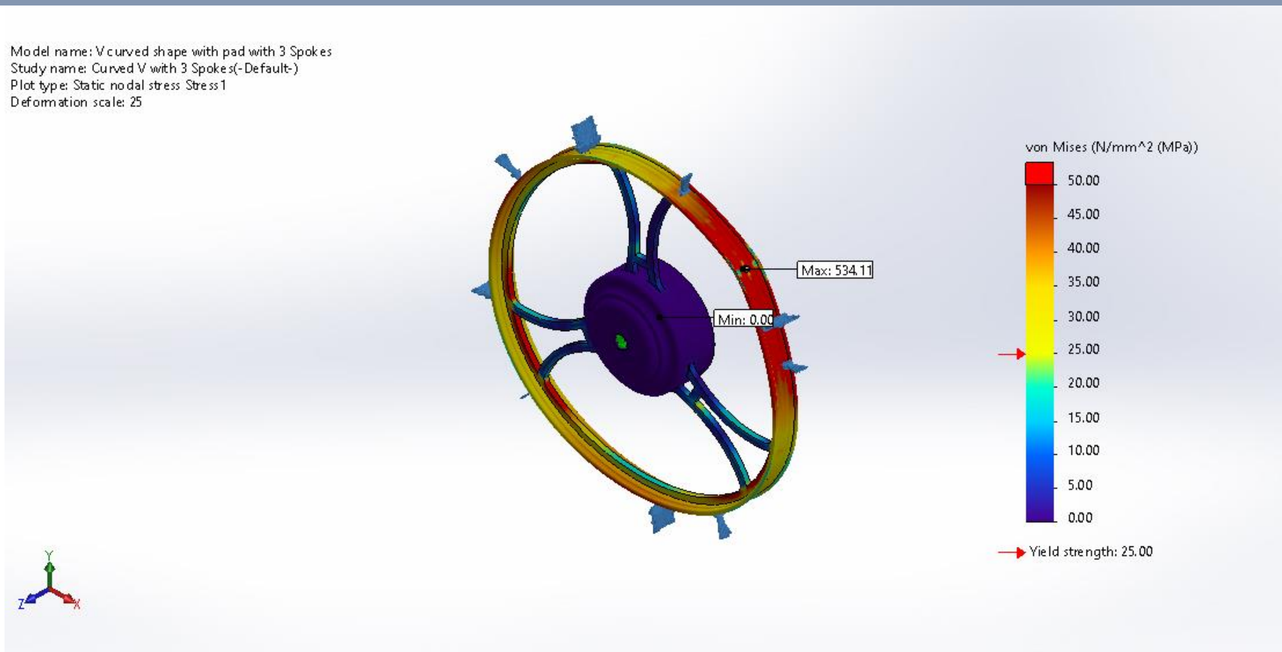

Fig. 14 Stress contour for V curved shape with pad with 3 Spokes

Analysis type	Failure criterion	Min Stress	Max Stress
Stress	VON: von Mises Stress	0.005257N/mm^2 (MPa) Node: 56904	336.3N/mm^2 (MPa) Node: 26693

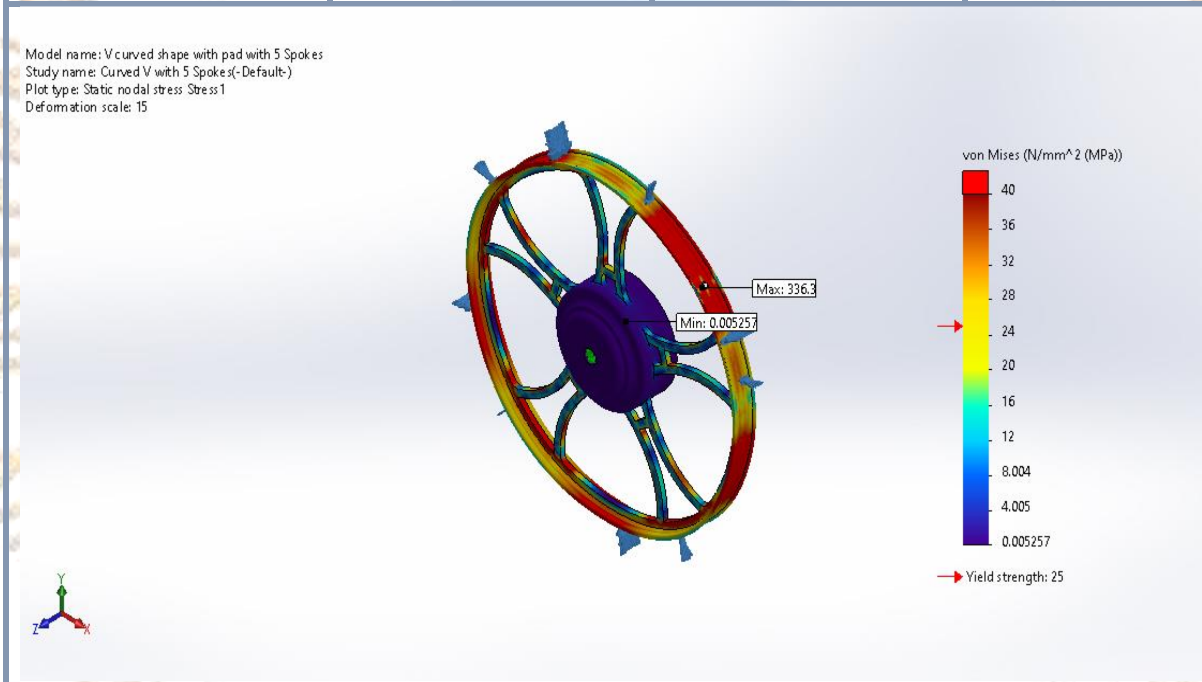

Fig. 15 Stress contour for V curved shape with pad with 5 Spokes

Displacement contours

Analysis type	Displacement type	Min Displacement	Max Displacement
Displacement	Resultant Displacement	0mm Node: 9615	0.3163mm Node: 33916

Analysis type	Displacement type	Min Displacement	Max Displacement

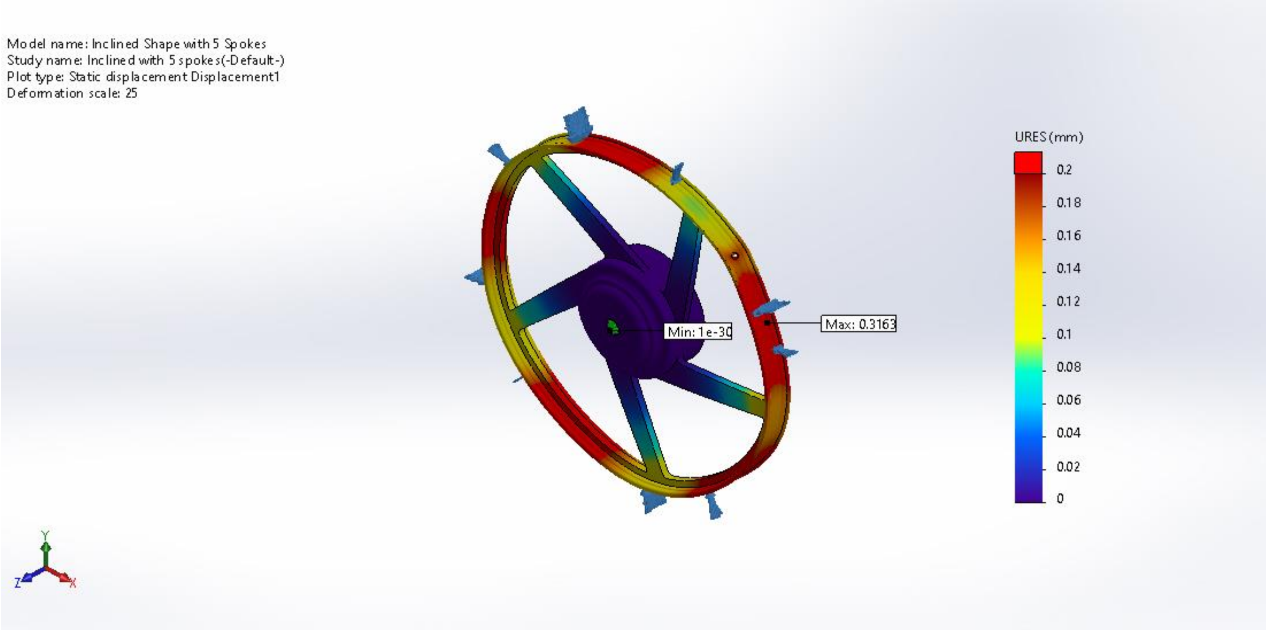

Fig. 16 Displacement contour for Inclined Shape with 5 Spokes

Analysis type	Displacement type	Min Displacement	Max Displacement
Displacement	Resultant Displacement	0mm Node: 9411	0.512mm Node: 12617

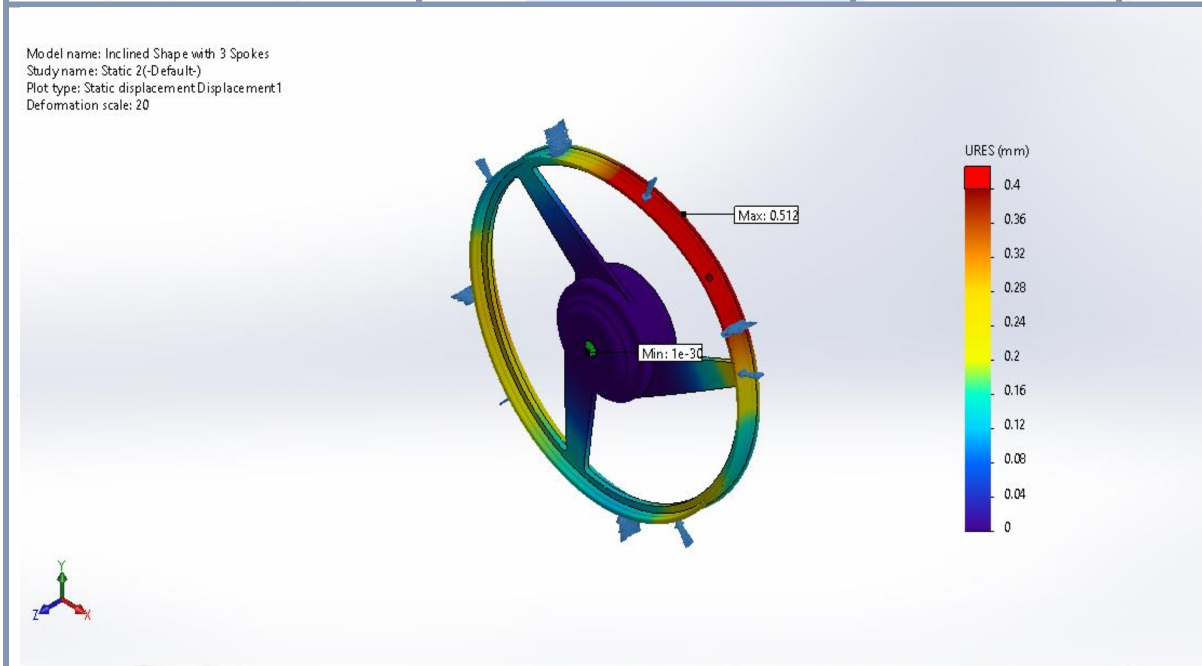

Fig. 17 Displacement contour for Inclined Shape with 3 Spokes

Displacement	Resultant Displacement	0mm Node: 8967	0.2596mm Node: 35697

Analysis type	Displacement type	Min Displacement	Max Displacement

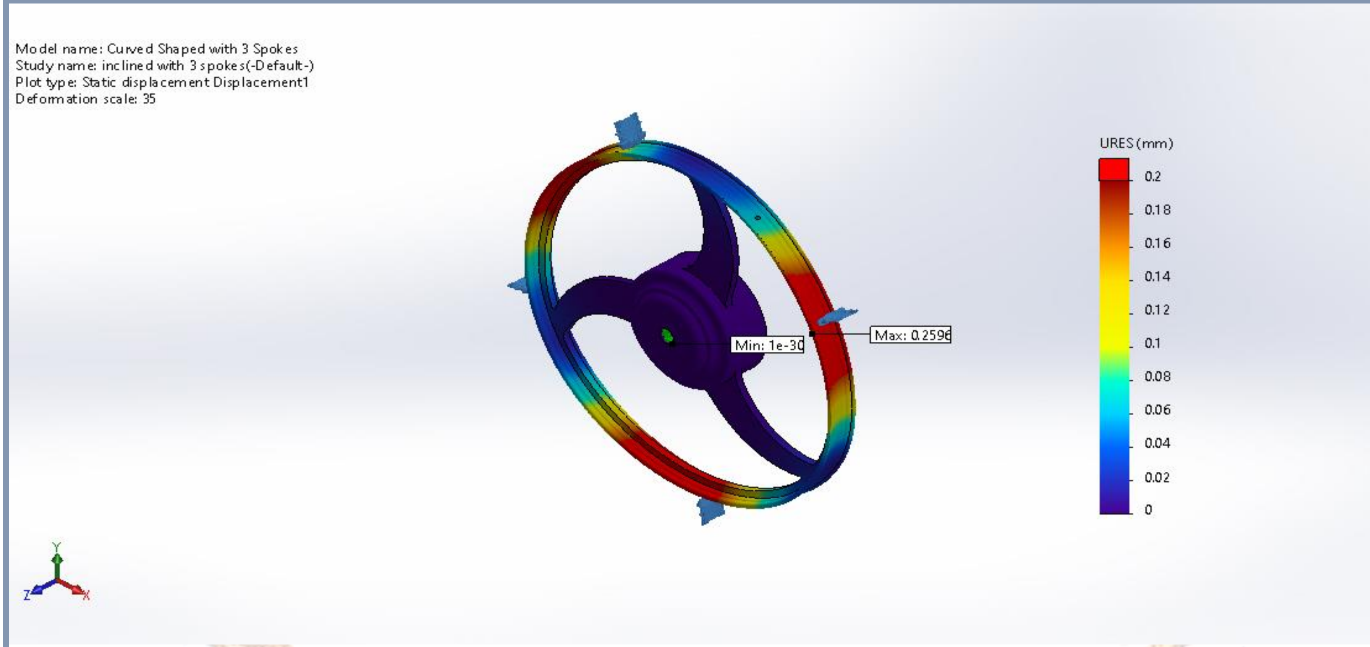

Fig. 18 Displacement contour for Curved Shaped with 3 Spokes

Analysis type	Displacement type	Min Displacement	Max Displacement
Displacement	Resultant Displacement	0mm Node: 8907	0.2186mm Node: 37249

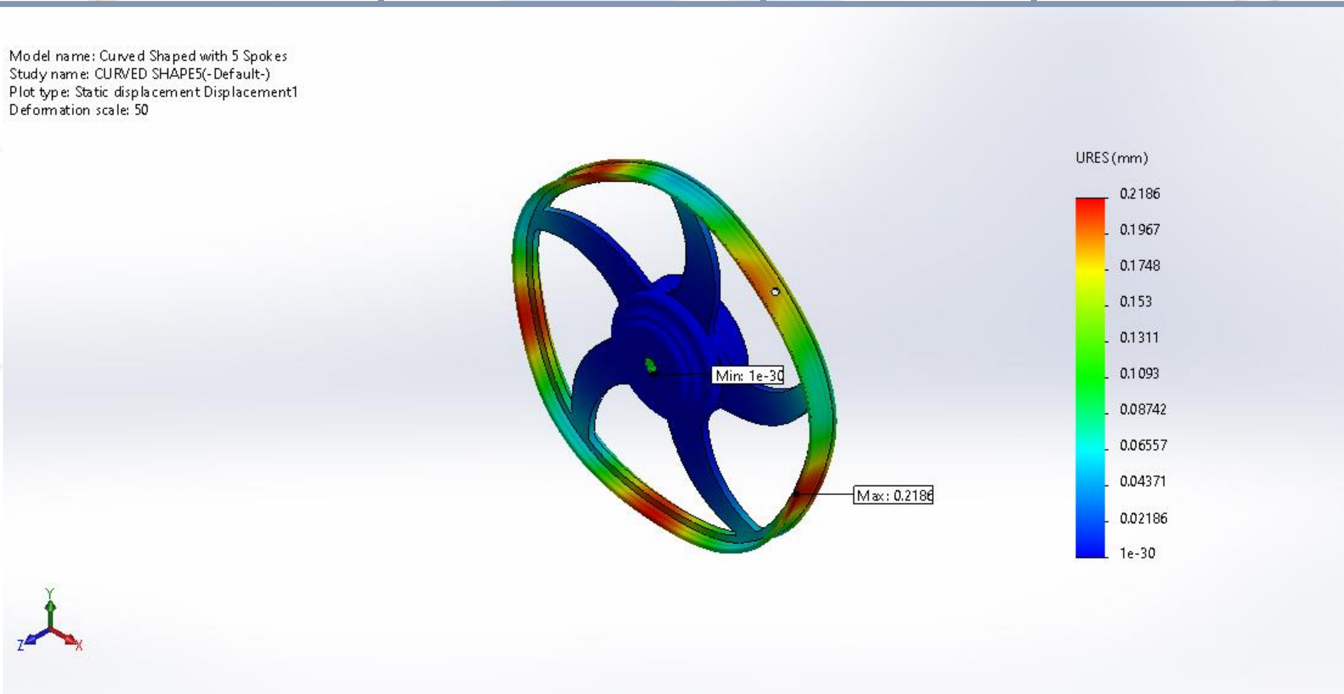

Fig. 19 Displacement contour for Curved Shaped with 5 Spokes

Displacement	Resultant Displacement	0mm Node: 9116	0.418mm Node: 5470

Analysis type	Displacement type	Min Displacement	Max Displacement

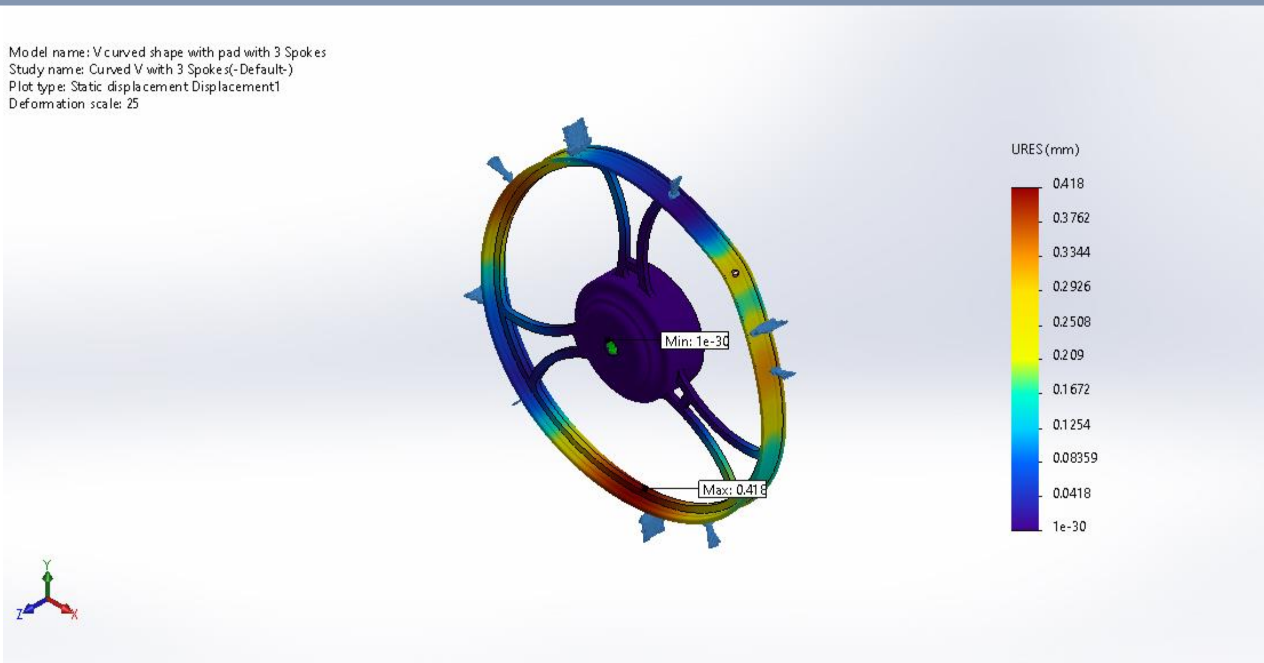

Fig. 20 Displacement contour for V curved shape with pad with 3 Spokes

Analysis type	Displacement type	Min Displacement	Max Displacement
Displacement	Resultant Displacement	0mm Node: 8920	0.2519mm Node: 21490

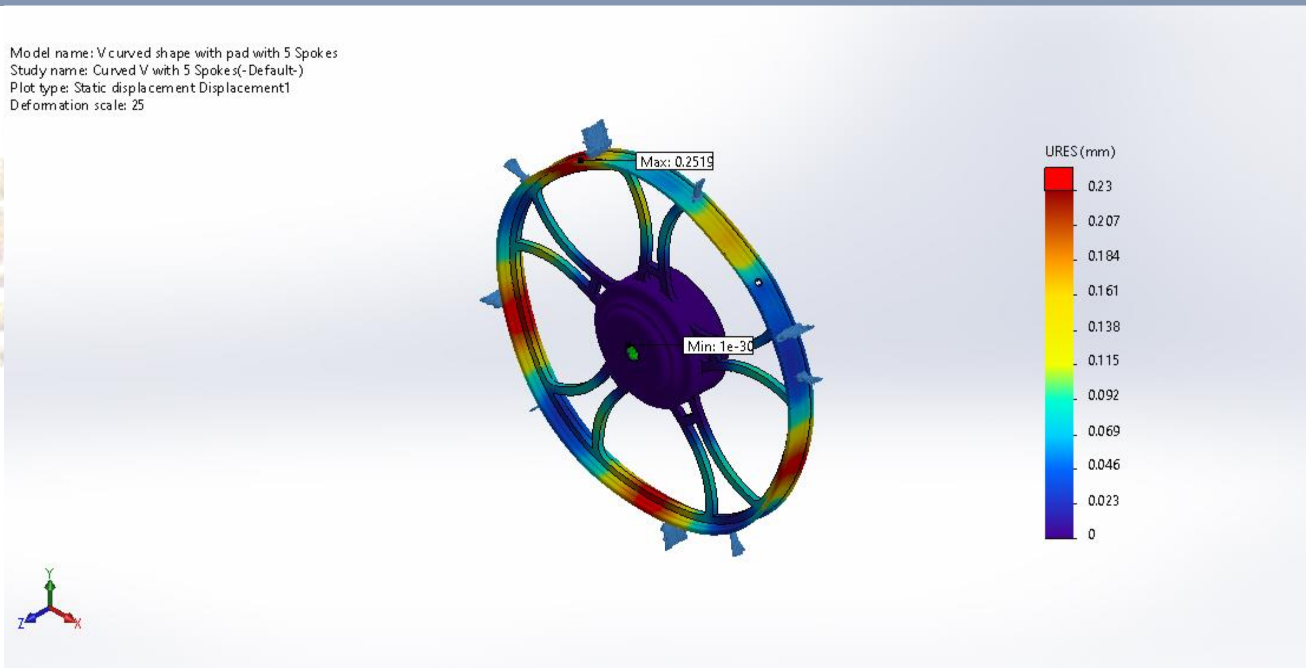

Fig. 21 Displacement contour for V curved shape with pad with 5 Spokes

Strain Contours

Analysis type	Strain Type	Min Strain	Max Strain
Strain	Equivalent Strain	9.316e-09 Node: 25539	0.004364 Node: 16148

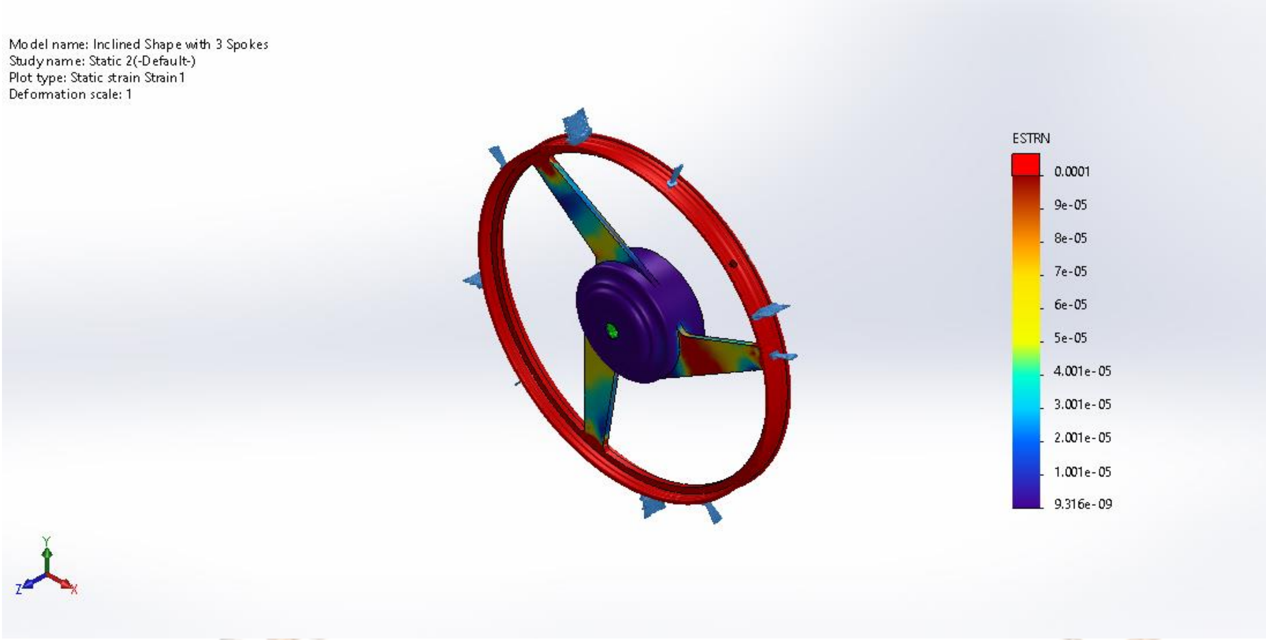

Fig. 22 Strain contour for Inclined Shape with 3 Spokes

Analysis type	Strain Type	Min Strain	Max Strain
Strain	Equivalent Strain	3.358e-08 Node: 27154	0.01034 Node: 28360

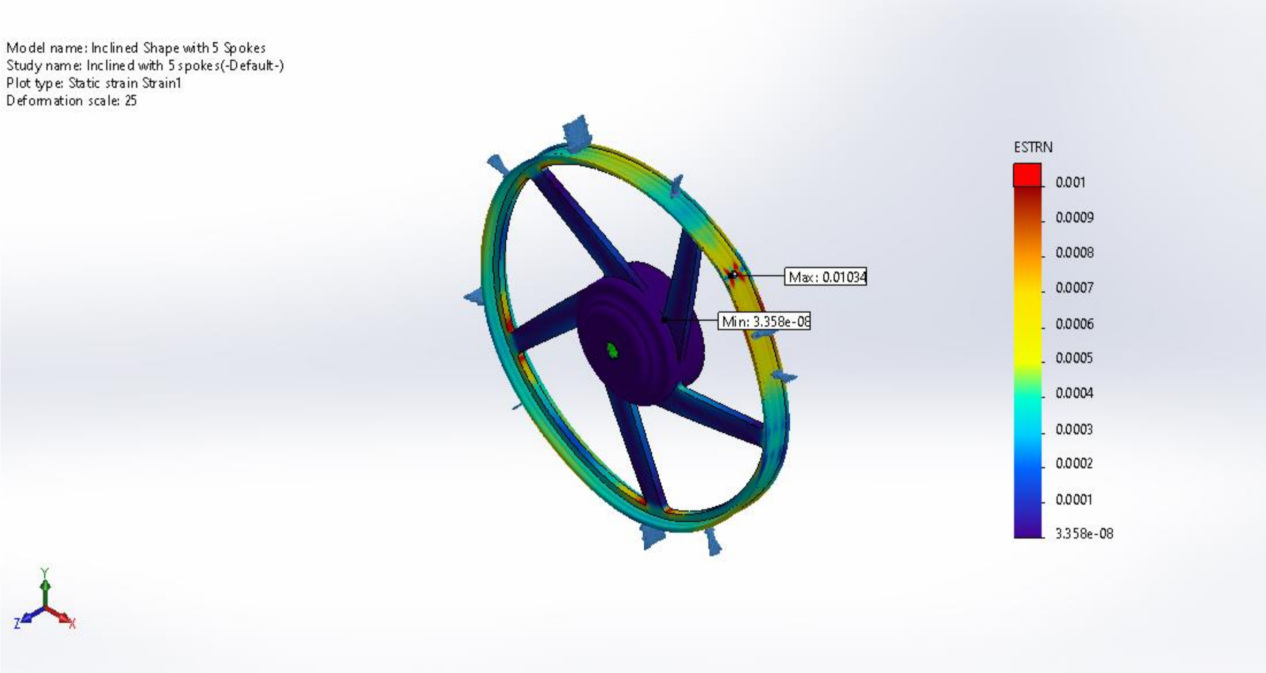

Fig. 23 Strain contour for Inclined Shape with 5 Spokes

Analysis type	Strain Type	Min Strain	Max Strain
Strain	Equivalent Strain	5.352e-09 Node: 24467	0.002189 Node: 9839

Analysis type	Strain Type	Min Strain	Max Strain

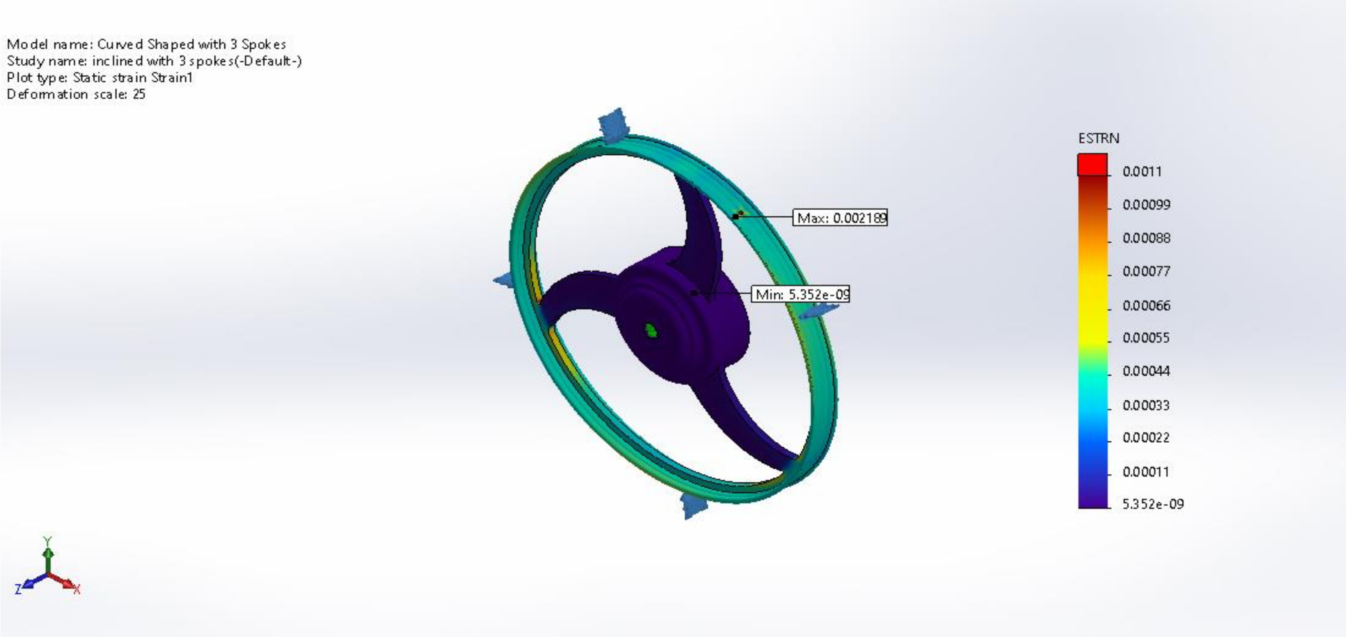

Fig. 24 Strain contour for Curved Shaped with 3 Spokes

Analysis type	Strain Type	Min Strain	Max Strain
Strain	Equivalent Strain	5.287e-08 Element: 22035	0.001751 Element: 40968

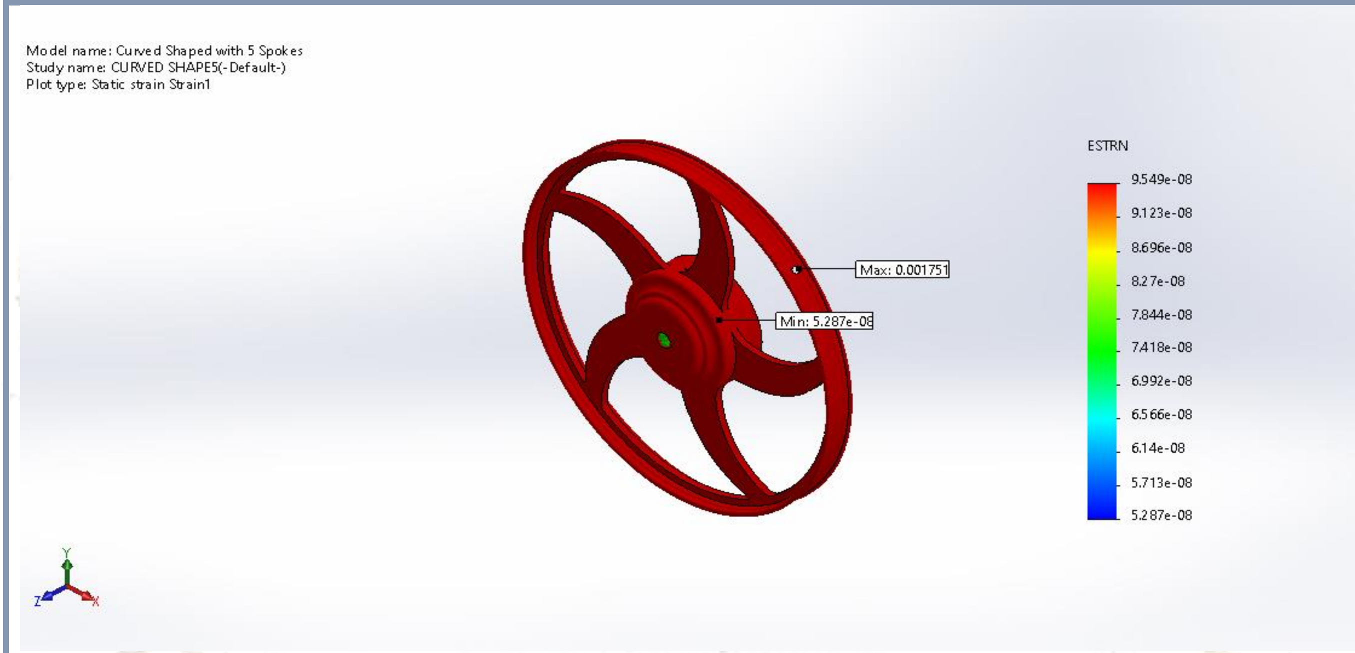

Fig. 25 Strain contour for Curved Shaped with 5 Spokes

Analysis type	Strain Type	Min Strain	Max Strain
Strain	Equivalent Strain	1.063e-08 Node: 57817	0.007069 Node: 26940

Analysis type	Strain Type	Min Strain	Max Strain

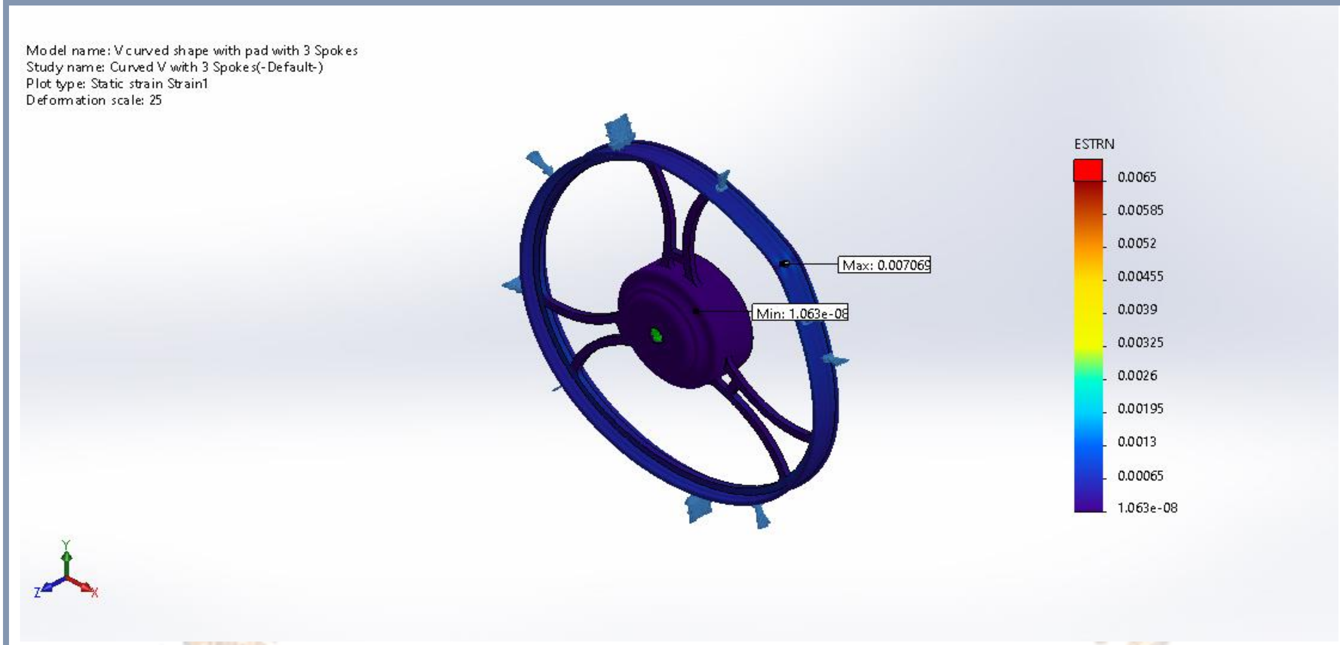

Fig. 26 Strain contour for V curved shape with pad with 3 Spokes

Analysis type	Strain Type	Min Strain	Max Strain
Strain	Equivalent Strain	6.957e-08 Node: 56904	0.004452 Node: 26693

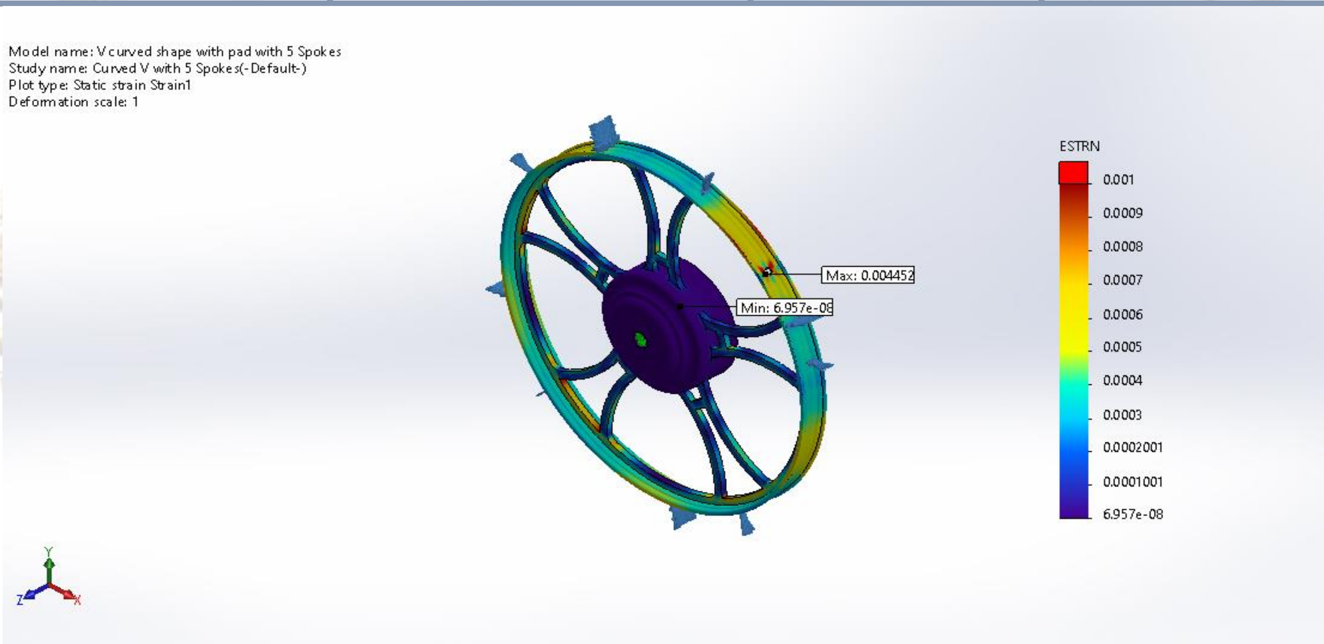

Fig. 27 Strain contour for V curved shape with pad with 5 Spokes

Discussion and Analysis of results

The results obtained from the test are analysed and discussed to determine the wheel variant that can withstand the highest stress, the displacement observed, and its stress-strain characteristics using the Stress-strain curve.

1. **Stress comparison of the wheel variants**

Table 4 shows the maximum, average and minimum stresses induced in the six selected models. It is observed that the wheel with inclined shape and 5 spokes has the highest stress value of 781.3 N/mm^2. This version of the wheel is most suitable for use under the same loading condition as it can withstand more stress than the other types of wheels.

Table 4 Average maximum, and minimum stress in the six selected models

	Stress (N/mm^2)		
Design	Average	Maximum	Minimum
Inclined shape with 3 spokes	98.4	329.7	11.4
Inclined shape with 5 spokes	83.8	781.3	6.524
Curved shape with 3 spokes	73.85	165.4	18.52
Curved shape with 5 spokes	74.27	146.6	11.55

Curved V shape with 3 spokes	91.96	534.11	1.4
Curved V shape with 5 spokes	65.82	336.3	1.127

2. Point of maximum displacement

The maximum displacements observed in the wheel variants are represented in table 5.

Table 5 Maximum displacement in the selected models

Wheel Shape and type	Displacement (mm)
Inclined shape with 3 spokes	0.5120
Inclined shape with 5 spokes	0.1630
Curved shape with 3 spokes	0.2596
Curved shape with 5 spokes	0.2186
Curved V shape with 3 spokes	0.4180
Curved V shape with 5 spokes	0.2519

From table 5 the wheel with the highest displacement is the wheel with inclined shape and 3 spokes. With a displacement of 0.512 mm, at the failure pressure of 329.7 N/m^2, it starts to fail from the part of the circumference closest to the air hole. Conversely, the wheel with inclined shape and 5 spokes has the least displacement of 0.1630 mm under same loading condition. As evident in table 4 and table 5, it is also the wheel with the highest stress capacity.

3. The critical point of failure

From the stress contours in figure 4.1 to 4.6, it is observed that all the wheels except the wheel with curved shape and 5 spokes, have peak stress levels at the air hole. It is also observed from the stress results that the nodes with least stress in all the wheel variants are at the inner section of the wheel hub. For the wheel with inclined shape and 5 spokes, the point of critical failure is at the air hole. With stress value of 781.3 N/mm^2 and maximum displacement of 0.163 mm when subjected to the same load condition as the other wheels.

4. Stress-strain characteristics

A probe test was conducted in the air hole region to ascertain the stress to strain relationship of the nodal elements in the hole. Table 6 shows the nodes and their corresponding stress and strain observed in the nodes in that region. For the sakes of simplification, 10 nodal samples were selected and used to plot the graph of stress against strain as shown in Fig 28.

Table 6 Stress-Strain values for 10 nodes in the air hole region

Node	Strain	Stress
1	0.00099	74.8
2	1.20E-05	0.9
73	8.45E-05	6.4
74	0.000102	7.7
75	0.000893	67.4
76	0.000894	67.5
77	0.000982	74.2
78	0.001113	84.1
79	0.001492	112.7
80	0.00638	482

As seen in the graph (Fig. 28), The stress-strain curve follows a linear path and gradually begins to curve as one approaches the nodes at the out exterior pars of the hole. This is consistent with theoretical representation of stress-strain relationship for ductile materials. Since the nodal elements used in the plot of the graph do not involve the element that failed, the point of failure is not represented in the graph.

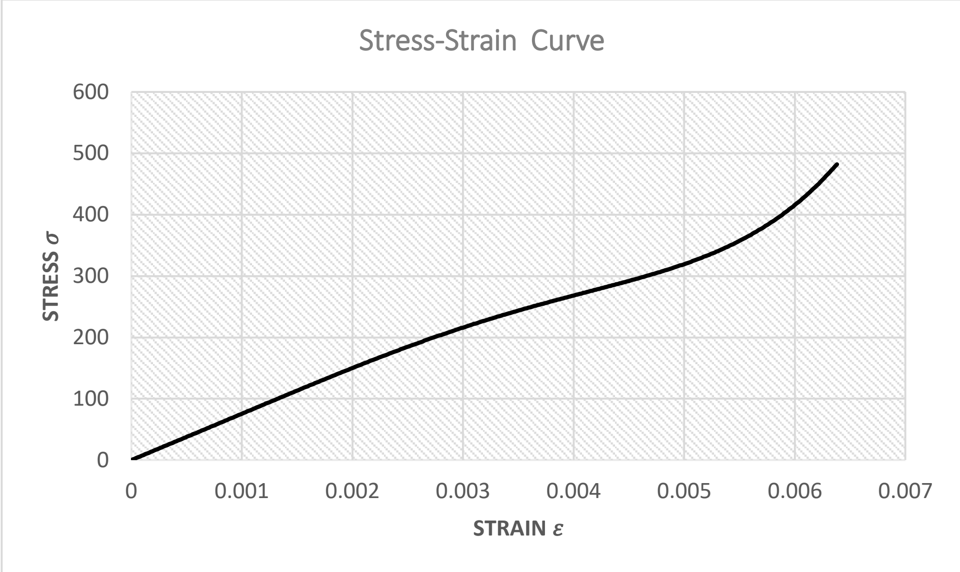

Fig. 28 Graph of Stress-strain of 10 nodal elements in the air hole of the wheel with inclined shaped 5 spokes

Findings and Deductions from the Study

The following findings and hypothesis can be made from this study

1. The curved shaped wheels with 5 spokes had the most mass and would cost more to produce despite not having the highest stress resistance (see table 1).
2. Under the same pressure loading conditions, the reactions at the support were different for the different wheels.
3. The stress concentrations as shown in the stress contours from fig. 1 to 6, are highest at the air hole region, except for the curved shaped and 5 spokes wheel which have the highest stress concentrations at the point of contact between the spokes and the outer section of the wheel.
4. The region of highest deflection (displacement) do not always coincide with the region of highest stress. Highest displacements are mostly close to the hole region but at nodes, goes furthest away from the spokes.
5. The wheels with 3 spokes had more displacements than the wheel with 5 spokes. Conversely, the wheels with 5 spokes could withstand more stress than the wheels with 3 spokes.
6. In most cases, large portion of the wheel is subjected to almost similar strain values as seen in the almost uniform coloration of the strain contours (see fig. 22 to 27).
7. The wheel with inclined shaped 5 spokes is best suited for the pressure loading conditions.

V. CONCLUSION

The simulation result showed that the maximum stress of 781.3 N/mm^2 can be obtained from wheel designed with the base dimension of the Bajaj CT 125X motorcycle with 5 inclined spokes. The critical point of failure is nodal elements in the air hole area. Judging by the comparison of results, other variants of the motorcycle wheel such as the curved and curved V shaped 5 spokes had more mass but could only support the maximum stress of 146.6 MPa and 336.3 MPa respectively. Highest displacements of the magnitude of 0.2 mm to 0.4 mm were observed at the regions furthest from the spokes. Thus, reinforcements can be made to resist the shear forces at the air hole region and bending stresses at the regions furthest away from the spokes.

Recommendations

i. According to the FEA results of the baseline design, the aluminum alloy rim design could be improved by reinforcing the weaker area and revising the geometry of the spokes and the number of spokes.

ii. Since the wheel is majorly used in motion, a study on the vibration and thermal characteristics of the wheels in motion using similar or same loading conditions should be carried out before the results in this study can be applied to real life designs.

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