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Numerical Analysis of Novel Design for Torque Coupler

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Abstract*: Design of torque coupling system is an important phase in the development of a hybrid vehicle. In a parallel hybrid vehicle, it is required to couple torque from 2 sources. A torque coupling system is required for the same. The system so used could be electronically or mechanically operated. Various designs for torque coupling systems have been developed in the past. In this paper, a novel design for torque coupling is developed using SolidWorks tool. This model aims at reducing the number of parts involved in torque coupling and thereby reducing the mass of the entire torque coupling system. A stress analysis of the new model is done to confirm this achievement. A comparative study of other designs of torque coupling is also done. The calculation and verification of total torque is followed in designing the coupler. The main objective is to create a lighter and simpler torque coupling mechanism. The analyses are done in ANSYS to study and understand the stress and strain distribution in the coupler.

Keywords: Torque Coupler, numerical simulation, Shear Stress analysis, total deformation distribution, Parallel hybrid power-train, Hybrid electric vehicle

I. INTRODUCTION

Torque coupling system is the most significant part of a parallel hybrid vehicle. Planetary gear systems and multiple differential gear systems are the most commonly used methods for torque coupling in a parallel hybrid vehicle. Some parallel hybrid power-trains also use electronic clutches to achieve torque coupling. During torque coupling, the individual torque delivered by the primary movers is compounded. In this paper a torque coupling mechanism where 2 primary movers, one internal combustion engine and an electric motor are coupled using the designed torque coupler. The output from both primary movers is delivered to the coupler through chain drive. The compounded torque is delivered to the crown gear of the differential for the purpose of driving the vehicle.
In the past, many studies have been conducted on designing various torque coupling mechanisms. C L Wang [1] achieved torque coupling with electronic controlled clutch system and dual driven air conditioning system. The study also involved use of ultra-capacitors in parallel hybrid powertrain. Rahman Z [2] conducted a comparative study between two parallel hybrid control concepts, ‘Thermostat’ and ‘power split’. To achieve a substantial improvement in fuel economy, the ‘thermostat’ control technique intended to improve the fuel efficiency of a series Hybrid Electric vehicle is adopted and designed for parallel Hybrid vehicle in this study. Among different ‘power split’ concepts developed for parallel hybrids only the ‘electrically assist’ algorithm is considered. These two control concepts are compared for three parallel HEV architectures: pre-transmission, post-transmission and continuous variable transmission hybrids. Yimin Gao, M Ehsani [3] introduced a torque and speed coupling hybrid drive-train. In this drivetrain, a planetary gear unit and a generator/motor decouple the engine speed from the vehicle wheel speed. Another shaft-fixed gear unit and traction motor decouple the engine torque from the vehicle wheel torque. Thus, the engine can operate within its optimal speed and torque region, and at the same time, can directly deliver its torque to the driven wheels. The paper discussed the fundamental architecture, design, control, and simulation of the drivetrain. Tai-Her Yang [4] discussed differential coupling and compound power system for a vehicle wherein magnetic coupling is used for power system compounding. Wolfgang Kriegler [5] invented a hybrid drive system wherein 3 primary movers, one in steady state mode and the other two in transient mode. Gradu M [6] discusses an alternate method of torque coupling specifically designed to convert a front wheel drive vehicle into an all-wheel drive vehicle. In this study, CAD models using Sloid Works and ANSYS are used to develop new models and determine the stress and strain distribution for each of the models.
In this paper, a novel design based on certain requirements of the vehicle (SAE IEEE formula hybrid vehicle) is presented. The objective is twofold, to reduce the number of mating parts and also to reduce the overall weight of the vehicle, keeping the strength of the component in consideration. Reducing weight of the component is achieved by removing material from the component by cutting holes of different shapes. The purpose of a torque coupler is to compound the individual torque delivered by primary movers and deliver it to wheels. A function previously served by planetary gear-set, multiple differential gear-sets or electronic clutches is

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obtained with a single component torque coupling mechanism. Numerical analysis of the coupler so designed is done with the help of ANSYS analysis software.

II. THEORY

The theory behind calculation of maximum torque appearing on the coupling element is discussed in this section. In order to calculate the maximum torque, it is required to know the torque response of both the primary movers in the parallel hybrid power-train. The 2 primary movers used are KTM Duke 200cc liquid cooled Spark Ignition engine and AGNI 95R (72V) pancake motor. Since the direction of rotation is same for both the primary movers, larger value of the 2 individual maximum toque would be the maximum shearing torque experienced by the coupler.

Maximum Torque delivered by the KTM duke 200 engine is 19.2 NM.

Maximum Torque delivered by AGNI 95 R motor is obtained from the Torque response sheet of AGNI 95 R.

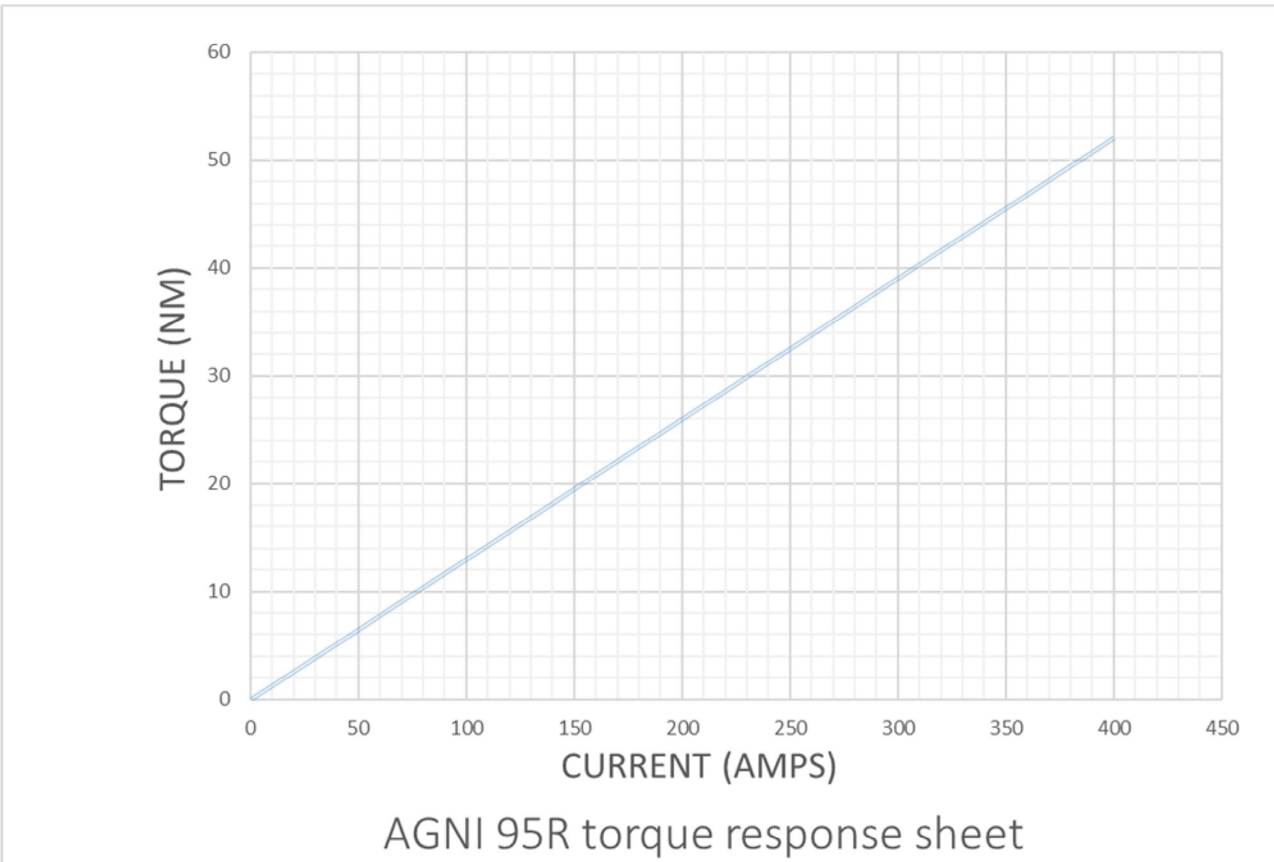

Fig 1: Torque response sheet – AGNI 95-R

From the Torque Vs current plot for AGNI 95 R , it is found that the maximum torque delivered is 52 NM at 400 amperes.

The 52 NM torque delivered by the pancake motor is hence used for designing the torque coupler. Even though the net torque being transmitted by the coupler to the differential gearset would be the summation of torque delivered by the IC engine and the electric motor, the maximum shearing torque appearing on the coupler would be maximum of the 2 individual torques which was found to be 52 NM.

III.DESIGN

In this paper two designs are considered, chosen with the intention of reduction of weight and interfering parts. A plain dual sprocket design with no cuts in middle and another dual sprocket design with non-circular holes in the cylindrical part joining the two sprockets and circular holes on the face of sprockets. The designs are shown in the figures below. In the second proposed design, holes are cut in the cylindrical part connecting the 2 sprockets to reduce the overall weight of the coupler.

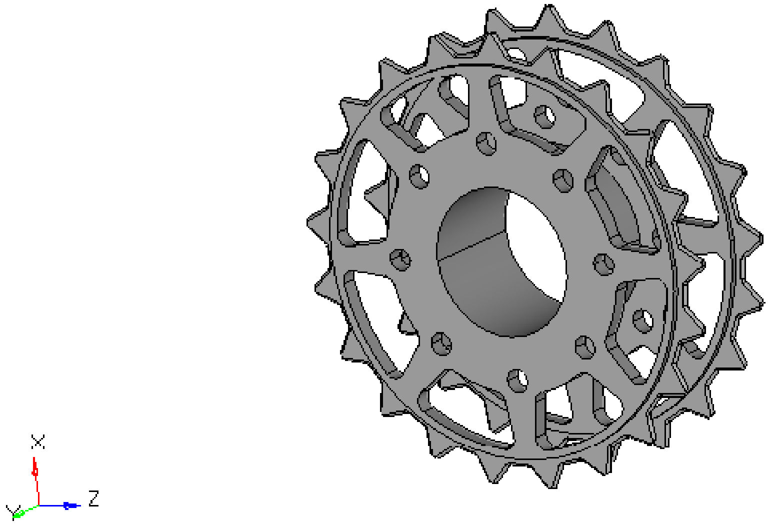

Fig. 2 proposed first design

Various designs proposed in the past use methods to couple torque in a parallel hybrid with the help of multiple differential gear systems or planetary gear systems. While these methods are functional, these designs are also bulky. As the number of mating parts increases, a considerable drop in mechanical efficiency is incurred. In this paper, we have reduced the number of mating parts and brought down the overall weight of the coupler by cutting holes on the component and thereby removing material.

Fig. 3: Proposed improved design

The next factor considered is strength of the coupler. This must be considered when the coupler involves thin sections, which is a result of cutting out large sections of materials from the cylindrical part. Thin sections on the coupler reduces the strength of the component, making it susceptible to high stresses or bending. Hence it is decided not to go for thin sections. Hence, material is removed from the cylindrical part of the coupler and from the face of sprockets, however care is taken to ensure that there are no thin sections formed in the coupler.

IV.MATERIAL

The widely used material for sprocket manufacturing is cast iron which consumes much fuel due to its high specific gravity.The torque coupling system is a vital performance component for a parallel hybrid vehicle; hence the structural materials used in the coupler should have some combination of properties such as good compressive strength, shear strength, wear resistant, light weight, good thermal capacity and economically viable [14]. The materials used for usual sprockets are Cast Iron, Steel and Stainless Steel. Grey Cast iron is usually used with dissolved carbon within its matrix between 2% and 4.5%. It is economically viable, thermally stable and easy to manufacture. While Steels and Stainless steels have higher density compared to gray cast iron, they also have high temperature strength and better resistance to corrosion [15]. The coupler is subjected to continuous shearing action as the two primary movers try to drive the coupler at their respective velocities. Hence shear strength of the material chosen is of utmost importance. While Gray cast iron is an economically viable option and has higher compressive strength compared to stainless steel, it has a lower shear strength than Stainless Steel. Hence, due to shear strength requirement, AISI 201 Stainless Steel is chosen as the material for coupler.

TABLE I
MATERIAL PROPERTIES

Parameter	Value
Material	AISI 201 stainless steel
Density	7.8 g/cm3
Poisson's ratio	0.28
Young's Modulus	200GPa

V. CAD MODEL AND MESH DETAILS

The cad model for the coupler is shown in figure. The overall dimensions are marked in the figure. The CAD model was created using SolidWorks. The total diameter of the disc is180 mm and the thickness is 3.40 mm. The hole diameters are 5 mm. A triangular mesh was applied and the element size was fixed after a convergence test. The meshed models are shown in the below table. Mesh convergence is a study to find the optimum element size to be used to capture the geometry and give the stress and displacements with more distributed results. For this a coarse mesh is taken at first and the analysis is run, then the mesh is refined with smaller element size and analysis is run again. This iteration is repeated until the values of stress or strain will no more change and give similar results even for finer mesh size.

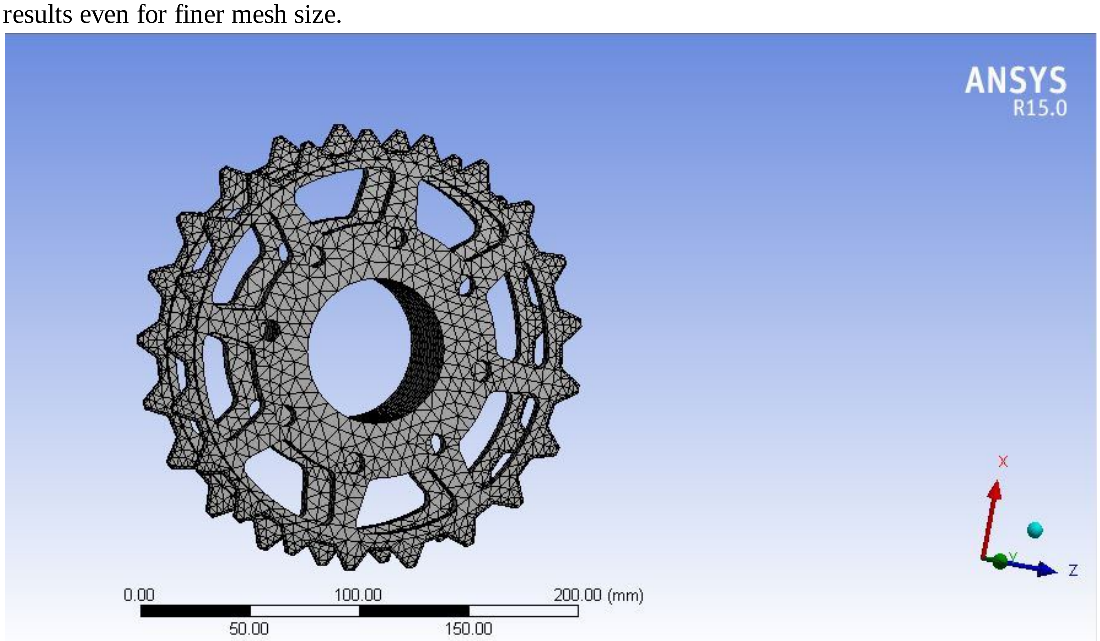

Fig. 4 Meshed component first design

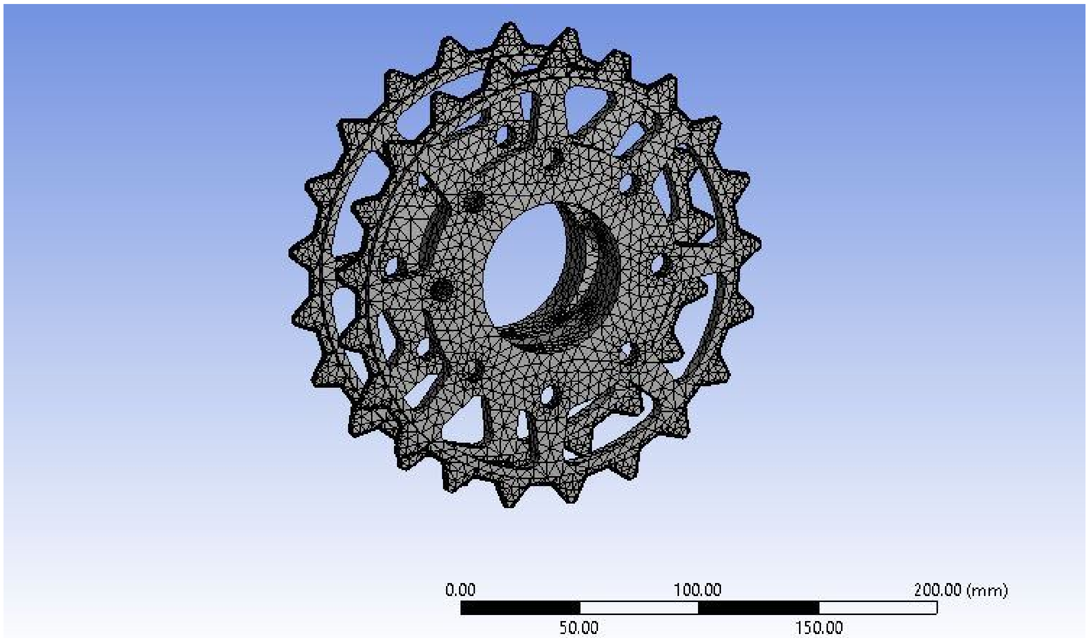

Fig. 5 Meshing in second component

Numerical Analysis. The simulation of the shearing action was setup in ANSYS 15.0 in a static structural system on the models described above with the help of subsystems embedded within the system. The analysis was done by fixing the center node and providing a shearing force around the component. The Finite Element Analysis work flow involved uploading the geometry followed by meshing using mechanical model with medium coarse and local refinement. Forces applied, and constraints were defined and so were the types of solutions. The process was aimed at obtaining stress and stain distribution for both the proposed models.

VI.RESULTS

The plots for maximum shear stress distribution are shown in the figures below. Both the designs are analysed and we see that themaximum shear stress in the improved design is slightly higher than in the originally proposed design. The new design has been successful in reducing the weight of the component with a slight increase in the shear stress developed. The maximum shear stress value has increased due to a shift in critical points on the component. The maximum shear stresses developed are 3.52 MPa and 5.34 MPa respectively.

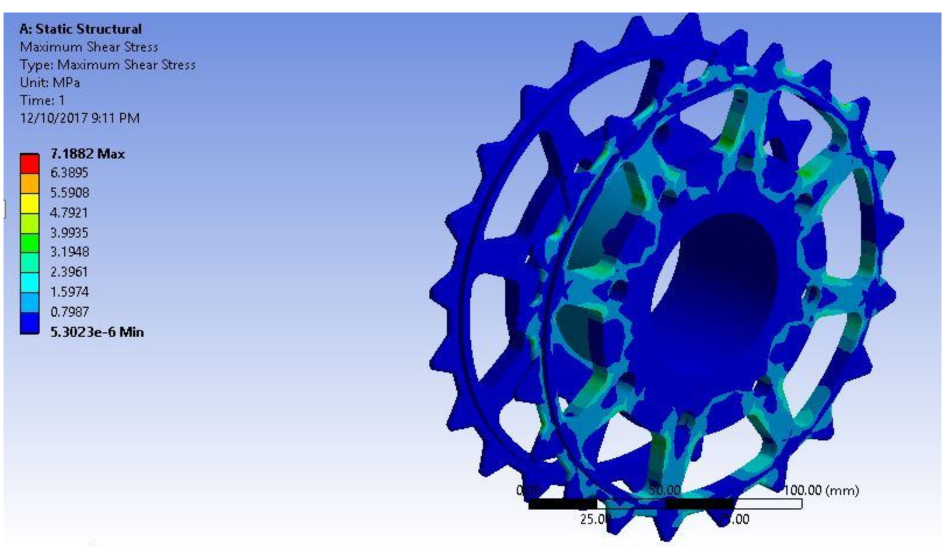

Fig.6 Maximum shear stress distribution in first design

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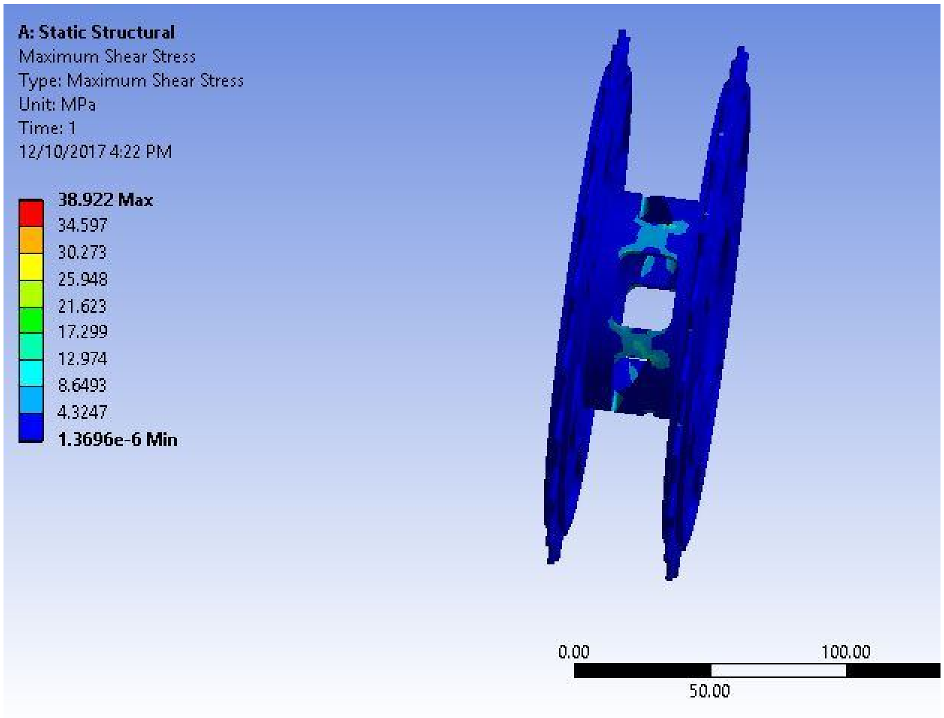

Fig.7 Maximum shear stress distribution in improved design

The plots for strain distribution on the couplers are shown below. Predictably, the strain distribution is lower for the originally proposed design. Due to the presence of cuts in the improved design, there is an increase in the total deformation on the coupler, however the increase is considerably low. The total deformation observed is 0.004695 mm and 0.011283 mm respectively.

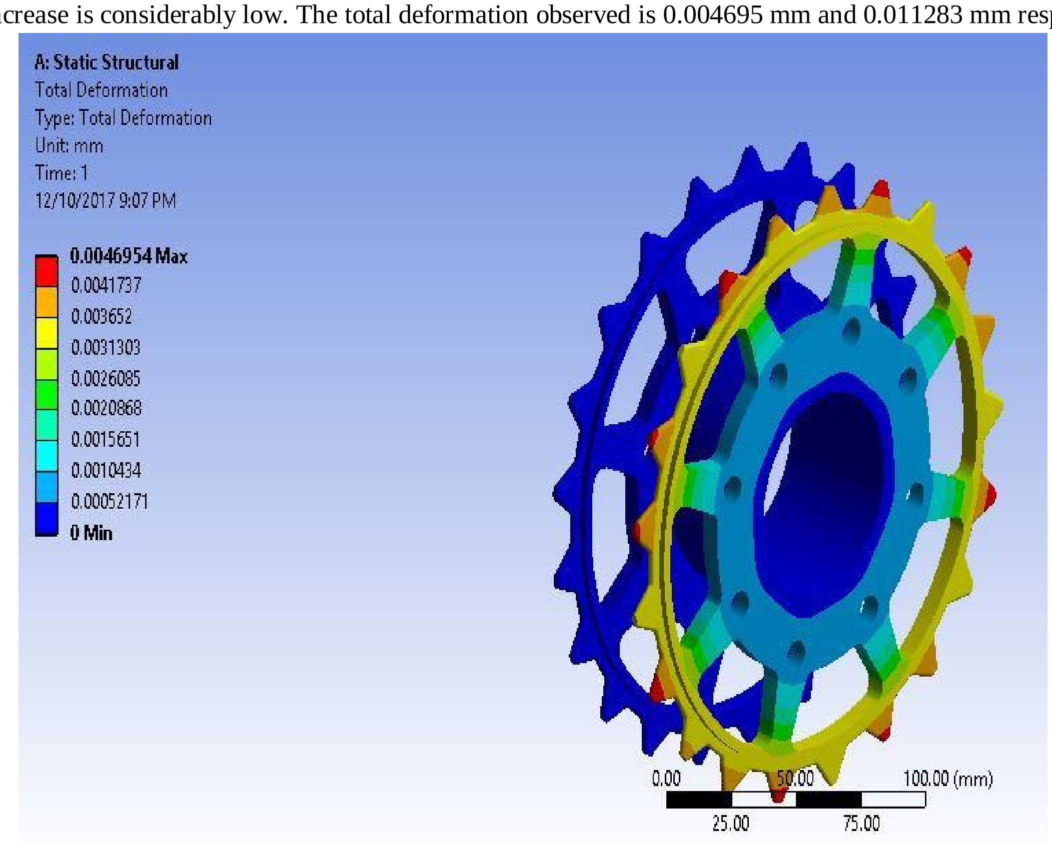

Fig. 8 Total deformation distribution in first design

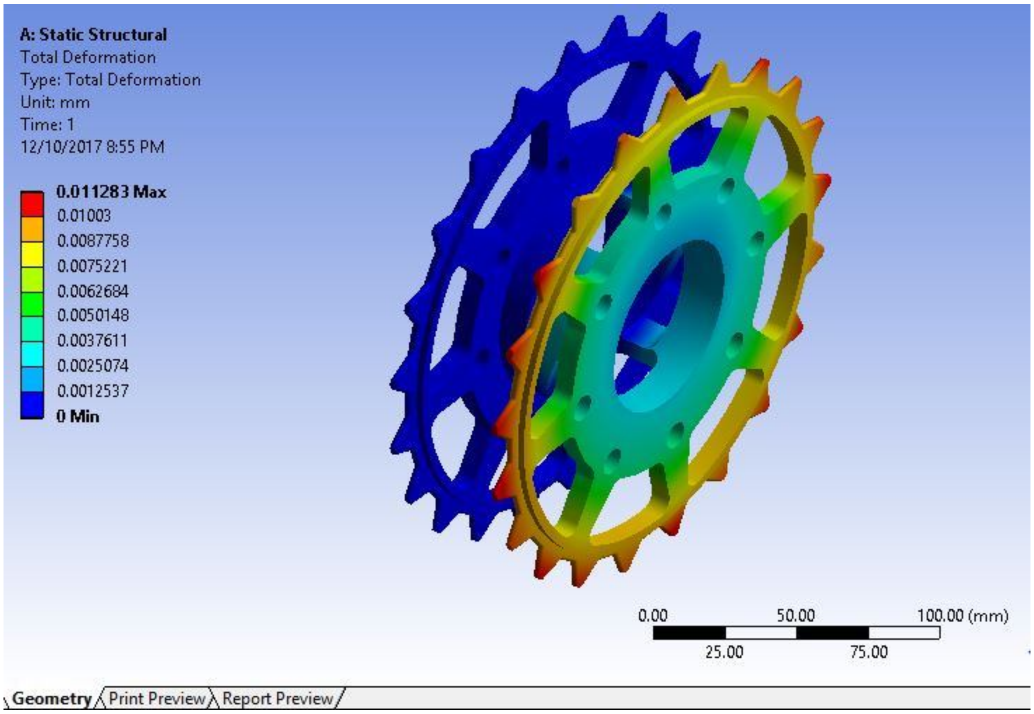

Fig. 9 Total deformation distribution in second design

VII. CONCLUSIONS

From the above results, we can conclude that the newly developed has reduced the mass of the component. The factor that contributed to this is the cuts made on the surface of the originally proposed coupler design. The following points are summarized:

A. The maximum shear stress and maximum total deformation increases upon removal of material from the coupler.
B. In both the proposed designs the factor of safety is well above ‘2’, hence both the models are safe to use.
C. Since weight of the second model is lower than the weight of first model, the second model is considered more optimal to be used in an SAE IEEE formula hybrid vehicle.
D. The originally proposed design was over-engineered and hence weighed more than the improved second design. The second design is an optimal design for torque coupling.

VIII. ACKNOWLEDGMENT

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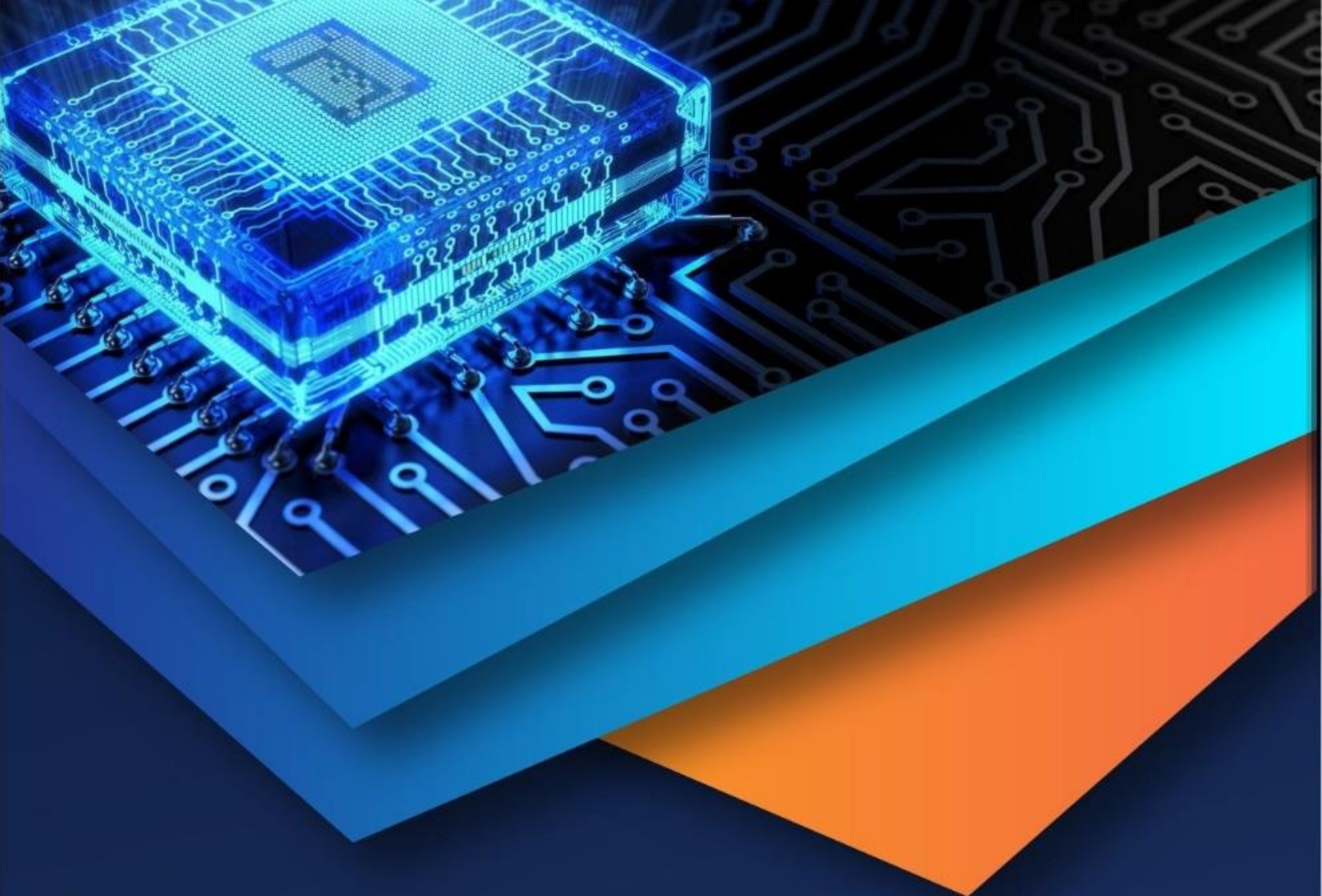

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