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Design and optimization of hub and knuckle for Formula SAE car.

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Abstract:- Formula SAE is an annual international university-level design competition organized by the Society of Automotive Engineers. The goal for the 140+ teams from around the world is to design, manufacture, and compete with a small open-wheel, open cockpit type racecar. The purpose for this thesis project is to design and manufacture the Formula SAE Vehicle Front and Rear Upright Assemblies. The purpose of an upright assembly is to provide a physical mounting and links from the suspension arms to the hub and wheel assembly, as well as carrying brake components. It is a load-bearing member of the suspension system and is constantly moving with the motion of the wheel. For the use on a high performance vehicle, the design objective for the upright is to provide a stiff, compliance-free design and installation, as well as achieving lower weight to maximize the performance to weight ratio of the vehicle. This then is the goal for the optimization process. The design of the 2014 upright assemblies achieved a total weight reduction of over 2.5 lb, which translates to a 22% reduction overall. This is achieved with no loss in stiffness according to the Finite Element Analysis in the computer.

Index Terms:- Formula SAE, Solid works simulation, Hub, spindle.

I. INTRODUCTION

Formula SAE is a student level competition, organized by Society of Automobile Engineers, wherein students are supposed to design, manufacture and run a prototype of open wheel racing car. This competition is conducted in various parts of world every year and about 80 universities participate every year from over the world. The purpose of the thesis is to design and manufacture the front and rear wheel upright assemblies for the use of STES Formula SAE race car. The goal is to produce a lighter design when compare with the highly successful 2013 car and not sacrifice performance in stiffness, thereby contributing to making the 2014 car better than its predecessor. The function of a vehicle upright assembly is to provide a physical connection from the wheels to the suspension links, and to provide mounting and installation for brake calliper. In the case of the current design, it also provides a means of adjustment to the suspension parameters such as camber geometry. For the purpose of the application on a high performance, racing vehicle, it has to meet the following criteria:
• Lightweight to maintain good performance to weight ratio of the race car
• Optimum stiffness to ensure low system compliance and maintaining designed geometries.
• Ease of maintenance for enhancing serviceability and setup repeatability.
• And for the purpose of this team, ability to manufactured the components in-house to reduce turnaround time and outside dependability.

II. RESEARCH PROCEDURE

1) Model loading:

The loads applied to model are based on the data collected in the previous years from the vehicle data acquisition system. The system records the maximum cornering force and this information is used in conjunction with the vehicle layout and weight distribution to determine the forces on the front and rear tires. For the cornering scenario, a lateral force (model y-axis) of 400lbf is applied to the front upright at the contact patch centre, along with a 800lbf of combined bump and lateral weight transfer caused by the lateral acceleration of the vehicle, applied to the vertical direction at the contact patch centre (model z-axis). For the rear upright, the load is scaled back to account for the smaller loads experienced by the rear tire.

2) Model constraints:

The upright model is constrained at the upper and lower ball joint plus the steering/rear toe pickup points. Since all the joints are made with spherical bearing, they do not offer any resistance to moment; their rotational constraints are all left to be free. For the lower ball joint on the race car, it is connected to the lower a-arm and also the pushrod. Under load, the a-arm will resist the movement in lateral and longitudinal direction, while the pushrod will resist the load in the vertical direction. Therefore the lower ball joints are constrained in the model in the displacement in x , y, and z axis. For upper ball joint, since there are no pushrod connection, it resists movement only in longitudinal and lateral direction, therefore it is assigned with constraints in x and y axis. For the steering/toe-link pickup, the only link that connects to this joint is either the steering link or toe-link. They only resist movement in the lateral direction, so only y-axis is constrained in the model.

3) Model Stress:

The FEA package allows for the computation of stresses in different ways, the stresses can be represented in principle stress, component stress, or Von Mises stress. Since it is important to know the yield and material limit, as well as the computation of safety factor, Von Mises stress is used in presenting the stress results. The FEA results are compared against the fatigue strength of the material corrected for a known service life. The correction factors followed that of a standard fatigue calculation and takes into account of load factor, size factor, surface quality, operating temperature, and reliability.

4) Optimization parameters:

The deflection of the upright assembly will be the basis for the optimization process. With stiffness being the performance standard and weight being the concern, the design goals are defined to be reduction in weight over the 2013 design with comparable stiffness. To optimize for weight, thickness for different faces of the upright are changed iteratively based on the previous run's stress distribution and deflection value, the material thickness were reduced in the areas where stresses are low. The limiting factor being stresses cannot exceed the material limit. With available thickness value based on available stock material, a number of combinations were analysed and the optimum front and rear upright designs were selected as the final designs.

5) Results:

The finalized designs and their associated FEA results can be seen in the figures below. Knowing the aforementioned issue with FEA results, interpretation in the boundary region of the mating edges between solid and shell element, the focus then is on the region that's around the boundary. As such, the stresses in those region combined with calculated endurance limit resulted in the fatigue safety factor of 1.07 for the front. The value may sound to be too risky, but knowing the conservative estimate for the fatigue cycle, as well as the actual joint design being more robust with multiple weldments, these values should be more than adequate. Based on the FEA model, maximum deflection of the upright assembly based on the given loading condition for cornering and bump is 0.0021", which is better than 0.005" of 2013 design. The gain can be contributed to the closer proximity of the bearing support housing to the outer perimeter of the upright body, since this where the maximum deflection occurs. The resulted design also weighs less in the model from than the 2013 design, due to the material reduction in the less critical area along the upper ball joint. The front upright is 2.03lb in the model compared to 2013 model's 2.39lb.

III. STUDIES AND FINDINGS

Following are the findings and results

Fig 1: Knuckle Mesh

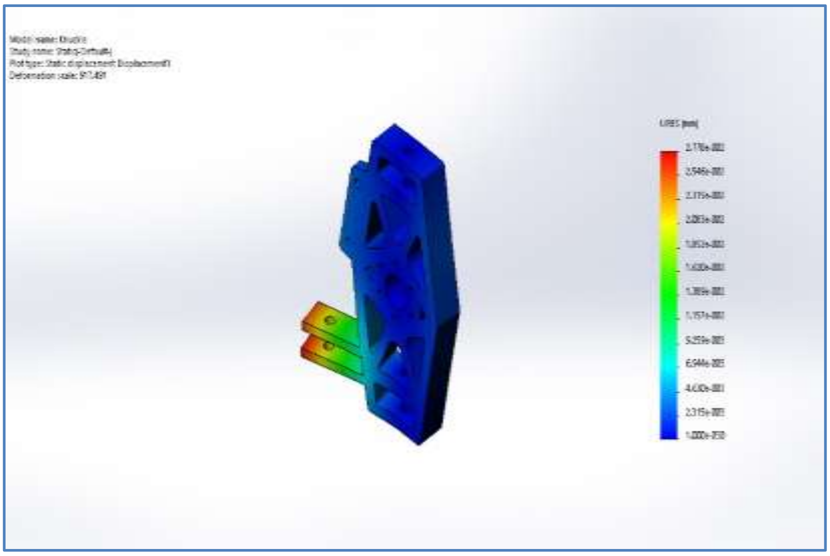

Fig 2: Knuckle Deflection plot

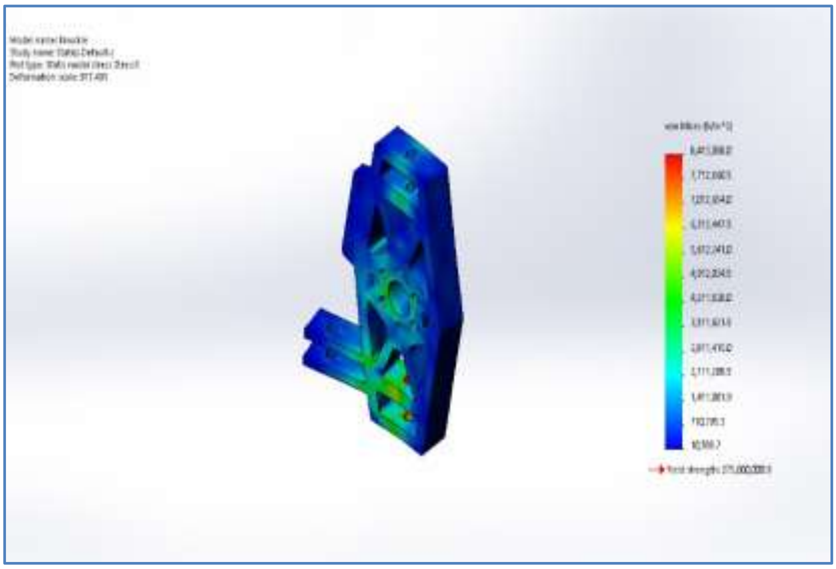

Fig 3: Knuckle stress plot

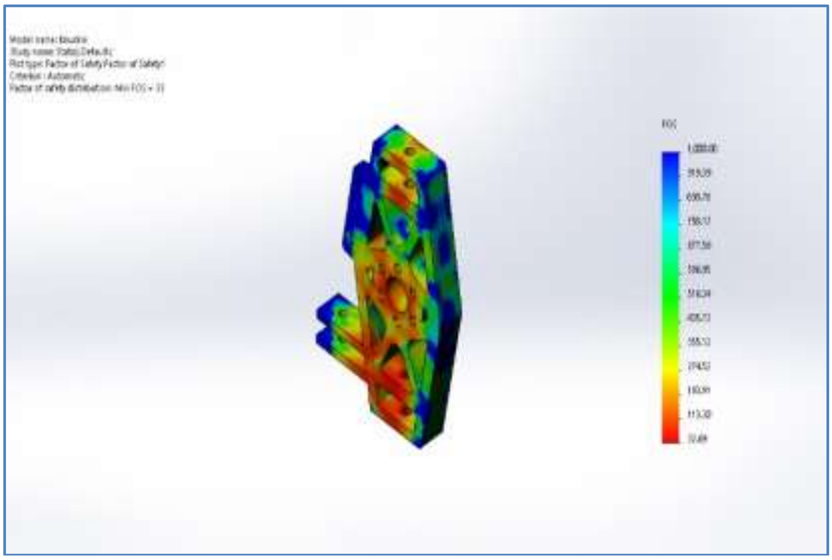

Fig 4: Knuckle FOS plot.

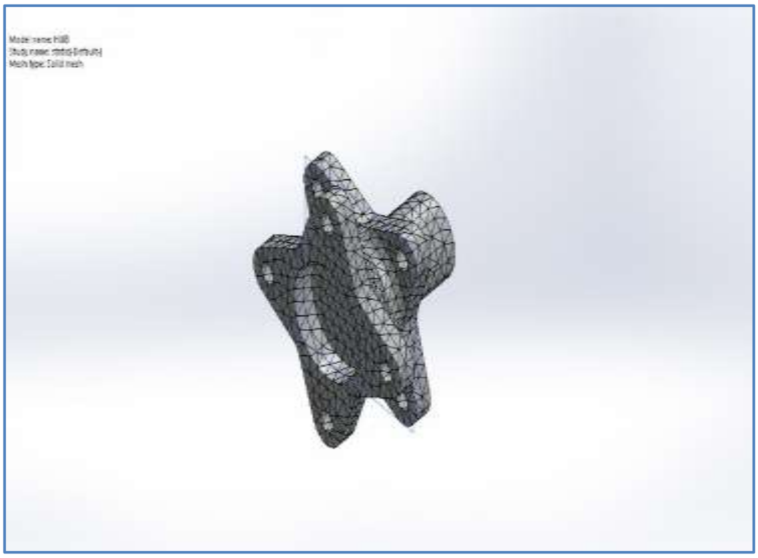

Fig 5: Hub mesh.

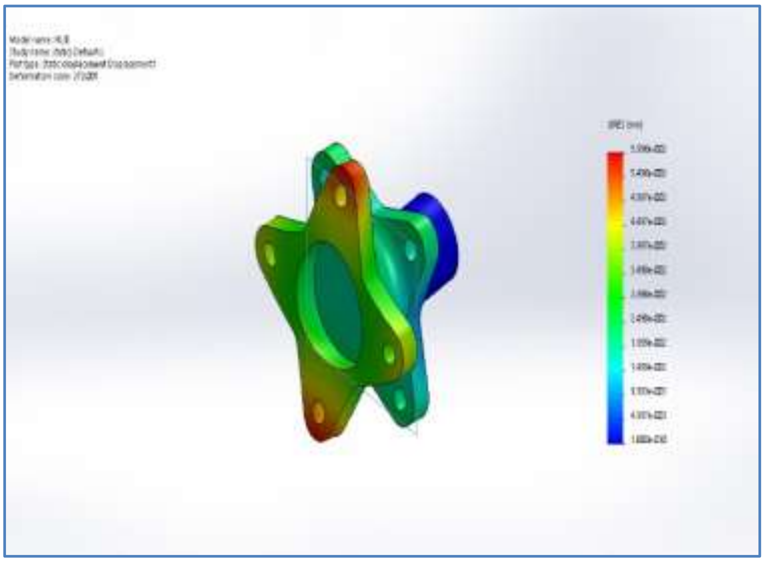

Fig 6: Hub Deflection plot

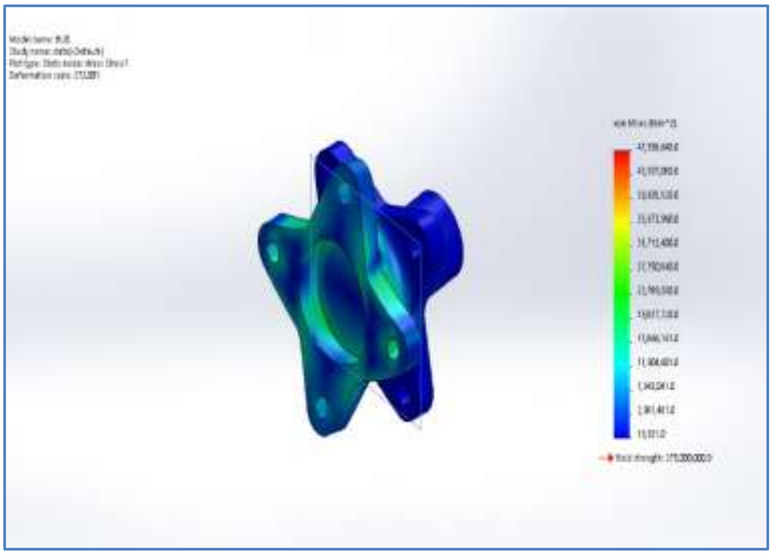

Fig 7: Hub stress plot

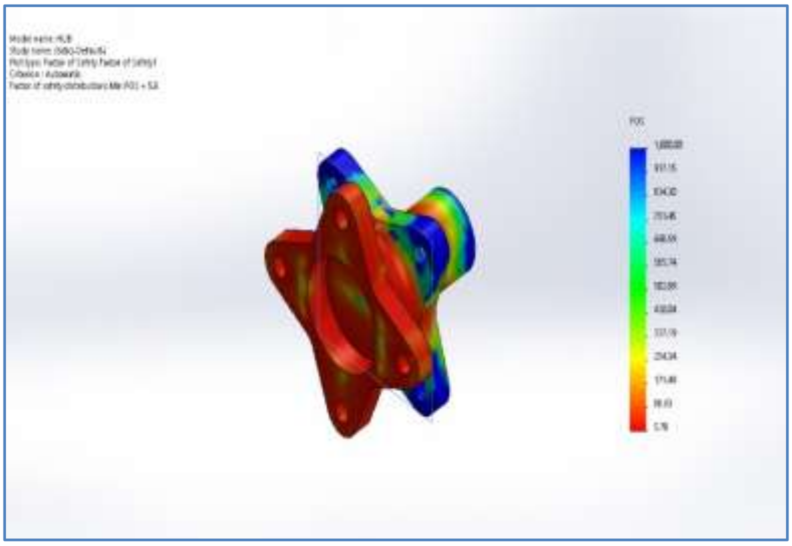

Fig 8: Hub FOS plot.

IV. CONCLUSION

The purpose of this thesis project is not only to design and manufacture the upright assemblies for the 2014 STES Formula SAE car, but also to provide an in depth study in the process taken to arrive at the final design. FEA model form the design seems to be a step forward from the design of 2013.With the overall design being carefully considered beforehand, the manufacturing process being controlled closely, and that many design features have been proven effective by the 2013 design, the 2014 uprights should be well within the performance requirement of the vehicle. In terms of quantifiable improvements, the 2014 design illustrates a significant weight reduction over the 2013 design, with the 4 uprights contributes to over 2.5 lb of weight loss on the 2014 vehicle, with the same level of deflection compare to the 2013 design in the FEA. Although actual gains cannot be seen until the vehicle hits the track, I am confident that the design should prove to be superior to that of the 2013 design

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