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Static Load Simulation of Steering Knuckle For A Formula Student Race Car

Bagus Aulia Saputro[1)], Ubaidillah[1,2*)], Dicky Agus Triono[1)], Dzaky Roja Pratama[1)], Sukmaji Indro Cahyono[1)], and Fitrian Imaduddin[3)]

[1]Mechanical Engineering Department, Faculty of Engineering, Sebelas Maret University, Surakarta 51726, Indonesia
[2]National Center for Sustainable Transportation Technology (NCSTT), SHERA Project, USAID
[3]Mechanical Engineering, Multimedia University, Bukit Beruang, Melaka, Malaysia

[*] Corresponding author: ubaid.ubaidillah@gmail.com

Abstract. This research aims to determine the stress distribution which occurs on the steering knuckle and to define its safety factor number. Steering knuckle is the most critical part of a car's steering system. Steering knuckle supports the tie rod, brake caliper, and the wheels to provide stability. Steering knuckle withstands the load which given on the front wheels and functions as the wheel's axis. Balljoint and king support the rotation of the suspension arm. When the car is in idle position, knuckle hold the weight of the car, it gets braking force when it's braking and cornering. Knuckle is designed to have the strength that could withstand load and to have a good safety factor value. Knuckle is designed using Fusion software then simulated using Fusion simulation software with a static load, moment braking force, and cornering force as the loads in this simulation. The simulation works in ideal condition. The result of this simulation is satisfying. This simulation produces a maximum displacement of 0.01281mm, the maximum shear stress is 3.707 MPa on the stub hole, and the safety factor is 5.24. The material used for this product is mild steel AISI 1018.

INTRODUCTION

Formula Student is an annual event organized by Society of Automotive Engineers International (SAE). This event is held in many continents and countries such as Japan, United Kingdom, United States, and Australia. The event gives a challenge to undergraduate and graduate student planning, designing, and constructing an automobile according to spirit 'MONOZUKURI.' This Event aims to improve the human skill in the field of technology, an automotive industry which will contribute to the government to advance it.

The goals of more than 100 teams are to design, manufacture, assembly, set, and race with open cockpit style formula car. Formula Student car must have a high standard of safety in every aspect. The rules that are guidelines has a purpose of making the car very safe. There are many systems in a vehicle. One of them is Steering system.

This project focused on the simulation of the knuckle to determine total deformation and how safety the knuckle is when getting loads. This project is also to fill the requirement and specification for SAE car. This knuckle is designed for formula SAE to get maximum performance on cornering, braking, and durability. The knuckle design must reduce weight and maximize the stiffness, and the design must also be easy to machining [1]. Lighter steering knuckle will produce a high power and less the vibration because of the inertia is less [4]. Knuckle design should have safety factor above three because it indicates that the project is indeed safety to get any loads.

The steering system is used to control vehicle's direction according to the driver's will. Most of the time, car's steering is controlled using two wheels, but nowadays it has developed into four wheels. Wheels should be easily controlled to prevent dragging when turning. Rudolf Ackerman found a way that if a vehicle is turning, then all of the wheels which made the cars turned should have only one turning point. The Ackerman principle is the front wheel must turn in such a manner that they always have a constant relationship to the rear wheels [10]. Steering knuckle or Knuckle arm is one of the critical components of the steering system. It functions to withstand load and holds the front

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wheels which makes the wheels able to turn. 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 [6]. Steering knuckle is the connection between the tie rod, stub axle and axle housing [4]. Steering Knuckle or Hub Holder is a casted part, usually consisted of the spindle and steering arm, and could make the front wheel turn [5]. This Steering Knuckle is one of the critical components of the vehicle which connects steering system, brake to the chassis, suspension and wheel hub [3].

The steering knuckle carries the power thrust from tie rod to the stub axle, hence it must be very durable and rigid [2]. Steering Knuckle gets some heavy load when on static condition, and more when on the dynamic situation. It should have high safety factor to indicate it safety Because of that should use a suitable material or suitable for making steering knuckle. Mild steel AISI 1018 is one of the options. A proper material selection will improve the strength of the rear knuckle and the combination of lightweight materials for the part will ensure the total weight of the race car can be reduced [7]. Steering knuckle got some load from car weight, braking and cornering force.

MATERIAL SELECTION

This knuckle uses mild steel material. Mild steel has properties and characteristics such as though, ductile, malleable and good tensile strength. This material is suitable to be used as knuckle, which principally designed as a support, so it needs materials which suit the properties, and also Mild Steel AISI 1018 was chosen because of its availability in Indonesia. Three essential criteria for material selection are mechanical, chemical, and physical properties. Such as white cast iron, S.G. (ductile metal), and grey cast iron that is preferred to be material of the steering knuckle [8].

TABLE 1. Mild Steel AISI 1018 chemical composition [11]

Element	Composition
Carbon	0.14-0.20
Phosphorus	0.04
Manganese	0.60-0.90
Ferum	0.05

The mechanical properties can be seen from the bend and tensile performance. [9]

- 463 MPa Ultimate Tensile Strength
- 310 MPa Yield Strength

Mild steel is a good conductor, so it has weldability which suits with any welding.

COMPUTATIONAL DOMAIN AND BOUNDARY CONDITION

The knuckle design must reduce weight and maximize the stiffness, and the model must also be easy machining[1]. The knuckle design must have a shape that distributes the loads.

Knuckle design is made using CAD software. The design is made using Fusion software and also to simulate the created model. The 3D model is rendered as web mesh, which later would give the simulation result. The smoother the webs, the more accurate the simulation result, and thus select fine mesh to create the mesh.

In this project, knuckle design will get three types of load. This load usually happens when this knuckle is doing its function. Static Load is designed as a weighted car with the driver. In Figure 1, The direction of the force is the Z-negative axis that works on the vertical plate. Cornering Force is given when the car does cornering. In Figure 1, the force is shown two blue arrows on X-negative axis. It pushed 2 A-arm mounting plates. The last is Momen Braking Force; it’s a force that works in brake mounting hole. It works when brake mounting hole holds brake caliper when it starts to braking. The fixpoint is tie-rod mounting hole and A-arm mounting hole.

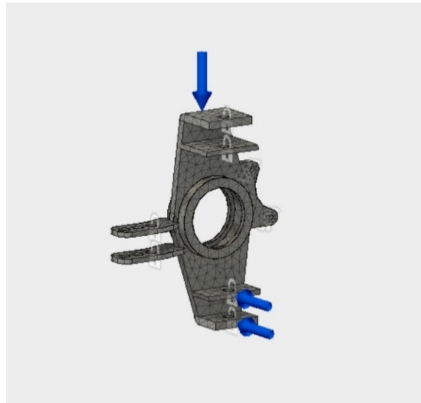

FIGURE 1. Knuckle Design with mesh view and boundary condition

STATIC ANALYSIS

The load type which will be given is Static load, Momen braking force, and Cornering force. This simulation will be conducted in extreme condition to accommodate big force that could actually happen. There are three types of load. According to J. Sri Harsha[2], the actions of load are in the table below.

TABLE 2. Load type equation list

Load type	Equation
Static Load	M * G
Cornering Force	3G
Braking Force	1.5G
Moment Braking Force	1.5G * l

Static load is the amount of weight that is held by knuckle; the braking force is longitudinal load transfer during braking, then cornering is the force that pushes when knuckle starts to cornering. Moment braking force is applied in brake mounting, the braking moment is calculated by multiplying brake force with distance from center point of the knuckle to the center point of brake mounting. Knuckle is designed to withstand the car and the driver's mass, which approximately 315 Kg for four wheels.

Load Calculation

The total mass of car with the driver is approximately 315 Kg; this mass was held by four-wheel. So the weight id 3090.15 N for four knuckles. The weight proportion of the car is 50%: 50% for front and rear, so every side gets 1545.075 N. Then divided by 2 for right and left knuckle, so one knuckle holds 772.53 N.

Three types of loads will be simulated in this research. They are Static load, Cornering force, and Braking moment force. The static load is the weight charged for the knuckle. Mass is multiplied by gravity force, so it gets 772.53 N for every knuckle. This load works on X-negative axis. Second is Cornering force, according to J. Sri Harsha[2], Cornering force is G-force multiplied by three, it's 3 * 9.81m/s^2 Kg * 78.75 Kg, so every knuckle gets 2317.61 N. The loads act in plates with Y-negative direction. The next load is braking moment force. According to J. Sri Harsha[2], Moment braking force is a braking force multiplied by the distance from the center of brake mounting to the center point of the knuckle. The distance from the center of brake mounting to the center point of knuckle is 80mm. Braking force is 1.5 multiplied by G-force, so it gets 1158.80 N. Then those numbers are multiplied by 80mm, so it gets 92704 Nmm for one brake mounting. Load acts on brake mounting; there are two mounting holes.

RESULT AND DISCUSSION

These simulations used Autodesk Fusion 360 software with student license. Some figures below is the simulation results. Figure 2 depicts displacement of the knuckle associated to its deformation. Figures 3 and 4 shows the stress distribution as well as shear stress occurred in the knuckle. Finally, Figure 4 portrays the safety factor of the knuckle.

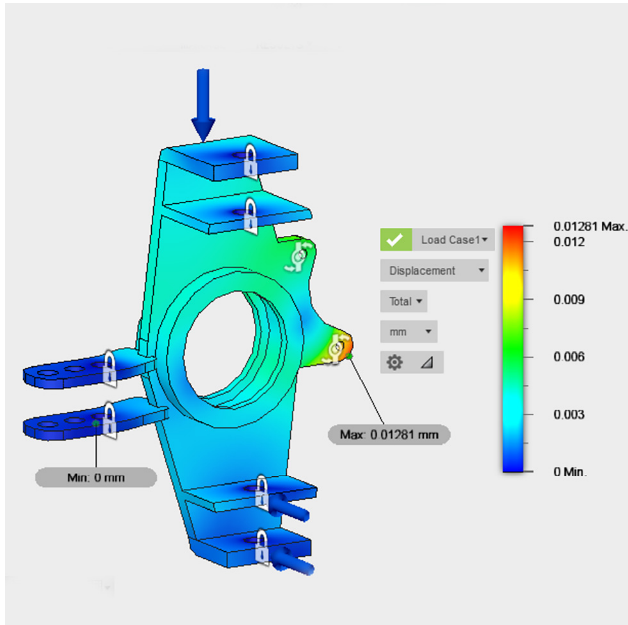

FIGURE 2. Displacement

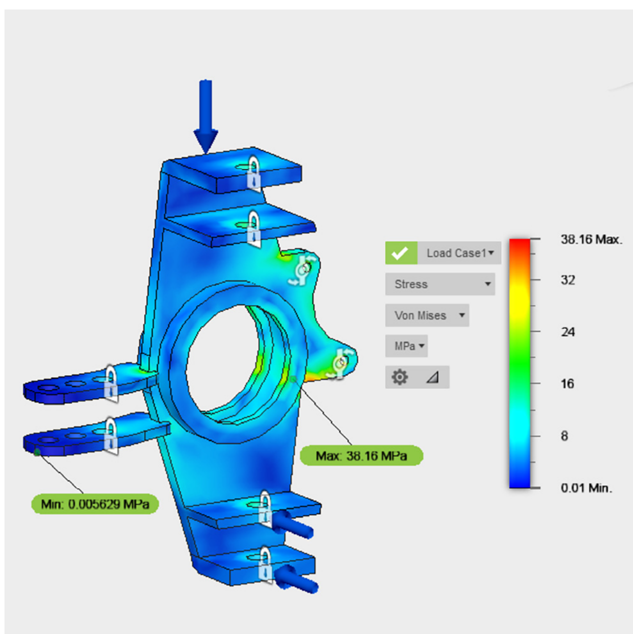

FIGURE 3. Stress distribution

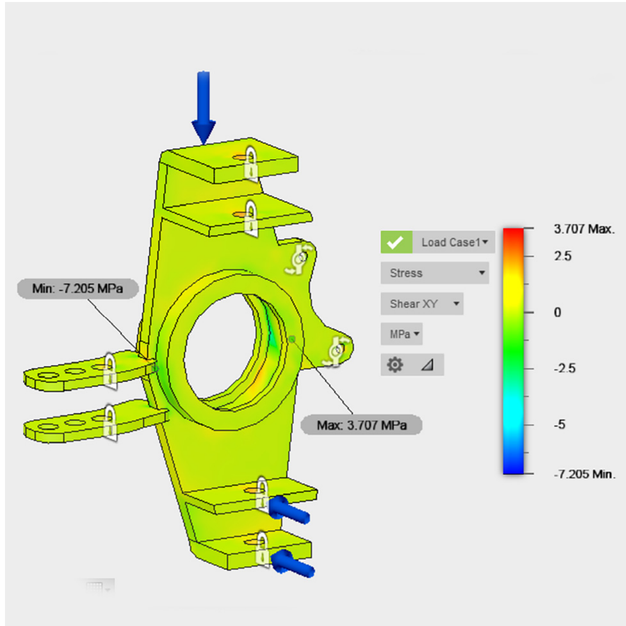

FIGURE 4. Shear stress

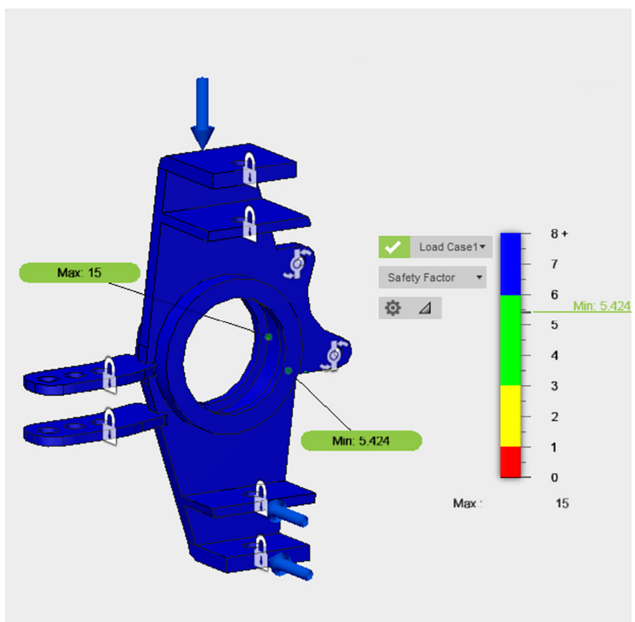

FIGURE 5. Safety Factor

After conducting the simulation, the results are Displacement, Stress Distribution, Shear Stress, and Safety Factor on the knuckle. Figure 2 shows the displacement after simulation. The static load affected the displacement. Upper plate, tie rod mounting plate, stub hole and brake mounting hole moved from their place as shown in the design. The minimum displacement is 0 mm, it happened in constraint point, then the maximum displacement is 0.01281mm in braking mounting point. The result is as expected before.

As shown in figure 3 and 4, the distribution stress and the shear stress that was given in the knuckle. The distribution stress spreads thoroughly. Almost every area receives the same stress. The most significant load is in two brake mounting. In that spot get 38.16 MPa, this happens because brake caliper receives big force when it's starting to brake, the brake caliper holds momentum of the car. The smallest force is in the hinge of tie rod mounting plate between the main plate, the hinge is actually the critical area in case of loading, but if it has good welding, it will be fine. Its value is 0.005629 MPa. The minimum and maximum shear stress are -7.205 MPa and 3.707 MPa. This shear stress is in XY axis. The maximum shear stress happned on the stub hole and the minimum shear stress happened on hinge between tie rod mounting and main body. This situation is as expected before simulation.

Figure 5 shows the safety factor number. It gets 15 for maximum and 5.24 for the minimum. 5.24 is safety enough, because the minimum target is 3. It's as expected before, that stress is spreaded evenly in the knuckle, this situation didn't make the only little area that holds so the displacement of the knuckle is minimum. And because of it, this knuckle gets high safety factor

CONCLUSION

From the result above, the range of safety factor is discovered about 5 until 15; this shows that the knuckle design is very safe to withstand a load of 772.53 N, 2317.61 N for cornering force, and double of 92074 Nmm for moment braking force, and there is no significant deflection happened after load. The right choice of material determines the strength of the knuckle. Mild steel is suitable for knuckle material because of its mechanical properties, which is hard and tough, ideal for the knuckles property needs.

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