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DESIGN AND OPTIMIZATION OF THE STEERING KNUCKLE FOR AN UTILITY VEHICLE

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ABSTRACT

This paper describes the design of the steering knuckle for a utility vehicle and its subsequent topological optimization. The steering knuckle is developed for the autonomous battery utility vehicle that is designed to meet a condition of efficient, safe and robust movement in medium terrain even under unfavorable conditions. The parameters of the steering knuckle were based on the technical parameters of the vehicle. The design was created in software Autodesk Inventor 2020. Subsequent topological optimization was performed in Autodesk Fusion 360.

Keywords: steering knuckle, utility vehicle, topological optimization.

INTRODUCTION

The steering knuckle is an important element of any vehicle. The wheel hub is placed in the steering knuckle using single or double row bearings. The steering knuckle is connected to the arms by ball joints. A ball joint is similar to the hip joint in human body. A round ball is positioned within a hollow socket. The ball can rotate and swivel to provide three-dimensional movement (Haefner, 2010). The brake caliper and the steering rod are still attached to the steering knuckle.

Due to the efforts to minimize unspring mass is required in the design to achieve the lowest possible weight of the steering knuckle however, with the defined dimensions and mechanical properties. Weight reduction can be achieved in several ways, such as technological modification, structural design or selection of a suitable material.

In the case of this study was to reduce weight using the method of topological optimization. This technology is increasingly becoming a very powerful tool in the development of new components due to the advent of more powerful computer technology. Topological optimization is a tool which allows the designer to fully use the potential of the given material space for the part. Problem is that it is highly sensitive to constraints and loads. Therefore, it is very important to be very certain about what constraints the designer is using and most importantly the way the part is loaded. In best case scenario, topological optimization is used to optimize already functional part in functional system. This system is put into excessive driving scenarios and then appropriate stresses or forces are measured. After this, these real forces are applied to the model and then it is only about the trust for the algorithm of the designer how far he is willing to go with material removal. (Querin, 2017).

METHOD OF DESIGN

There is not a methodology for creating the shape of a steering knuckle. It usually comes as a compromise result of design choices of the components that are attached to the knuckle. There are two groups of components which define its shape. These are divided by the mechanism of choosing these elements.

a) Shaped by components function and resulted dynamic forces (brake system (brake caliper and disc), hub (driven or not), type and size of rim, wheel bearing).
b) Shaped by required kinematics of the suspension system (type of the suspension and its hardpoints, attachment of a steering rod and its hardpoint, joint type in the hardpoints).

Next step is to choose the appropriate material. With choosing material comes the decision of which technology is going to be used for manufacturing the part. This decision will not only highly affect the overall cost of the part, but structural integrity, mechanical properties, fatigue life and overall size of the part itself.

DESIGN SPECIFICS OF THE AXLE

Because this is fully electric, autonomous, utility vehicle, it can move in both directions in the same way. Unlike for example passenger car, where the main mean of travel is specified (forward). This resulted in specific kinematics requirements for the axle (location of the hardpoints). As for the joints, ball joints were decided to be used. For the design of the knuckle, the location of upper and lower arms ball joints is important as well as the location of the steering ball joint. One of the specifics of this suspension system is geometry which allows us to have close to zero value of the scrub radius. This results in lower load of the knuckle (but most importantly steering rack) during excessive driving scenarios - hitting an obstacle or pothole. Unfortunately, this requires the upper ball joint to be in position which causes an excessive bending moment during braking and acceleration, therefore higher requirements for the material of the knuckle (see Figure 1). This solution is still beneficial for the lower load of the steering rack.

Fig. 1 - The quarter design of suspension system

RESULTS

To start, we fixed the hub and loaded the knuckle in hardpoints but this does not simulate bending moment from brake caliper. Therefore, we changed the philosophy of loading the knuckle - constraints in the hardpoints, forces on the hub and brake caliper, Table 1. For the hub, there were three forces involved - Fx, Fy, Fz - reactions from the tire contact patch (vertical load, force reaction from steering and acceleration of the vehicle - either positive or negative). The brake caliper was replaced with geometrically simple body (mesh simplicity) of high stiffness and force was applied to an appropriate face (equal to the middle plane of the brake disc) to get force and bending moment into the knuckle from braking (force from braking Fx which is in the hub is only a acceleration reaction). Last force is an equivalent force from steering input.

Table 1 - Mean value of mechanical properties of composite layers

Force designation	Force value [N]	Comment
Fx	11000	deceleration reaction
Fy	11000	turning reaction
Fz	13500	vertical reaction
Fs	3500	steering rack reaction
Fb	3000	braking force

For topological optimization it is needed to specify which regions of the model should be preserved. These regions are highlighted on the model, which can be seen in Figure 2, together with the forces.

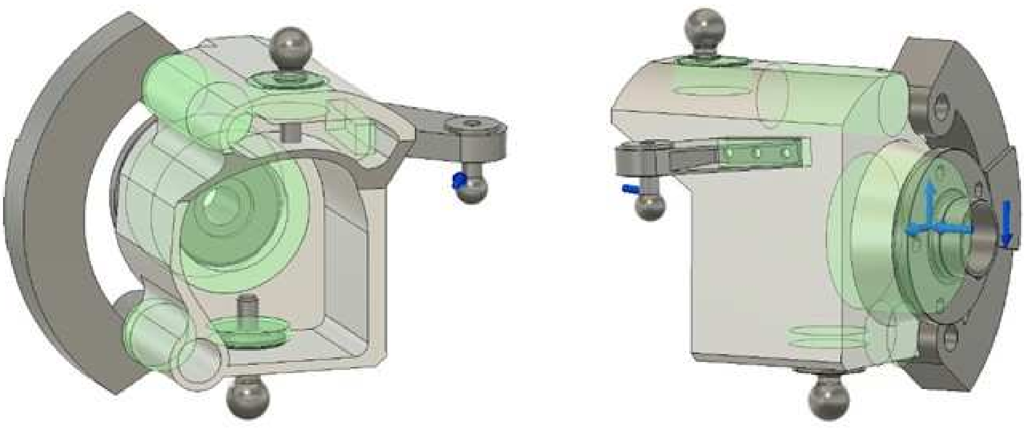

Fig. 2 - Showing of the preserved regions

We decided to be very conservative with using this tool because of upcoming reasons. The vehicle does not yet exist, therefore we could not measure the actual forces in the suspension system. We had to rely on forces calculation by knowing the geometry of the suspension system, expected position of the center of gravity, basic tire data and resulted expected dynamic properties of the vehicle. Because of this, the result of the optimization is for us more about showing us the direction in which the knuckle can be designed and we decided to remove only the really unused material of the part. Still, this resulted in approximately 60% weight saving of the model (before making it manufactural using 3-axis mill).

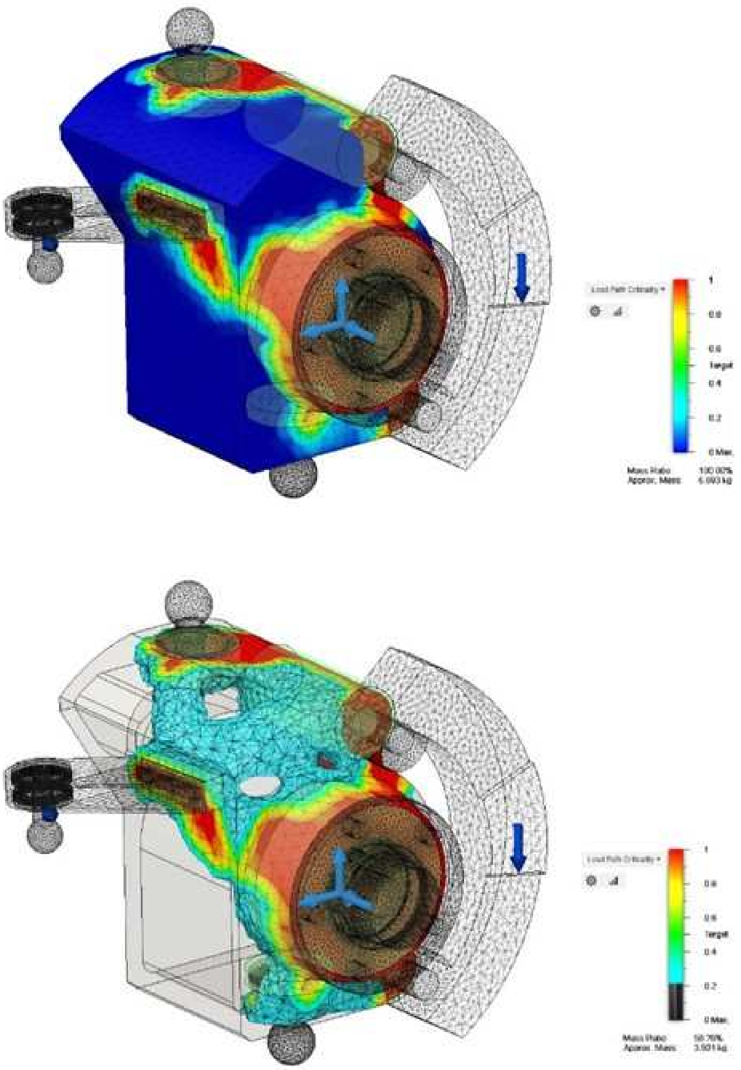

Fig. 3 - The result of topological optimization of steering knuckle

As mentioned above, 3-axis milling was chosen as a manufacturing process. As it can be seen from Figure 3, the resulted shape from the optimization is basically a tetrahedral mesh which is unsuitable for milling operations. Therefore, it was needed to optimize the shape in order to make it manufactural. This goal was achieved by changing the CAD model accordingly (see Figure 4). This was a challenging process to achieve a good compromise between the added weight and cost due to the complexity of the design. In the end, the price for this optimized part was equal to the original model.

Fig. 4 - Final CAD model of steering knuckle

CONCLUSIONS

This first evolution of the knuckle is experimental and mainly for experimenting with kinematics of the axle, it was decided to use the aluminum alloy EN AW 7075 T6 and, as a manufacturing process, 3-axis milling was chosen. This alloy is cold formed and by the process of milling with cooling its internal structure and therefore mechanical properties will not be changed. These decisions gave us the confidence that the mechanical properties of the final part will not be different due to manufacturing process and so we can be more aggressive or less conservative with the topological optimization (which results in lower overall weight).

As mentioned above, the main purpose was to gain an experience on designing this part but more importantly, the knuckle will be used with the rest of the suspension assembly to measure the real behavior of the system from kinematics point of view. Therefore, the knuckle will be equipped with fully adjustable (in all three directions) housings for the ball joints, which can be in many variants as well (concentric or eccentric). Thanks to that, we will be able to study many different settings and its consequences to the overall behavior of the vehicle. The main challenge will be to find a good compromise of hardpoints positions because both of the arms are laying in bushings with relatively low stiffness. So, the real position of each hardpoint dynamically changes during the vehicle operation, especially with different amount of load put onto the vehicle (mass properties and center of gravity position change - different forces in the whole vehicle). After finishing the kinematics, final knuckle will be designed by using the knowledge gained by this development. Because for the whole vehicle 4 knuckles will be needed, there is a possibility that we would change the manufacturing process from milling to die casting, which would allow us to be more aggressive in topology usage (possibility to use the result, tetrahedral mesh, as a final model) and lower the overall cost.

ACKNOWLEDGMENTS

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A common simplication of an Ackerman steered vehicle used for geometric path tracking is the bicycle model. Section 3.1 includes a detailed discussion of Ackerman steering and the kinematics of the bicycle model. For the purpose of geometric path tracking, it is only necessary to state that the bicycle model simplies the four wheel car by combining the two front wheels together and the two rear wheels together to form a two wheeled model, like a bicycle.Â where Î´ is the steering angle of the front wheel, L is the distance between the front axle and rear axle (wheelbase) and R is the radius of the circle that the rear axle will travel along at the given steering angle. This model approximates the motion of a car reasonably well at low speeds and moderate steering angles. 2.2 Pure Pursuit. The existing vehicle designs exhibit a high level of coupling. For instance the coupling in the suspension and steering systems manifests itself through the change in wheel alignment parameters (WAP) due to suspension travel. This change in the WAP causes directional instability and tire-wear. The approach of the industry to solve this problem has been twofold.Â through optimization of the link lengths and joint positions, but we cannot satisfy all three FRs. simultaneously using a four bar linkage. Both.Â In the new six-bar suspension system, the steering knuckle moves exactly vertically (in the Z-direction). It does not have any horizontal motion or any angle changes. This allows the use a cylindrical joint in place of ball and socket joints. power steering lines for FC. power steering lines for FC. Karissa Hosek LS3 Build. Motor Engine.Â Construction:- The most common arrangement of hydraulic brakes for passenger vehicles, motorcycles, scooters, and mopeds, consists of the following: Brake pedal or lever A pushrod (alsoâ€¦ Jared Luttrell car systems. Automotive Engineering.