IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Vol. 6, Issue 12, December 2019

Design of Clevis Joint for Steering Rack to Minimise Bump Steer Phenomena

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Abstract: Formula student vehicle is formula styled open-wheel single-seat four-wheel car which is built by students to compete in engineering design event. Steering and suspension are one of the critical systems in this type of vehicle. The primary aim here is to design clevis joint for steering rack extension to minimize undesirable bump steer phenomena seen during dynamic conditions while driving the car. Bump steer point must be precisely placed for improved performance and eliminating undesirable steer experiences when wheel travels vertically on the bump or during the corners. Considering various constraints and simulation of hard-points of the suspension system on LOTUS- SHARK vehicle simulation software, a clevis joint design is performed with the help of SOLIDWORKS modelling and analysis.

Keywords: Bump steer, toe point, clevis clip, tie rod, toe angle, wheel travel. Steering system, FSAE car

I. INTRODUCTION

Automotive car design is to be performed with accuracy so that all subsystems of a vehicle work in harmony. Improper selection of any parameter may lead to errors and subsequent failure of any system. Thus it will harm both the car and the driver. Performance and handling are key factors to be considered while designing. Suspension parameters including camber, caster, kingpin inclination, scrub radius, Ackerman angle, steering ratio, suspension and steering geometries along with precise wheel alignment are utmost important in a race car. If there is a slight variation in these parameters, it becomes difficult to control the vehicle while riding on bumps or corners. Bump steer is undesirable steering of the wheel when the wheel moves upward or downward. Wheel steers in a different direction than given input. In other words, the toe of wheel changes with suspension travel. When the wheel moves upward or downward, wheel undergoes in toe-in or toe-out movement, which is unwanted during driving. A driver needs extra efforts to overcome this situation, so it is required to keep the exact length of the rack and tie links.

A. *Geometry Plotting*

By plotting suspension and steering geometry together, Bump steer point can be determined. First, deciding wheel packaging. Then suspension geometry is plotted. From this design, possible steering arm point or tie-rod outer point was obtained. Rack position achieved by considering steering geometry -in which Ackerman angles decided. Further, bump steer geometry plotted after determining steering arm point in 3 dimensions. Following figures show the present position and desirable positions (obtained by plotting bump steer geometry) of bump steer point. Linkage is drawn in three different cases, first- Static (black colour), second- Two-inch bounce (Red colour) and third- Two-inch Jounce (Blue colour).

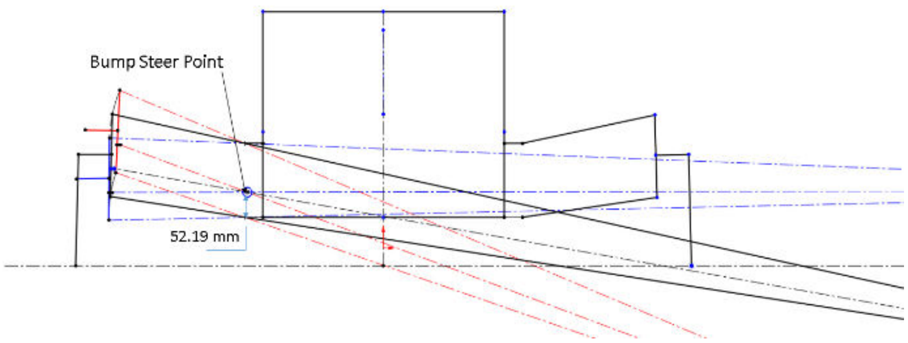

Fig 1 – Bump steer geometry

Steering arm point and Instantaneous centre of upper and lower arms connected in each case. And the point where all these three lines intersect is the point where bump steer is zero. This is the point, where rack clevis point or inner tie-rod point can be placed, to get zero bump steer characteristics.

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II. METHODOLOGY

A. Problem Analysis

For the steering system of this car, the rack and pinion mechanical linkage is used, which converts the rotary motion of steering wheel into linear displacement of a rack and connected tie links. Design, assembly location of the rack and other parts of the steering system is crucial in Formula Student car. It is necessary to follow the rules and regulations, which are designed considering the driver safety while designing the formula student car. There is one specific rule for an internal cross-section of the vehicle around the driver's legs. Figure shows the template used for inspection purpose during the technical inspection. [1]
An internal cross-section must be spacious enough to accommodate this template, so the driver can swiftly pull out his legs in the panic situation. Lowering the rack position will not obstruct the movement of the driver's legs.

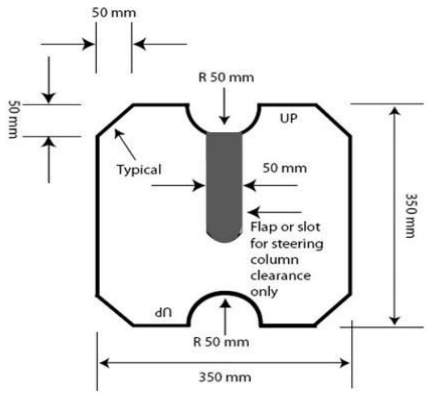

Fig 2 – Internal cross-section Template

Here originates the main problem while installing the steering rack. Height of chassis front hoop (chassis in front of the driver) has a constraint due to driver sight. Further increase in height to accommodate the template may obstruct the front vision of the driver, which may need extra judgement to the driver while driving. One additional issue of rack position will occur if the height is at a minimum possible level. If rack moves vertically downward, the clevis clip point or steering rack endpoints down will shift down.

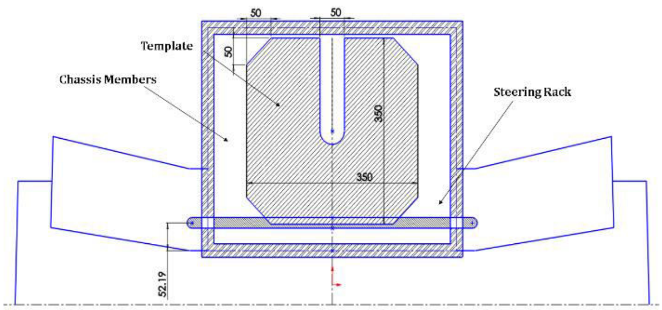

Fig 3 – Interference of Rack with Template (Current position (Front View))

Desirable position of zero bump steer point is 52.19 mm above the lower inner wishbone point (Chassis Hard points).

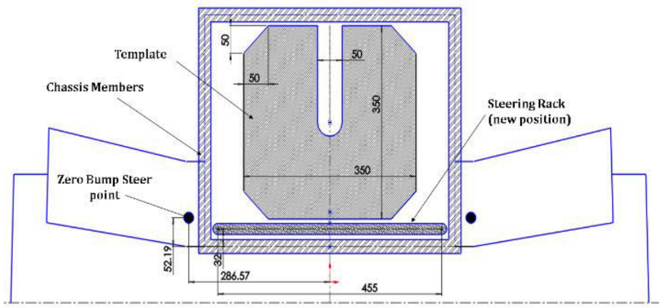

Fig 4 – Possible Position of Rack (Front View)

Rack installation at the required axis will not satisfy the rule, as rack will interfere with the template during the inspection. Either increasing the height of front hoop will be the solution for this problem or shifting the rack

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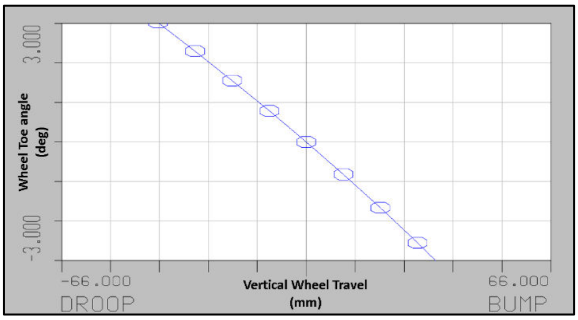
downward. Since there is a limitation on the height of front hoop, the only solution for this issue is to shift rack position. These rack endpoint has been shifted to a downward position, shifting the rack will introduce the bump steer characteristics.

B. Simulation

A simulation performed on LOTUS SHARK vehicle simulation software to find bump steer characteristics, and the significant difference seen in two distinct points. Various graphs presented are.

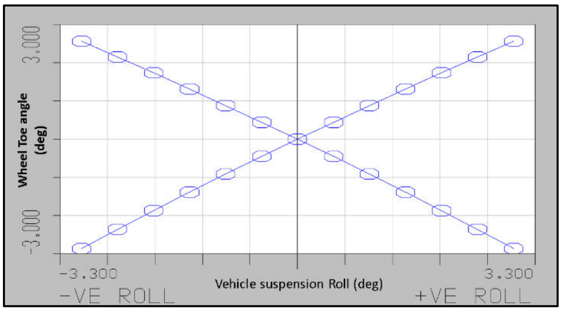
I. Bump v/s Toe angle
II. Roll v/s Toe angle

If steering rack is placed below with inline rack endpoints, the following graphs show characteristics of Toe angle and camber angle in bump as well as roll condition.



Graph 1: Bump (mm) v/s Toe angle (deg)

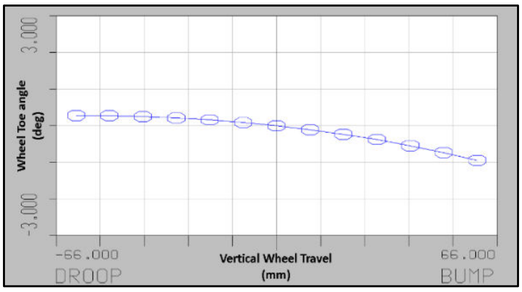
Toe is zero at the static condition (at zero wheel travel). More than 3 degrees toe change for 50 mm wheel vertical travel seen in a wheel (in graph 1).



Graph 2 - Roll (deg) v/s Toe angle (deg)

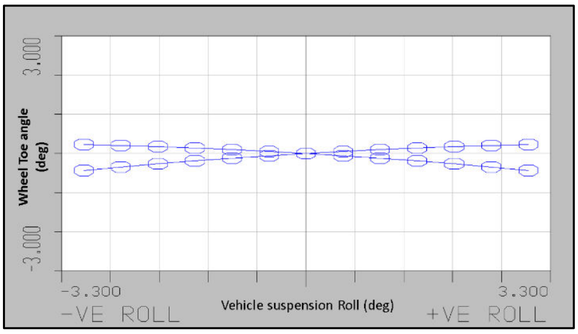
Graph 2 shows the characteristics of vehicle roll v/s toe angle variance. About 2-degree toe change for a 2.5-degree roll of the vehicle. These characteristics are undesirable in dynamic conditions.

In conclusion, zero bump steer must be obtained to minimise these undesired characteristics. So it is essential to maintain the height of the rack low but at the same time, clevis endpoints or tie-rod inner point at an estimated zero bump steer point (52.19 mm above the lower inner wishbone hard point). If zero bump steer point is achieved, then the following graphs presented which show acceptable characteristics.



Graph 3- (At zero bump steer point) Bump (mm) v/s Toe angle (deg)

In graph 3, toe change with vertical wheel travel is negligible. Toe is zero at static condition, while it varies to +0.2 degrees in droop and -1 degree in bump. This is an agreeable characteristic, where bump steer is minimum.



Graph 4-(At zero bump steer point) Roll (deg) v/s Toe angle (deg)

Graph 4 shows the Toe change with change in the roll. Same as bump steer phenomena, roll steer characteristics have also minimised. Change in the toe of the wheel is not more than -0.5 deg and +0.2 deg with a 3-degree roll.
In reality, a roll of a vehicle will not exceed 2 degrees, thus these characteristics are favourable.

III. DESIGN AND ANALYSIS

A. Cad Modelling

Solution for this situation is a design of the new clip, which will connect rack at a lower position (20 mm below the estimated zero bump steer point) and inner tie-rod endpoint shown by dark solid circles in figure 4. By applying this solution template rule can be satisfied, the rack will not obstruct the movement of driver's legs and bump steer phenomena can also be minimised as well.

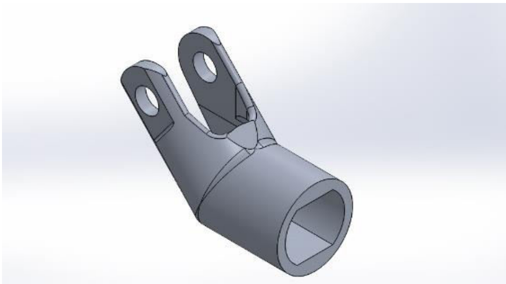


Fig 5 – Designed Clevis Clip (Iso-view)

Specific shape was given to the pocket where clip connects to the rack to restrict rotation of clip about axis of the rack.

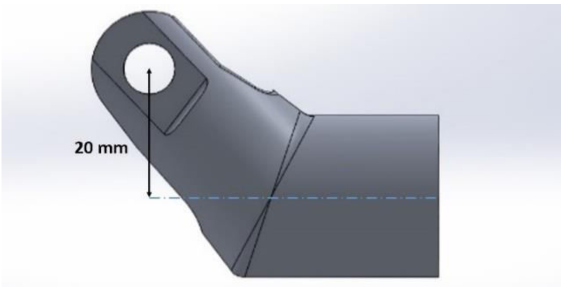


Fig 6 – Designed Clevis Clip (Front View)

3D cad model created on SOLIDWORKS and its FEA analysis was carried out. As shown in fig. 6, M8 bolt-hole centre is kept 20 mm above the steering axis.

B. FEA Analysis

Material used for clip was Aluminium alloy Al 7075-T6. Force of 800 N was applied in direction same as tie-rod axis, which was estimated as maximum possible force on steering assembly.

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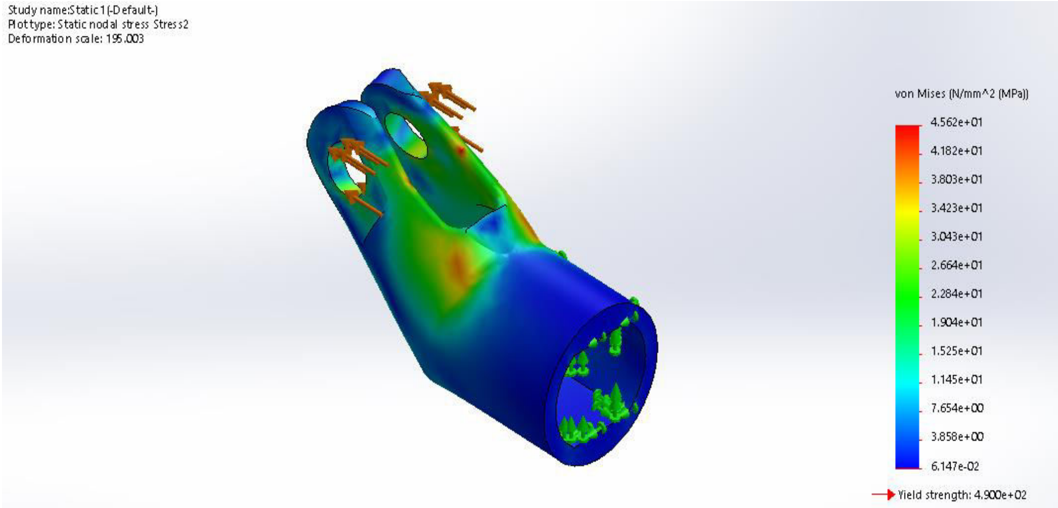

Fig 6 – Stress Analysis

Maximum stress induced (45 MPa) did not exceed the yield strength (450 MPa). Von-Mises stress induced are shown above.

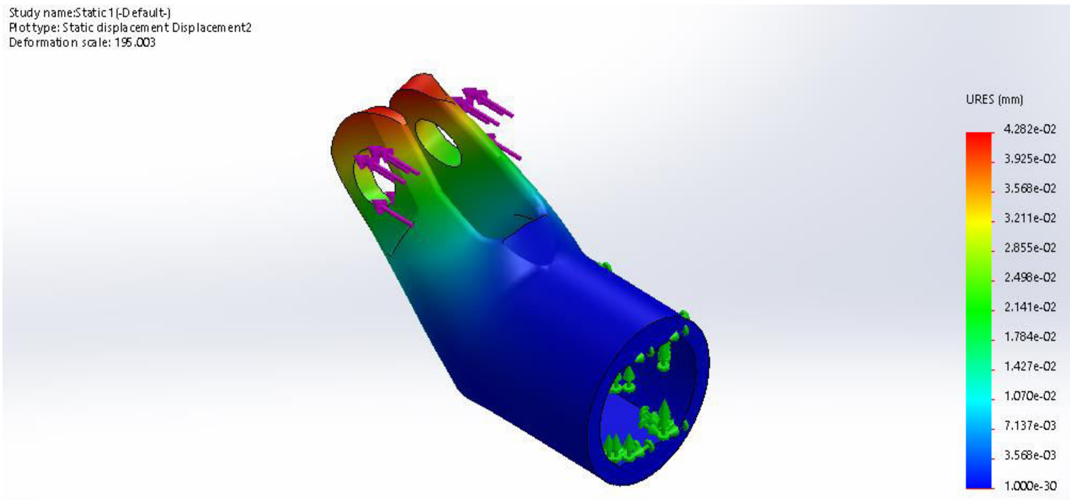

Fig 7 – Displacement Analysis

Displacement of clip was noticed not more than 0.05 mm.

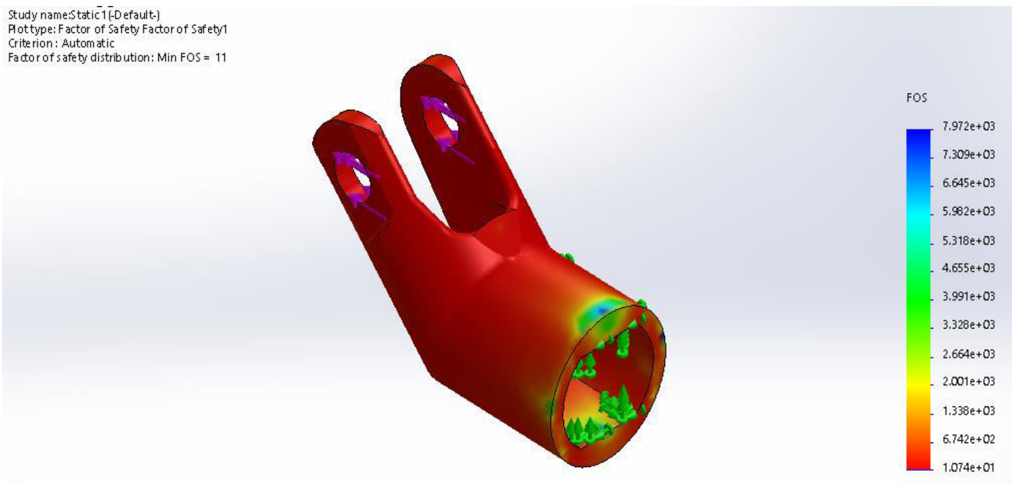

Fig 8 – Factor of Safety Analysis

Minimum Factor of Safety of this clip found was 10, which shows design is acceptable and safe.

IV. CONCLUSION

Bump steer characteristics varies with change in position of clevis joint or tie-rod inner end point where it connects the steering rack. Attaining zero bump steer position is utmost important since slight variation in position may lead to undesired dynamic characteristics.

Co-ordinates of zero Bump steer point estimated by plotting bump steer geometry was inserted in LOTUS SHARK and simulation results obtained proved that point estimated by geometry is precise.

For given boundary condition or constraints of steering rack position, steering arm position and tie-rod axis, design of new clevis clip satisfies all conditions. After installation of new clip variation in toe angle of wheel for change in vertical travel of wheel is limited to +o.2 degree and -1 degree, which are within acceptable limit. Drastic change in characteristics can be seen before and after installation of clip.

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