Redesign of Steering Knuckle for a Sports Utility Vehicle (SUV) for Improved Fatigue Life

Ramachandran S., *Monish Gowda M.H., Hima Kiran V.

Faculty of Engineering and Technology, Ramaiah University of Applied Sciences, Bengaluru

*Contact Author E-mail: monish.aae.et@msruas.ac.in

Abstract

A steering knuckle is a structural component that houses the suspension, brake calipers, wheel, lower control arm and the upper control arm. The main function of the steering knuckle is to drive the wheel, have straight motion and transfer the load to the suspension. Various types of load act on the steering knuckle. The design of the steering knuckle is to be robust to withstand the forces. Steering knuckle is subjected to fatigue loading during its service. This project deals with a steering knuckle of an SUV that failed due to fatigue. Attempt is made to improve its fatigue life by changing the design. Steering knuckle identified for a SUV is reverse engineered and using cloud of points data, the 3D model was created using CATIA software. The 3D model was later used for structural analysis. The virtual prototype of SUV was built in ADAMS car software and torture test track was built. The vehicle was run at different constant speeds of 20 kmph, 40 kmph and 60 kmph respectively on the torture track. The dynamic loads at hard points like upper control arm, steering arm, lower control arm and wheel hub were exported. These loads were given as input to structural analysis using ANSYS Workbench and the stresses were determined using inertia relief method. Fatigue life was calculated for the existing steering knuckle. Design changes were made for the existing steering knuckle for improved fatigue life. With the existing steering knuckle and vehicle running at constant speed of 60 kmph the maximum principal stress was found to be 314 MPa and estimated fatigue life was 3767 cycles. Five design iterations were carried out by changing the existing design of the steering knuckle to improve the fatigue life. Among five design iterations, iteration five with added features like ribs and drafts resulted in 52% reduction in principal stress and improved fatigue life of 1000000 cycles.

KeyWords: Steering Knuckle, CATIA Modeling, ADAMS Car, Dynamic Analysis, FEA, Fatigue Life.

1. INTRODUCTION

Indian market, booming with various models and segments of passenger vehicle, attracts customers towards purchasing them. In today's trend there is about 10% of Sports Utility Vehicle (SUV) on the Indian roads. Selection of make and model depends on performance, reliability and stability. Demands in SUV has a major increase in the market as the performance is better compared to other vehicle. These SUV are well adapted, suitable for rough and terrain roads. To have the comfort during driving on the rough roads these vehicles must have high build quality. SUV's should provide good safety to passengers there for they are equipped with sophisticated and complex safety systems, making them bulky and massive in size. As they become bulky loads acting on them proportionally increase. Un-sprung mass that supports the SUV are to be built to withstand these loads. As these vehicles are driven at higher speeds in rough road, they face loads at 4g. Generally steering knuckle is prone to failure as it is a load carrying member [1]. Excitations from the roads are transferred from steering knuckle to the suspensions. Therefore they must be robust to withstand fatigue loading.

2. SOLUTION PROCEDURE

2.1 3D Modeling of Steering Knuckle:

The steering knuckle assembly of an existing SUV (Tata Safari Dicor 2.2L) was used for reverse engineering. The existing assembly is as shown in Figure 1. This assembly has steering arm fastened using steering bolt with two M8 bolts. In order to avoid the self-loosening of the bolts tab washers are used. Steering knuckle is manufactured using casting process. Steering knuckle is made from SG500/7 steel material.

Fig.1 Steering Knuckle Assembly

2.2 Geometric Modeling

The original Tata Safari Dicor 2.2L steering knuckle component was scanned using non-contact type scanning machine and the point data was obtained. Point data is shown in Figure 2. There are about four lakh points obtained from the IGES file. Using CATIA V5R21 software the point data was converted to solid model using solid modelling techniques. Generated 3D was compared with point data to ensure the same original geometry model is matched. Features like fillets and chamfers are captured accurately in order to capture the geometric discontinuities. Comparison of point data and steering knuckle is shown Figure 2. Later steering knuckle part is assembled with the steering arm using the M8 bolts. The overall size of the component is 300 mm x 240 mm x 250 mm. Weight of the component is approximately 8kg.

2.3 Dynamic Analysis using ADAMS/CAR Software

The SUV model built in ADAMS car software is shown in Figure 3. National Centre for Automotive Testing (NCAT) performs various tests for automobiles. Belgian track, pothole track, corrugated track and chassis twister tracks are used to determine the loads and the fatigue failures. In this project the torture test track was built in ADAMS/Car software to simulate the SUV similar to real physical test track condition. The road plank width considered is 2m, plank length is 2m, plank height is 1.5m and the road is shown in Figure 3 [5].

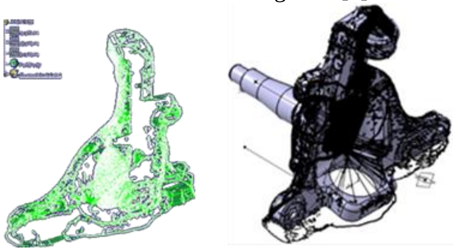


Fig. 2 Cloud Point Data

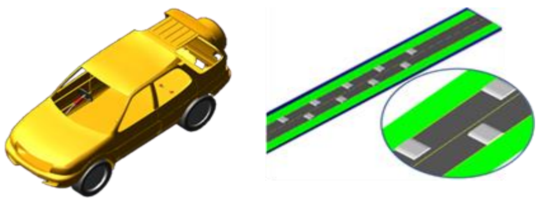


Fig. 3 SUV Model in ADAMS/Car

The vehicle was made to run at constant speed of 20, 40 and 60 kmph on the torture test track to extract the loads acting along X-axis, Y-axis and Z-axis directions from lower control arm, upper control arm, wheel bearing and the steering linkages. Figure 4 shows the load extracted at Y axis of lower control arm when simulated at 20 kmph. It can be observed from graph shown in Figure 10 that the load reaches to 4000 Newton at 4.5 seconds. Similarly loads are extracted for other speeds

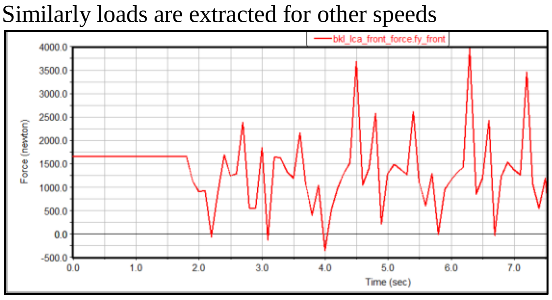


Fig. 4 Loads in Z-axis at 20 kmph in LCA

2.4 Structural and Fatigue Analysis Using ANSYS

Using ADAMS postprocessor, result files are loaded to extract the force verses time data which are later used as input loads in ANSYS Workbench. The loads are applied at corresponding hard points on the steering knuckle. Loads obtained for each case are provided as inputs to areas highlighted in red colour. Area "A" is the surface where upper wishbone is connected. Loads corresponding to UCA are applied at surface "A". Surface "B" is the named selection for lower control arm. Area "C" is the wheel bearing surface where all the loads on wheel hub are applied. Named surface "D" is the steering link where all steering loads are applied. Figure 5 illustrates the loading points.

Figure 5 shows the finite element mesh of the model from ANSYS Workbench. The assembly is constructed as a single part. Initially there are 49018 elements and 80313 nodes in steering knuckle. Tetrahedron element is used to mesh the model. Loads for speeds at 20 kmph, 40 kmph and 60 kmph are applied in the corresponding named selections to determine the maximum stress and the fatigue life.

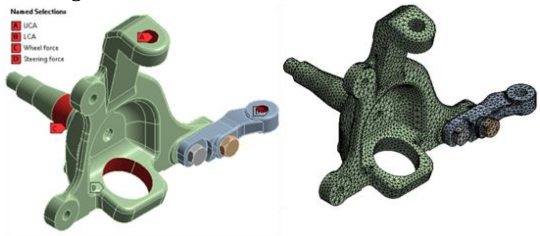


Fig. 5 Load Application Areas in ANSYS

2.5 S-N Curve

S-N curve (alternating stress versus number of fatigue cycles) shown in Figure 6 is input for the material. From S-N curve the material has infinite life if the stress is below 250 N/mm2. Fatigue cycle testing is increased from 3910.8 cycles to 1E6 cycles.

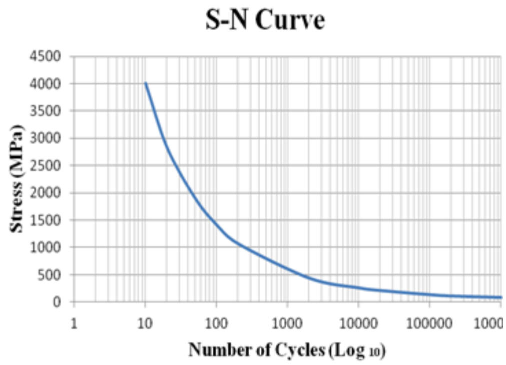


Fig. 6 S-N Curve for SG500/7

2.6 Stress on Original Model

For load cases pertaining to 20 kmph, steering knuckle has maximum stress of 241.3 MPa at the steering arm indicated in red as shown in Figure 7. Among the parameterized loading the maximum load case is taken where the von Mises stress in the highest, the rest of the loads are not considered. Maximum load 241.3 MPa is lower than the yielding stress for the material but at higher speeds the loading will shoot-up. Therefore analysis is performed for 40 and 60 kmph speeds. Inertia relief concept is adapted for solving these cases. Using the inertia relief concept the component was not applied with boundary conditions. [6]

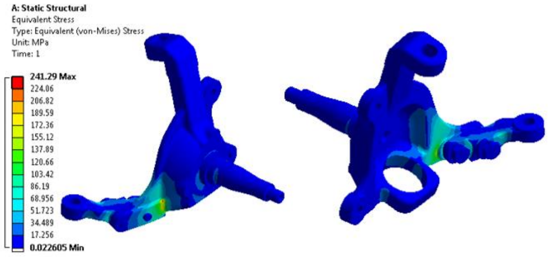


Fig.7 Stress on the Original Component

2.7 Fatigue Life of Original Model

The loading is assumed to be fully reversed. For the bolted design the life component is 10738 numbers of cycles at the stressed zone. Fatigue zone of the component is shown in Figure 8.

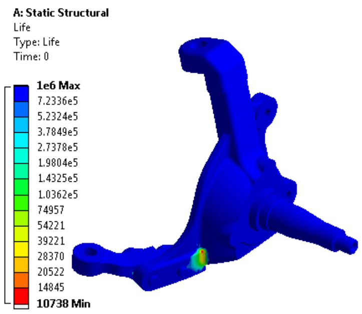


Fig. 8 Fatigue Life for the Original Model

2.8 Design Iterations of Knuckle

Modifications are considered to the steering knuckle in order to increase the fatigue life and avoid the failure. Five different configurations are analysed for low stress and fatigue life. These iterations for the design change are shown in Figure 9 to Figure 13. Iteration one has the steering arm directly casted to the main knuckle without any projections. Iteration two is added with material on the steering arm. Iteration three is the material is removed on the steering arm to make it simpler that iteration two. Iteration four is the same with addition of draft and fillets to have a simplified geometry. Iteration 5 is with small rib added on the front of steering arm. In all the iterations the modifications are done only to the steering arm.

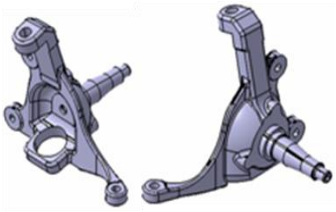


Fig. 9 Model for Iteration One (The steering arm is integrated, without ribs)

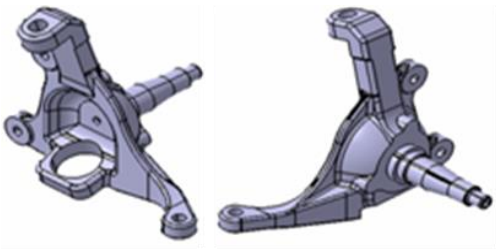


Fig. 10 Model for Iteration Two (The steering arm is integrated, with rib)

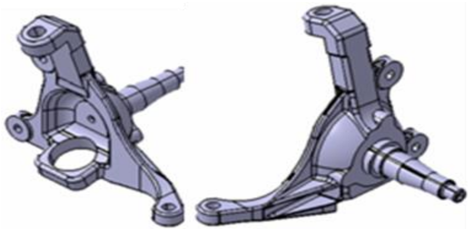


Fig. 11 Model for Iteration Three (The steering arm is provided with double rib)

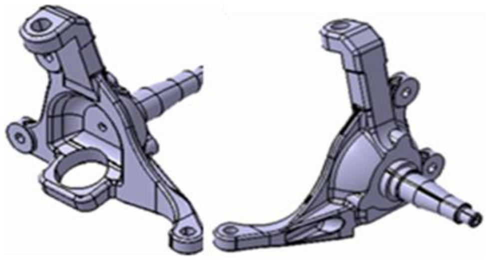


Fig. 12 Model for Iteration Four (The steering arm double rib is filleted)

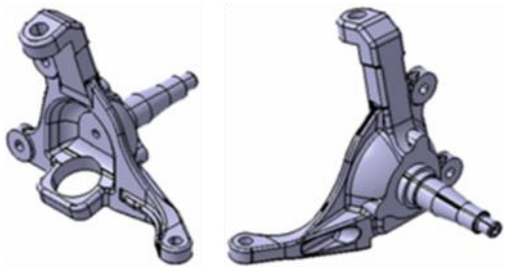


Fig. 13 Model for Iteration Five (The steering arm double rib is filleted and additional rib is provided in the front)

3. RESULTS AND DISCUSSIONS

Comparison of the maximum principal stress and fatigue life of all the analysed steering knuckle configurations, including the original and other five design iterations, is summarised in Table 1.

Table 1. Comparison of stress and fatigue life at 60kmph

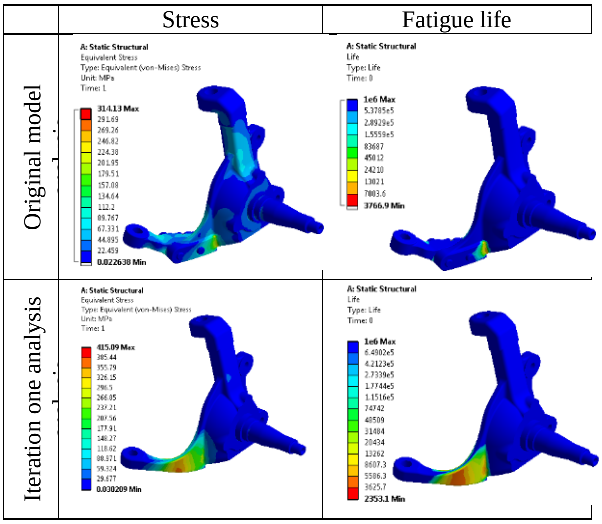
Speed	Model	Max. Principal stress (MPa)	Fatigue life cycle
60 kmph	Original Model	314.13	33580
	Iteration 1	253.39	11097
	Iteration 2	144.65	44007
	Iteration 3	148.39	1000000
	Iteration 4	324.79	5016.6
	Iteration 5	149.79	1000000

As the simulation was performed till 80 kmph, the failure of the knuckle was seen in the speed of 60 kmph, the results are populated at 60. The stress and fatigue life of all the iteration models at 60 kmph is shown in Figure 13. It is observed that the stress is more near steering arm in original, iteration 1 and iteration 4 model. The stress is more at upper control arm region in iteration 2, 3 and 5 models.

4. CONCLUSIONS

The results of structural analysis conducted for the steering knuckle and five iterations are summarized below.

- In Original model, magnitude of stress at the steering arm was determined to be 314 MP and fatigue life of the component is 3767 cycles. Since the original model has fatigue life less than the design reference this design does not suit the requirements.
- In Iteration one model, stress obtained was observed to be 450 MPa. As the stress is more than permissible yielding stress leading to lower fatigue life of about 2353 cycles, hence this design is not safe.
- In Iteration two the material was added to high stress zones. Principal stress obtained from analysis at steering arm is 145 MPa and fatigue life of 1000000 cycles. Stress were reduced by 53% compared to original model. Hence this design is safe.
- In Iteration three model, the principal stress was analysed and found out to be 148 MPa. Fatigue life also increased to 5749 cycles. Compared to stress in original model there is an improvement by 52%. There was a shift in stress to the upper control arm, therefore redesign of iteration four was required.
- Stress analysed on iteration four model was found to be 325 MPa, which is higher than yielding stress. Fatigue stress was also reduced to 5000 cycle. Hence this design is not safe.
- The magnitudes of the stress and fatigue life of for iteration 5 model were determined to be 150 MPa and 1000000 cycles respectively. Compared to the original design there is an improved stress by 52%. Hence this design is safe and recommended for this SUV.



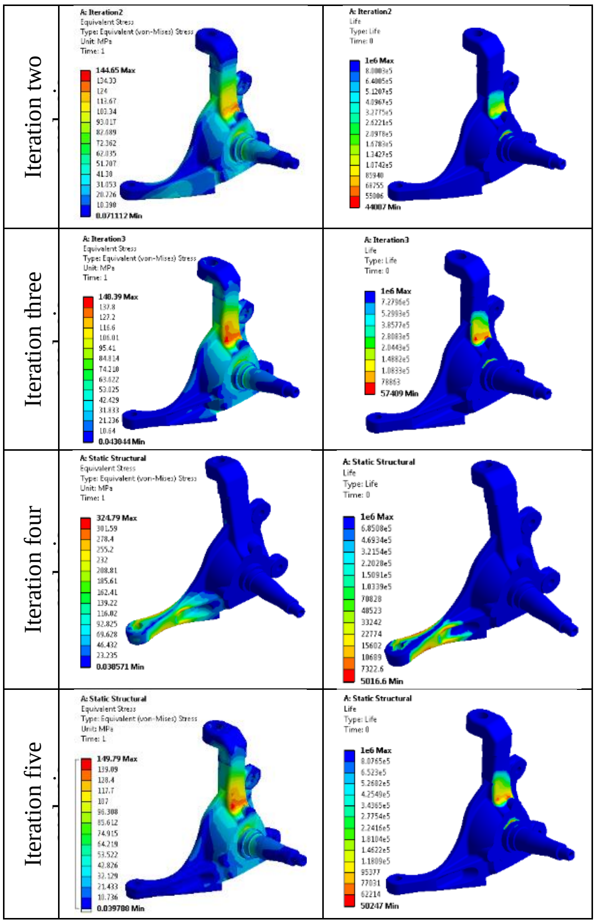


Fig. 13 Comparison of stress and fatigue life of all the iteration models at 60 kmph

REFERENCES

[1] Triantafyllidis, Georgios & Antonopoulos, A. & Spiliotis, A. & Fedonos, S. & Repanis, D.. (2009). Fracture Characteristics of Fatigue Failure of a Vehicle's Ductile Iron Steering Knuckle. Journal of Failure Analysis and Prevention. 9. 323-328. 10.1007/s11668-009-9245-y.

[2] Unknown, Tata Safari suspension Arm Breakage, http://www.teambhp.com/forum/technical-stuff/49181-tata-safari-suspension-arm-breakage-4.html, retrieved on Dec 2016.

[3] Unknown, https://bloozeown.weebly.com/rear-end/category/suspension-design/3. Retrieved on Dec 2016

[4] Unknown, https://www.steelexpress.co.uk/cast-iron-bar/grade500-SGiron-EN-GJS-500-7.html, retrieved on Dec 2016

[5] Michael Blundell, (2004) "Multibody Systems Approach to Vehicle Dynamics"

[6] Liao, Lin. (2011). A Study of Inertia Relief Analysis. 52nd Structural Dynamics and Materials Conference. 10.2514/6.2011-2002