Analysis of Combined Effect of Caster Angle and SAI on Steering Performance of the Vehicle

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Abstract

Proper selection of wheel geometry during design stage can lead to easier steering and direction stability. So it is very important to study about these wheel geometries in order to achieve reduced steering effort. In this work combined effect of caster angle, steering axis inclination and scrub radius on steering performance of the vehicle has been analysed. SUV vehicle was built in ADAMS/Car and SLC tests were performed at the speed of 50 km/hr. The SLC test at same speed was done using actual vehicle by performing outdoor tests. The steering torque graphs from virtual and outdoor tests were compared for different caster settings. Results obtained by both the methods were almost equal. After validation of ADAMS model, Design of Experiment (DOE) study was performed using ADAMS insight. The selected wheel geometry parameters after DOE study resulted in 3.6 % reduction in steering torque.

Key Words: Suspension Geometry, Design of Experiments, MBD Analysis, Caster, Steering Axis Inclination

1. INTRODUCTION

Vehicle Dynamics is a study of forces and moments acting on four palm sized patches, when the vehicle is under dynamic conditions. Performance, handling and ride are the three matrices of vehicle dynamics. Study of vehicle Performance, ride and handling characteristics during maneuvering is very important for safety and comfort point of view. Ride and handling behavior of the vehicle directly depends on design of suspension and steering system of the vehicle. Handling behavior of the vehicle manly depends on different Wheel geometries like camber, toe, caster, Steering Axis Inclination (SAI), scrub radius and Included Angle. Proper wheel geometry setting will lead to easier steering, longer tire life, direction stability, better fuel economy and safety of driver and co-passenger. So it is very important to study about this geometrical wheel alignment parameter in order to achieve better steering performance. Caster angle and SAI helps in achieving steering return ability and the amount of steering effort required to maneuverer the vehicle during cornering will depend on caster offset and scrub radius. ADAMS/Car is a virtual simulation software which is used for performing multi body dynamic analysis and ADAMS/CAR is a module under ADAMS software which is used to perform vehicle dynamic simulations. With the help of this simulating capability, OEM can save lot of time and money during vehicle design or vehicle performance modification stages. [1]

2. SOLUTION PROCEDURE

2.1 Selection of Vehicle

Mahindra Scorpio m Hawk 2WD SUV vehicle is selected as benchmark vehicle to study the combined effect of variation in caster angle and Steering axis inclination on steering performance of the vehicle. Selected vehicle Mahindra Scorpio m Hawk 2WD is shown in Figure 1 With the help of ADAMS/Car software Multi Body Dynamic (MBD) model of "Mahindra Scorpio m Hawk 2WD" is created. The steps involved in creating MBD model of Mahindra Scorpio m Hawk 2WD are

- Selection of hard point
- Data collection of various subsystem
- Template building, subsystem and assembly creation

Front and side view of Mahindra Scorpio MBD (multi body Dynamic) model is shown in Figure 2.

Fig. 1 Mahindra Scorpio m Hawk 2WD [2]

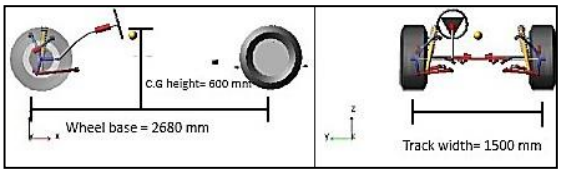

Fig. 2 Front and side view of Mahindra Scorpio MBD model

2.2 Testing & Validation of Adams Car Model

Testing & Validation of ADAMS/Car Model for Single Lane Change at constant speed of 50kmph was done on Mahindra Scorpio Vehicle. Test procedure based on ISO-3888-1 is shown in Table 1.

Test track standard dimension used for single lane change as per ISO 3888-1 as shown in Figure 3.

Actual test track is created with as per ISO 3888:1 standard as shown in Figure 3.

Table 1. Test procedure based on ISO-3888-1

Test Procedure	
The test is performed is based on **ISO 3888-1**	
1	After installation of the instruments and setup drive the vehicle around for about 15 min for the vehicle to reach working temperature and for SBG Ellipse INS initialization.
2	This test is performed at Partially laden condition with Driver and co-Driver.
3	Initially a few trial runs are performed to judge the vehicle behaviour.
5	The test is performed at constant entry speed and the throttle is held constant throughout the course.
6	It is recommended to use the cruise control option if available.
7	The test is considered as a pass if the vehicle maneuvers through the course without knocking off any cone.
9	Perform multiple trails to obtain repeatability.

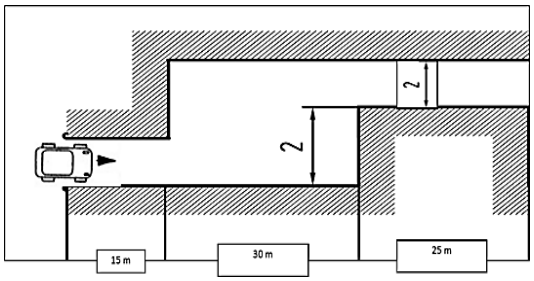

Fig. 3 Test track dimension as par ISO 3888:1 [3]

Single lane change test is performed on Mahindra Scorpio vehicle. The testing is done for three different settings of caster angles. Three different caster angle settings considered for outdoor Single lane change test are 2.82°, 3.67° and 1.73°.Nine test trails of Single Lane Change test were performed at the speed of 50 km/hr with three different caster angle settings. So with each caster angle settings three test trail has been conducted. All the real time test data was recorded in data acquisition System. Single Lane Change outdoor testing is performed at 50 km/hr.

2.3 Single Lane Change Test Simulation

Single Lane Change transient analysis is performed for Mahindra Scorpio MBD model with the help of ADAMS/Car software. Single Lane Change test is performed in order to know the control and stability of a vehicle during lane change operation. Wheel geometrical parameters considered during the simulation are; caster angle 3.2°, Steering axis inclination (SAI) angle is 8.22°and Scrub radius is 34.96 mm. Input simulation parameter for single lane change test is shown in Figure 5.

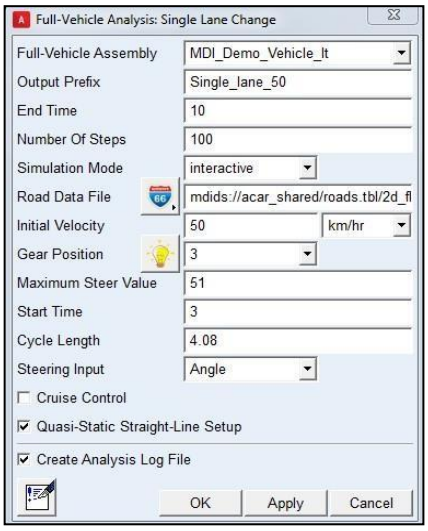

Fig. 4 Single Lane Change Simulation parameter

2.4 Doe Study For Single Lane Change

Design of Experiment (DOE) study is performed in order to study and analyze the combine effect of caster angle, scrub radius and steering axis inclination (SAI) on steering performance of the vehicle. Steps involved for performing DOE study is shown in Figure 2.8.The Basic ADAMS/Car simulation of MBD model for single lane change is performed and Steering assist toque is defined as design objective. In ADAMS/Car Insight lower control arm outer (Y-axis) and upper control arm outer (X-axis and Y-axis) hard points are selected as factors during DOE study. Hard point range (Minimum and maximum value) for caster angle, scrub radius and Steering axis inclination (SAI) is shown in Table 2.

Table 2. Hard Point range for DOE study

hpl_uca_outer (X)		
Caster angle		
1 degree	3.2 degree	4 degree
222.069	233	237.26
hpl_uca_outer (y)		
SAI angle		
5 degree	8.82 degrees	9 degree
-674.422	-655	-654.091
hpl_lca_outer(y)		
Scrub radius		
-20 mm	+34.96 mm	+80mm
-741.979	-700	-670.735

3. RESULTS AND DISCUSSIONS

In this paper following results are discussed:

- Validation of Single Lane Change outdoor testing result with ADAMS/Car Simulation result
- ADAMS/Car Single Lane Change results with benchmark vehicle model
- DOE study results for Single Lane Change simulation using ADAMS insight

3.1 Validation Of Single Lane Change Outdoor Testing Result With Adams/Car Simulation Result

After post processing the data it was understood that data recorded during first caster angle setting was not correct due to wrong position on sensor fitment. For validation of MBD model remaining data (Trail 4 to Trail 9) was used. With the same input parameter of caster angle, steering angle and speed of the vehicle six trails were performed in ADAMS/ Car software. Maximum steering torque for actual test data vs ADAMS/Car test data is shown in Figure 5.

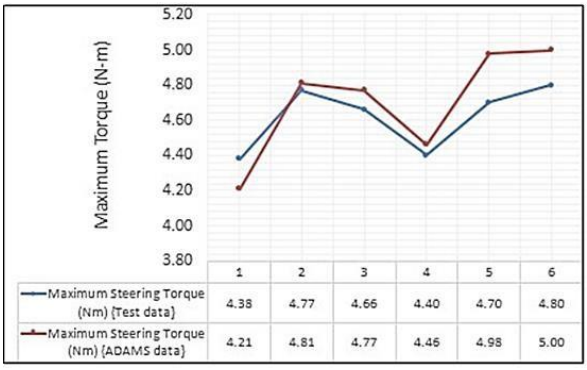

Fig. 5 Maximum steering torque for actual test data vs ADAMS/Car test data

As per Figure 5 maximum steering torque form actual test and from ADAMS/Car test data is following same trend when all other parameter remain same. Table 3 is shown another comparison of outdoor testing and ADAMS/Car software. Results obtained by both the methods are almost equal. With the help of Figure 6 and Table 3 it can be concluded that MBD model created in ADAMS/Car model is giving steering performance results same as actual vehicle. Hence ADAMS/Car vehicle model is validated with outdoor testing results. So this validated model is further used for performing simulation in ADAMS/Car and ADAMS insight software to study the combine effect of caster angle and SAI on steering performance of the vehicle.

3.2 Adams/Car Single Lane Change Results With Benchmark Vehicle Model

During Single Lane Change simulation the value of caster angle is 3.2°, Scrub radius is 34.96 mm and Steering axis inclination (SAI) angle is 8.82° is selected The total cycle length considered for the simulation is 4.08 seconds and maximum steering wheel angle value considered is 51 degrees. Single Lane Change simulation result of Steering assist torque vs time is shown in Figure 7. Maximum steering torque obtained during the simulation is 5.78 N-m.

Table 3. Validation of MBD model of Mahindra Scorpio

Castor Angle	Maximum Steering Angle (Deg)	Maximum Steering Torque (N-m) (Field Test)	Maximum Steering Torque (N-m) ADMAS software
First Setting(2.82°)	51	N.A	4.61
Second Setting(3.67°)	51	4.66	4.77
Third Setting (1.73°)	51.74	4.40	4.46

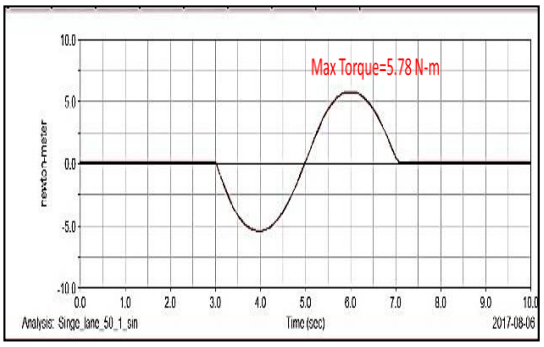

Fig. 6 Steering assist torque vs Time graph

3.3 Doe Study Results For Single Lane Change Simulation Using Adams Insight

During DOE analysis total sixty four trails were performed but only thirty trail combinations of caster angle, Scrub radius and SAI was possible to simulate which are shown in Table 4.

Minimum steering assist torque of 4.85 N-m is obtained during trail 35. Caster angle during trail 35 was 1 deg which result in lesser steering return ability. Hence hard point data's of trail 43 was suggested as the data to be considered during design of Mahindra Scorpio vehicle. Trail 43 has Caster angle of 2.9°, steering axis inclination of 6.61°, positive scrub radius of 46.81 mm and steering torque 5.58 N-m.

4. CONCLUSION

- Methodology for selecting caster angle, SAI and scrub radius during initial phase of suspension design was developed
- Actual steering assist torque from outdoor tests and ADAMS/Car model results are following same pattern and difference between average torque values is only 0.09 N-m.
- Caster angle of 2.9°, steering axis inclination of 6.61° and positive scrub radius of 46.81 mm was selected based on DOE Study
- In Single Lane change analysis, steering assist toque is reduced from 5.78 N-m to 5.58 N-m. (Improvement by 3.6 %)

Table 4. DOE study result for single Lane change Simulation

S. No.	Trial	hpl_uca_outer.y	uca_outer.x	hpl_lca_outer.y	Steering assist torque (N-m)
1	Trial 35	-660.87	222.07	-694.48	4.88
2	Trial 39	-660.87	227.13	-694.48	5.23
3	Trial 43	-660.87	232.20	-694.48	5.59
4	Trial 62	-654.09	237.26	-718.23	7.53
5	Trial 58	-654.09	232.20	-718.23	7.38
6	Trial 54	-654.09	227.13	-718.23	7.23
7	Trial 50	-654.09	222.07	-718.23	7.08
8	Trial 63	-654.09	237.26	-694.48	5.82
9	Trial 57	-654.09	232.20	-741.98	8.53
10	Trial 46	-660.87	237.26	-718.23	7.56
11	Trial 42	-660.87	232.20	-718.23	7.42
12	Trial 38	-660.87	227.13	-718.23	7.27
13	Trial 34	-660.87	222.07	-718.23	7.13
14	Trial 47	-660.87	237.26	-694.48	5.96
15	Trial 18	-667.65	222.07	-718.23	7.16
16	Trial 19	-667.65	222.07	-694.48	4.99
17	Trial 30	-667.65	237.26	-718.23	7.56
18	Trial 23	-667.65	227.13	-694.48	5.35
19	Trial 27	-667.65	232.20	-694.48	5.73
20	Trial 26	-667.65	232.20	-718.23	7.43
21	Trial 22	-667.65	227.13	-718.23	7.30
22	Trial 31	-667.65	237.26	-694.48	6.12
23	Trial 2	-674.42	222.07	-718.23	7.17
24	Trial 15	-674.42	237.26	-694.48	6.29
25	Trial 6	-674.42	227.13	-718.23	7.30
26	Trial 11	-674.42	232.20	-694.48	5.88
27	Trial 10	-674.42	232.20	-718.23	7.42
28	Trial 7	-674.42	227.13	-694.48	5.49
29	Trial 14	-674.42	237.26	-718.23	7.55
30	Trial 3	-674.42	222.07	-694.48	5.11

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