Influence of vehicle parameters on handling characteristics and its control using torque vectoring

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Influence of vehicle parameters on handling characteristics and its control using torque vectoring

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Abstract— Handling characteristics of any vehicle refer to its directional control and stability for given steering input. The vehicle parameters such as mass, mass moment of inertia and location of C.G. play a vital role and decide handling response of vehicle under different scenarios. Safe drive is ensured by vehicle's responses such as yaw rate, roll rate and vehicle lateral acceleration. This paper presents steady state and transient state simulation of XUV 500 model in accordance with ISO 4138 and ISO 3888 test standards using CarSim-Simulink Co-simulation. Influence of changes in above mentioned parameters on Vehicle response during both tests is investigated. Further, control of power train output using torque vectoring is implemented in both tests and its effect on vehicle response is evaluated. The results show that understeer tendency of the vehicle is reduced in steady state test (Constant radius test: ISO 4138). Critical vehicle responses of yaw rate, roll rate, lateral acceleration and path tracking showed improvement during the DLC manoeuvre (ISO 3888) hence, improving stability at higher lateral accelerations.

1. Introduction

The concept of vehicle handling has always been more subjective than objective, based on how a trained test driver describes his drive. There are however, objective metrics developed to understand a very particular quality of a vehicle which give an idea of how it will behave under specific conditions. Subjective handling tests are, moreover, comparison based and largely depend on driver. Sideslip angle data measured on vehicles clearly indicated that vehicles were safe in cornering but psychophysics showed that driver can get a perception of vehicle not being safe[1]. Thus, subjective tests can sometimes misguide the evaluation. Variation in tyre slip leads to perception of stability or instability. Thus, Objective metrics of vehicle also need to be evaluated.

1.1. Steady state circular driving behaviour-open loop test

ISO 4138 prescribes standard tests to determine Understeer characteristics of vehicle. Various tests prescribed in this standard are listed in the table below [2]. The gradient is measured as a slope of the plot of the Measured vs. Varied parameter.

Table 1. List of tests as per ISO 4138

Test	Radius	Steer angle	Speed
Constant radius test	Constant	Measured	Varied
Constant steer wheel angle test	Measured	Constant	Varied
Constant speed discrete turn radii test	Varied	Measured	Constant
Constant speed discrete steering wheel angle test	Measured	Varied	Constant

A real-time factor that was observed to affect the performance of vehicles in steady state cornering tests was torque distribution to the wheels. This directly related to how the power train was set up and which wheel received greater torque during turns. This bias of torque created a virtual assist/hinder to load transfer during these tests.

1.2. Double lane change test

ISO 3888 gives general rules to follow for a double lane change manoeuvre test [4]. DLC test is used to determine vehicle transient handling characteristics. It simulates emergency turning or cornering manoeuvre. Vehicle will only avoid accident if it is controllable during sudden manoeuvre, otherwise it can go out of control and can result into roll over.

1.3. Torque Vectoring to improve Vehicle Handling

To prevent the spinning and drifting of vehicle especially during sharp manoeuvres, there is a need to monitor the yaw stability of the vehicle. The yaw stability control system is either a differential braking based or torque distribution based [5]. But, the vehicle systems based on brakes, on sharp manoeuvres, deteriorate the longitudinal performance [6]. Hence, here we are dealing with a vehicle incorporated with torque distribution. Different control strategies can be used for torque distribution depending upon the control algorithm used. Due to independently controlling the drive torque to each wheel, vehicle's stability and handling characteristics are significantly enhanced. The main focus of vehicle's dynamic control system is to improve control of vehicle to prevent unintended vehicle behavior and thus to ensure safety of both driver and vehicle.

In this paper, the handling and stability performance of the vehicle is investigated by means of CarSim and Simulink co-simulation. A Simulink model is designed to vary the left and right torque distribution. Characteristic to be controlled is the understeer behavior of the vehicle [7]. The results indicate that the torque management strategy is generally very effective in reducing the understeer characteristics of vehicle and improve handling characteristics at higher vehicle speeds. In this Simulink model the resulting system shows a significant improvement over conventional driveline configurations (without torque vectoring control) under aggressive cornering.

1.3.1. Torque distribution strategy. Based on the handling and stability characteristics, a left and right torque distribution controller is modelled to optimize the vehicle maneouverability for various conditions proposed earlier like variation of position of the CG, mass, etc. Georg Rill investigated and analyzed different torque distribution ratios for front left and right wheels [8]. It was proved that greater torque to the outer wheel reduced the understeer gradient. Based on this, a controller is designed to give a fixed torque distribution of 90:10 (outer: inner) while cornering and steady state test is performed.

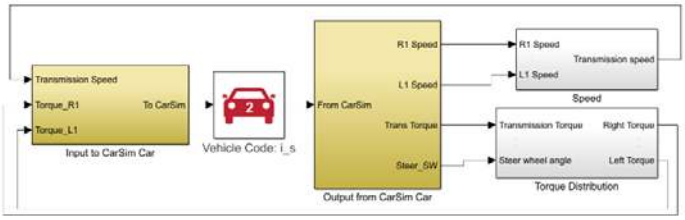

Figure 1. Simulink model of Torque vectoring strategy used.

1.3.2. Yaw rate Control strategy. Vehicle stability is achieved in this paper by controlling the vehicle yaw rate with the help of torque controller model designed in Simulink [9] - [12]. The yaw rate error (e) is formulated as follows,

$$e = r - r_d \tag{1}$$

Where, r = Actual Yaw rate input from CarSim and r_d = Desired Yaw rate

The desired Yaw rate is calculated by using,

$$\left.\begin{aligned} r_d &= r_d && |r_d| < \left(\frac{\mu \times g}{V_x}\right) \\ &= \left(\frac{\mu \times g}{V_x}\right) \times \operatorname{sgn}(r_d) && |r_d| \geq \left(\frac{\mu \times g}{V_x}\right) \quad \text{Where } r_d = \left(\frac{V_x}{\left(l \times \left(1 + \left(K \times V_x^{2}\right)\right)\right)}\right) \times \delta \end{aligned}\right\} \tag{2}$$

V_x : Longitudinal Velocity l = Wheel Base δ = Front Wheel Steer Angle

The Stability factor (K) takes the form, $K=\frac{m}{l^2}\times\left(\left(\frac{l_r}{C_f}\right)-\left(\frac{l_f}{C_r}\right)\right)$ (3)

The desired yaw moment is then calculated using the following formula,

$$M_{zz}=\left(I_{zz}\dot{r}_d-I_{zz}\dot{r}\right) \tag{4}$$

From the above moment, corrective torque T_z is found as follows,

$$T_z=M_{zz}\times\left(\frac{R}{d}\right) \tag{5}$$

Where, R = Wheel radius d = Track width

This is implemented in CarSim Simulink as shown in figure 2 below and DLC test is performed.

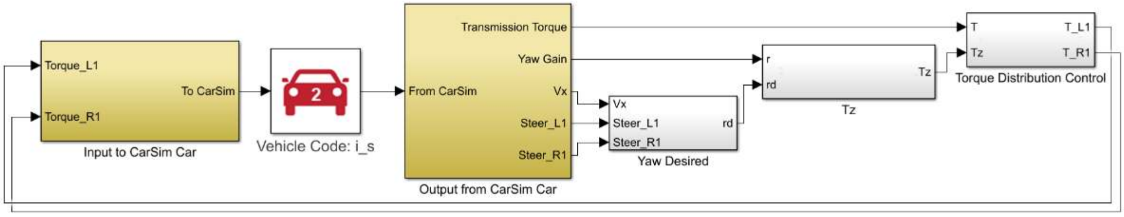

Figure 2. Simulink model of Yaw Control Strategy used.

2. Vehicle Model

CarSim software was used to simulate ISO Constant radius test and DLC test in order to study handling of vehicle. Mahindra XUV 500 was modelled to perform the tests.

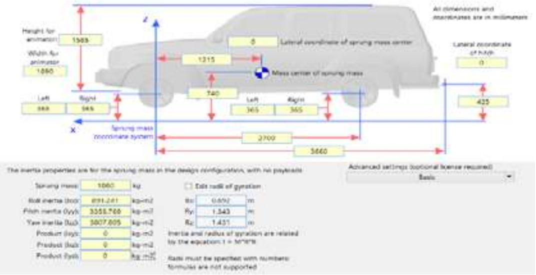

Figure 3. Vehicle Dimension, Sprung Mass and Inertia input screen in CarSim.

3. Results

3.1. Steady state circular driving behaviour-open loop test method- ISO 4138 Constant radius test

From figure 4, very less variation is observed in steer angle with variation in mass at lower values of lateral acceleration. It is clear that the understeer characteristics of vehicle show almost no change with variation in sprung mass. From figure 5, little variation is observed in required steer angle with variation in C.G. height at lower speed. Whereas at lateral acceleration above 0.65 g, there is some deviation in required steer angle to manoeuvre the same turn. Vehicle shows reduction in understeer with decrease in C.G. height and increase in understeer characteristics with increase in C.G. height.

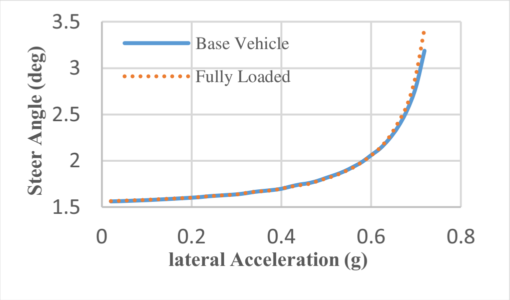

Figure 4. Effect of variation of sprung mass on Steer angle.

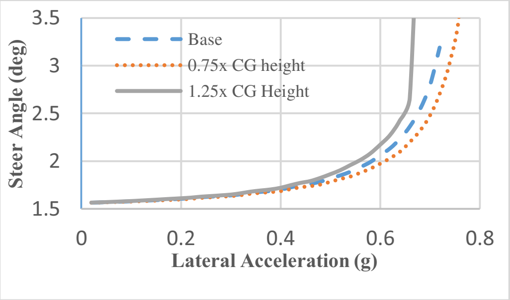

Figure 5. Effect of variation of C.G. Height on Wheel Steer angle.

From figure 6, vehicle's behaviour shows overall reduction in understeer with shifting longitudinal position of C.G. behind and increase in understeer characteristics with shifting longitudinal position of C.G. ahead.

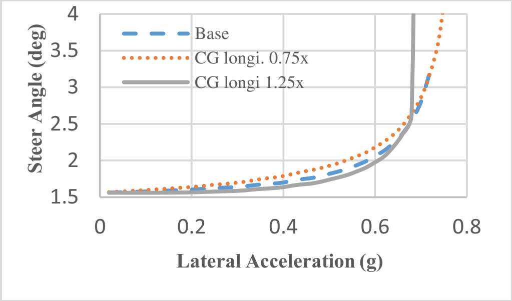

Figure 6. Effect of variation in longitudinal position of C.G. on Steer angle.

3.2. *Torque Vectoring to improve Vehicle Handling*

From figures 7 and 8, it is evident that even in extreme variations in location of C.G. in both vertical and longitudinal directions (which increases understeer behaviour), understeer tendency of the vehicle significantly reduces after torque vectoring. The lateral acceleration limit (after which the vehicle response overshoots as seen in the plots) increases from about 0.66g to about 0.73g in case of 25% increase in C.G. height and from 0.68g to 0.76g for 25% shift of C.G. towards front axle. Similar trend is observed in case of full load condition as seen in figure 8.

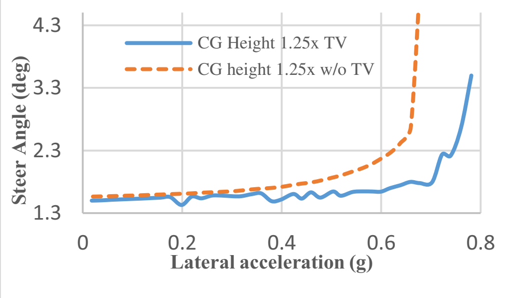

Figure 7. Variation of C.G. Height on Wheel Steer angle with & without Torque Vectoring.

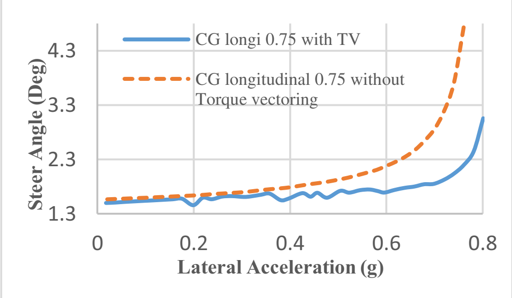

Figure 8. Variation in longi. position of C.G. on Steer angle with & without Torque Vectoring.

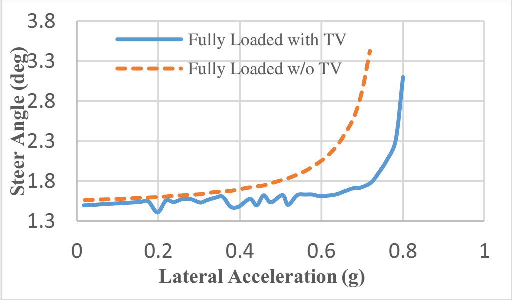

Figure 9. Effect of variation of sprung mass on Steer angle with and without Torque Vectoring.

3.3. *Double lane change test- ISO 3888*

It can be observed from figure 11 that roll rate of the sprung masses in the vehicle is extremely sensitive to changes in vertical C.G. location with a 50% increase in height of C.G. giving a RMS change of about 85% at 50kmph and 90kmph both. Such a severe change in roll rate will affect a real driver's response and results in an actual test may therefore vary.

All the characteristics (Roll rate, Yaw rate and steering input) show a significant increase when the vehicle speed used to simulate the test is increased. The vehicle follows the prescribed path closely at

50kmph and a greater deviation is seen when the vehicle speed is increased to 90kmph. Therefore, it can be concluded that the compliance to the prescribed path is a major function of vehicle speed

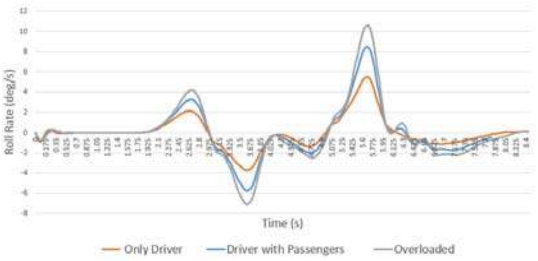

Figure 10. Roll rate vs. time for Driver only, Fully loaded and Overloaded Condition.

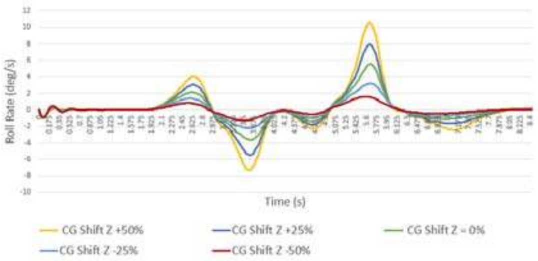

Figure 11. Roll rate vs. time for Variation in C.G. Height.

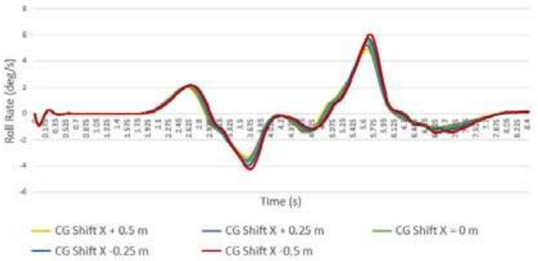

Figure 12. Roll rate vs. time for Longitudinal Variation in C.G.

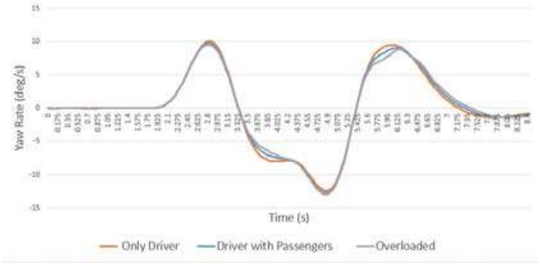

Figure 13. Yaw rate vs. time for Driver only, Fully loaded and Overloaded Condition.

3.4. Yaw rate Control strategy

Vehicle yaw rate, Lateral Tracking, roll angle, Lateral acceleration for the vehicle with and without torque vectoring are compared. Figure 14 represents the lateral tracking of the vehicle during performing DLC test from which it is observed that the vehicle with torque distribution strategy implemented on it resembles to the target path more closely as compared with the vehicle without implementing the torque distribution. Figure 15 is a measure of vehicle's stability in terms of its yaw rate experienced while performing the test. Vehicle with control strategy happens to follow the desired track as closely as possible due to corrective torque applied unlike the vehicle without any control strategy. Roll angle of the sprung masses as shown in the Figure 16 for the vehicle with and without control strategy states about the tendency of the vehicle to roll while maneouvering. Less roll angle in case of the vehicle with control strategy ensures the vehicle stability. Comparison of the lateral acceleration given in the Figure 17 shows that controlled vehicle experiences less lateral acceleration which is desirable during maneouvering as compared to the uncontrolled vehicle i.e. without any control strategy.

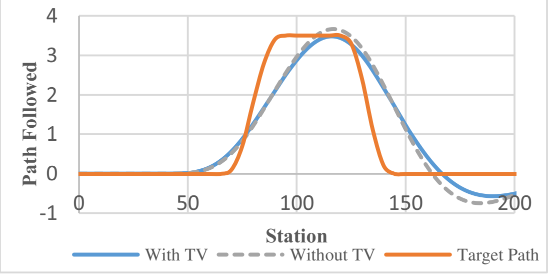

Figure 14. Lateral tracking for vehicle with and without Torque Vectoring

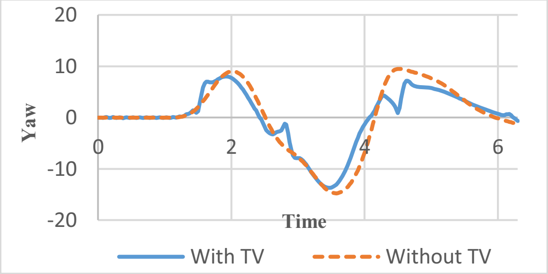

Figure 15. Yaw Rate vs. time for vehicle with and without Torque Vectoring

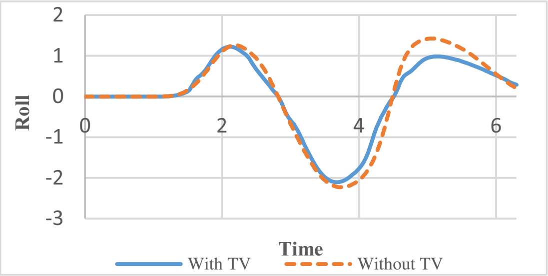

Figure 16. Roll angle vs. time for vehicle with and without Torque Vectoring

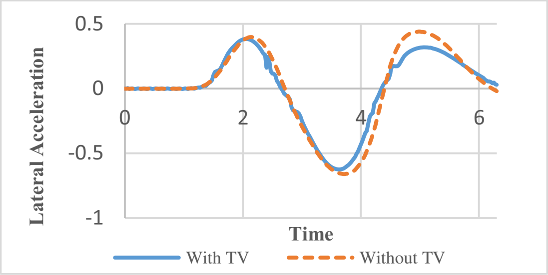

Figure 17. Lateral Acceleration vs. time for vehicle with and without Torque Vectoring

4. Conclusion

Torque vectoring is observed to be effective in steady state as well as transient scenarios. With implementing torque vectoring control strategy it was observed from the respective graphs that in steady state test, understeer gradient of vehicle was reduced from 0.5114 deg/g to 0.3288 deg/g for fully loaded condition, 0.7516 deg/g to 0.5168 deg/g for C.G. longitudinal variation and from 0.6211 deg/g to 0.4259 deg/g for C.G. vertical variation case. While in transient test, RMS values of yaw rate, lateral acceleration and roll angle of the vehicle indicated reduction of 18%, 14% and 15% respectively. This system can be designed for any vehicle and optimized to improve handling performance and safety characteristics.

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