Parametric Study of the Complete Vehicle Model - The effect on the Roll Gradient of the Vehicle

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Abstract :

There are different factors which quantify the dynamic behaviour of a vehicle. The Roll Gradient, Steering Sensitivity, Understeer Gradient are some of them. In this paper an effort has been made to identify the factors affecting the Roll Gradient and to evaluate the degree of effect on the Roll Gradient of a vehicle.

The complete vehicle model of a vehicle was created using the ADAMS/Vehicle module. The identified parameters are Sprung Mass of the Vehicle, Location of the CG of the Vehicle Sprung Mass in X and Z direction etc. The parameters were varied in their respective ranges. For each case a dynamic analysis was carried out and the value of the Roll Gradient was evaluated. The same approach of "Parametric Study" can be used for establishing the nature of behaviour of the other factors governing the dynamic behaviour of the vehicle.

Introduction :

In the conventional suspension design process the testing of the prototypes for the vehicles is carried out and their dynamic behaviour is established by subjecting them to various dynamic tests. The feed back from these tests is used to refine the suspension designs. The same tests is repeated for evaluating the correctness of the suggested changes. The design cycle time can be reduced by adopting the concept of "Virtual Prototyping". In virtual prototyping the system is represented in the form of a model in the computer and the effects of various design changes and extreme conditions are simulated. This serves in improving the design process by reducing the development time and the resources required for the building of the physical prototypes.

This study forms a part of the first phase of the virtual prototyping of vehicles. This is achieved by the creation of the model of the complete vehicle in the ADAMS software and then by carrying out a parametric study on the same. The phenomenon of interest in this study is the "Roll Gradient" of the vehicle, which is counted as one of the measures to understand the dynamic behaviour of the vehicle. The parametric study has provided an opportunity to validate the ADAMS model against the actual test results and the conventional vehicle design values.

General Discussion about Parametric Study :

The parametric study used to observe the behaviour of any system for the variation of the identified parameters. The aim of a parametric study is to study the effect of the variation of the specific parameters on some phenomenon quantifying the behaviour of system and to rate the parameters on the basis of their sensitivities. The specific parameters are varied in the predetermined ranges and the change in the phenomenon of interest in evaluated.

The "Sensitivity of the Parameter" is defined as the percentage of the percentage change in the output per percentage change in the input parameter.

The procedure of the Parametric Study is as follows

- Identify the Phenomenon to be studied
- Select the System Parameters which are likely to govern the Phenomenon under consideration.
- Identify the Range of variation each Parameter.
- Carry out the actual parametric analysis
- Extract the results
- Analys the results to calculate the Sensitivity of the various Parameters
- Identify the most significant Parameter for the selected Phenomenon

The parameters are selected on the basis of the experience or by using some basic calculations.

Roll Gradient :

The Roll Gradient / Roll Gain or Roll Stiffness of a vehicle is defined as the rate of change of vehicle roll angle with steady state lateral acceleration values.

It represents the amount of roll angle developed in the vehicle per "G" of the lateral acceleration. The Roll Gradient of the vehicle accounts for all the flexibility's resisting the roll motion of the vehicle including the roll stiffness of both front and rear suspensions. The roll motion the effect of the centrifugal force acting at the C.G. due to the lateral acceleration (centrifugal acceleration) generated when the vehicle is undergoing a cornering manoeuvres. The graph of the roll angle developed in the vehicle against the steady state lateral acceleration of the vehicle is plotted. This graph is linear in nature for the steady state range of the lateral acceleration. The slope of this graph is the Roll Gradient of the vehicle. Average value is taken at 0.15 G's of lateral acceleration. Typical values range from 4.0 to 8.0 Deg/G.

Methodology for the Study :

The parametric study of the full vehicle model was carried out to check it's dynamic behaviour for the different values of the specific variables. The study was mainly aimed at observing the change in the Roll Gradient of the vehicle for the variation of the selected parameters. The Study was carried out in the following steps

1. Creation of the Complete Vehicle Model
2. Identification of the Aim of the Parametric Study
3. Selection of Parameters
4. Selection of the Dynamic Vehicle Test
5. Parametric Study
6. Calculation of the Sensitivities
7. Observations
8. Conclusion

Creation of the Complete Vehicle Model :

The models for the front and rear suspension of a vehicle was created using the templates in the ADAMS/Vehicle Module of the ADAMS Software. The kinematic analysis of the suspensions was carried out to confirm the correctness of the input data. The Suspension Characteristics like Castor Angle, Camber Angle, KPI, Roll Rate, Ride Rate, Height of the Roll Center were validated with the design and calculated values. The full vehicle model was generated by assembling the front and rear suspensions in ADAMS/Vehicle by specifying the full vehicle parameters like wheel base, sprung mass etc. The assembly of the front and the rear suspensions is achieved through ADAMS/Vehicle and the further requests are created using ADAMS/View. The request statements are required generate the outputs of the parameters of interest like roll angle and the lateral acceleration.

Model Description :

The complete vehicle model includes the front and rear suspension, the steering geometry and the Antiroll Bar at the front. The suspensions at front and rear fall under the category of independent suspensions. The complete steering geometry is not required to be modelled for the purpose of this study. Hence the mechanism upto the Steering Rack is modelled and the input is given at the rack. The Antiroll Bar is included as a torsional spring force between two parts, which are connected to the left and right lower links at front. The shock absorbers at the front and rear are modelled as non-linear velocity dependent forces. The tyres are modelled as a combination of 3 forces and 3 moments governed by the FORTRAN subroutine supplied with ADAMS/Tire module.

The CAD Models of the complete front and rear suspensions, consisting of the assemblies of the components were used to extract the properties like Mass, Moment of Inertias and CG Locations. The CAD Models were available in the other CAD Package. The other properties like Bushing stiffnesses, Anti-roll Bar Stiffness were calculated using the preliminary design procedures. The tyre properties in the tire property file are selected on the basis of the past experience and on the basis of elementary measurements.

Assumptions in the ADAMS Model :

The present vehicle model does not contain the effects of the following aspects.

- The Flexibility of the Shell of the Vehicle.
- The Flexibility of the individual components in the suspension and steering linkage.
- Non-linearity of the Suspension Bushings
- Clearances or plays in various joints in the actual vehicle.
- Effects like friction, wear
- Aerodynamic Aspect of the vehicles
- Power Train Dynamics
- Differential Gear Box
- Change of Gears

Parameters for the Parametric Study :

The following 8 parameters were identified for the parametric Study.

1. CG location in Longitudinal Direction : CG_x (Distance from the Front Axle)
2. CG location in Vertical Direction : CG_z (Height from Ground)
3. Sprung Mass of the Vehicle : M
4. Steering Rack Travel for the Step Input
5. Diameter of the Antiroll Bar
6. Stiffness of Tyres in Vertical Direction
7. Stiffness of Tyres in Lateral Direction
8. Time Interval for Steering Input

Steady State Circular Test :

In this test the vehicle is made to rotate in a circle of a specific radius at a constant speed. The quantities like Roll Angle, Forward Velocity, Lateral Acceleration for the vehicle are measured. The same measurements are repeated for different speeds of the vehicle. ISO - 4138 specifies the complete details of this test. The outputs generated by this test are the Roll Gradient of the vehicle, Maximum Lateral Acceleration that can be sustained by the vehicle, Understeer / Oversteer tendency of the vehicle.

For the simulation of this test in ADAMS Software, the vehicle model initially is allowed to attain a static equilibrium. Then the vehicle is allowed to travel in a straight line for a certain time duration to remove the transient effects of the initial motion. This motion is achieved by specifying initial velocities to all the parts in the model. After the steady state is achieved a step input in displacement form is applied at the Steering Rack and held in that position for the complete analysis. The value of Steer Input decides the diameter of the circular motion of the vehicle. The speed of the vehicle is maintained constant by means of controller torques acting at the wheels, which adjust their magnitudes by sensing the difference in the actual and the desired vehicle speed in forward direction. After the analysis a graph of the roll angle developed versus the lateral acceleration is plotted. The slope of this graph will give the Roll Gradient or Roll Stiffness for the vehicle.

Parametric Study :

Firstly the model is submitted to the static analysis to achieve the static equilibrium. The model is submitted to a dynamic analysis each time after the change in the parameter was made. The dynamic analysis is run for 25 seconds with 100 time steps per second of simulation time.

The Sensitivity of Parameter is defined as follows

$$\text{Sensitivity} = \frac{\text{Percentage\_ Change\_ In\_ Roll\_ Gradient}}{\text{Percentage\_ Change\_ In\_ Input\_ Parameter}} \text{ X } 100$$

1. C.G. Location of in Longitudinal Direction (Distance from the front Axle)

Sprung Mass = 600 kg : Speed = 30 kmph : Rack Movement = 20 mm

Sr No	CG x	Lat Acc mm / sec ^2	Lat Acc G	Roll Angle Deg	Roll Grad Deg / G
1	1000	4930	0.5025	3.264	6.495
2	1125	"	"	3.4145	6.795
3	1250	"	"	3.832	7.625

2. C.G. Location in Z-Direction (Height from the Ground)

Sprung Mass = 600 kg : CG x = 1000 mm : Speed = 30 kmph : Rack Movement = 20

Sr No	CG z	Lat Acc mm / sec ^2	Lat Acc G	Roll Angle Deg	Roll Grad Deg / G
1	400	5015	0.5112	2.086	4.0804
2	425.0	"	"	2.225	4.353
3	450.0	"	"	2.3868	4.669
4	500.0	"	"	2.6554	5.194
5	600.0	"	"	3.2629	6.385

3. Sprung Mass of the Vehicle

CG x = 1000 mm : CG z = 500 : Speed = 30 kmph : Rack Movement = 20

Sr No	*Sprung Mass*	Lat Acc mm / sec ^2	Lat Acc G	Roll Angle Deg	Roll Grad Deg / G
1	600	5015	0.5112	2.086	4.0804
2	700	"	"	2.156	5.041
3	800	"	"	2.225	6.194

4. Steering Rack Movement

Sprung Mass = 800 kg : CG x = 1000 mm : CG z = 400 mm : Speed = 20 kmph

Sr No	*Rack Move*	Lat Acc mm / sec ^2	Lat Acc G	Roll Angle Deg	Roll Grad Deg / G
1	10	1017	0.1037	0.6378	6.15
2	20	2418.6	0.2465	1.5184	6.158
3	30	3984.5	0.4061	2.5158	6.194
4	40	5741.8	0.5853	3.51	5.997

5. Diameter of the Antiroll Bar :

Sprung Mass = 800 kg : CG x = 1000 mm : CG z = 400 mm : Speed = 20 kmph

Sr No	*ARB Dia.*	Lat Acc mm / sec ^2	Lat Acc G	Roll Angle Deg	Roll Grad Deg / G
1	18	3984.5	0.4061	2.697	6.641
2	19	"	"	2.632	6.481
3	20	"	"	2.5158	6.195

6. Stiffness of Tyres in Vertical Direction

Sprung Mass = 600 Kg, : CG x = 1000 : CG z = 500 : Speed = 33 kmph
Rack Movement = 15 mm

Sr No	*Vertical Stiff N / mm*	Lat Acc mm / sec ^2	Lat Acc G	Roll Angle Deg	Roll Grad Deg / G
1	250	4442.4	0.4528	2.3672	5.227
2	225	"	"	2.4035	5.308
3	200	"	"	2.4637	5.441

7. Stiffness of Tyres in Lateral Direction :

Sprung Mass = 600 Kg, : CG x = 1000 : CG z = 500 : Speed = 33 kmph
Rack Movement = 15 mm

Sr No	*Lateral Stiff N / mm*	Lat Acc mm / sec ^2	Lat Acc G	Roll Angle Deg	Roll Grad Deg / G
4	50	4442.4	0.4528	2.3672	5.227
5	40	"	"	2.3848	5.266
6	30	"	"	2.4065	5.315

8. Time Interval for the Steer Input :

Sprung Mass = 600 Kg, : CG x = 1000 : CG z = 500 : Speed = 33 kmph
Rack Movement = 15 mm

Sr No	*Time Interval sec*	Lat Acc mm / sec ^2	Lat Acc G	Roll Angle Deg	Roll Grad Deg / G
1	0.5	4442.4	0.4528	2.333	5.152
2	0.8	"	"	2.312	5.106
3	1.1	"	"	2.309	5.099

Observations :

The following table shows the comparison of the sensitivities for this Parameteric Study.

Sr No	Parameter	Sensitivity (%)	Relationship
1	CG Location in X-Direction	69.59	Direct
2	CG Location in Z-Direction	112.96	Direct
3	Sprung Mass	**115.39**	Direct
4	Steering Rack Travel	0.83	-
5	Dia. of ARB	60.44	Inverse
6	Stiffness of Tyres in Vertical Direction	20.47	Inverse
7	Stiffness of Tyres in Lateral Direction	4.21	Inverse
8	Time Interval for Steering Input	0.85	-

- The Change in the Roll Gradient due to CG_x & CG_z is attributed to the moment arm of CG from the roll axis of the vehicle.

- The parameters Sprung Mass and CG_z have been observed to be most sensitive parameters for the Roll Gradient of the vehicle

- Roll Gradient is the least sensitive to the Rack Travel indicating that the graph of Roll Angle Vs Lat. Accn. has a linear nature in the steady state zone.

- The increase in the stiffnesses of ARB and Tyres attribute to increase in the overall stiffness of the vehicle, hence reducing the value of developed Roll Angle.

- Even though the Roll Gradient is observed not to be sensitive to the Time Interval for the Steering Input, a lot of variation is observed in the Roll Angle Characteristics in the Transition between the two steady states viz. the state before the Steering Input and that after the Steering Input

Conclusion :

- Roll Gradient is observed to be most sensitive to the “Sprung Mass” and the C.G. Height from the Ground out of the selected parameters

- The trend of the effects of the selected parameters on the Roll Gradient of the vehicle was established.

- The procedure of the simulation of the Steady State Circular Test in ADAMS Software was established.

- By carrying out a further exhaustive parameteric study with more number of parameters having larger ranges of variation, an array of the values of the Roll Gradient can be established, which in future can be used as a reference table for the different configurations of the vehicle.

Remarks :

- A considerable amount of interaction between the design, testing and analysis department is necessary for carrying out the full vehicle simulations. This further requires a lot of data collection in the areas of the Tyre Properties, Bushing Characteristics, the actual testing procedures etc.

- The same approach of "Parametric Study" can be used for establishing the nature of behaviour of the other factors governing the dynamic behaviour of the vehicle e.g. Steering Sensitivity, Understeer Gradient, Cornering Compliance etc.

- With further refinements this full vehicle model can be used for carrying out dynamic simulations like lane change manoeuvre, Sine Wave Input Test, Random Input Test, Ride Comfort Analysis, Braking / Acceleration Tests, Service Load Analysis. Steering Effort Estimation etc.

References :

1. Reference, User's Manuals for ADAMS Modules Ver 8.1
2. Rrof J.R.Ellis - Vehicle Dynamics
3. SAE - J670e - Vehicle Dynamics Terminology - SAE recommended Practice
4. ISO - 4138 - 1982 (E) - Road Vehicles - Steady State Circular Test Procedure
5. D.J.Bikerstaff - The Handling Properties of Light Trucks - Ford Motor Company - SAE 760710
6. N.Orlandea - Deere & Company & M.A.Chace - The Univ. of Michigan - Simulation of a Vehicle Suspension with the ADAMS Computer Program - SAE 770053