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Caster Angle and KPI Variation through Worst Case & RSS Method

Ravindra Kachare[1] Mohan Patwari[2]

[1]*Team Lead, Tata Technologies, ERC, Chassis, Tata Motors, Pune Maharashtra, India*
[2]*Tech Lead, Tata Technologies, ERC, Chassis, Tata Motors, Pune Maharashtra, India*

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Abstract - *Caster angle is one of the main parameters of suspension system which has significant impact on a vehicle's handling at time of cornering, straight-line stability and high speed stability. Caster angle is a slope created by an imaginary line passes from upper ball joint to the lower ball joint i.e. KPI (king pin inclination) to center line of tyre when seen from side of vehicle. Caster angle is said to be positive if strut top point in MacPherson suspension is inclined towards rear side of vehicle or KPI line inclined towards vehicle rearward. Caster angle is said to be negative if KPI inclined towards vehicle front which creates angle with center line of front tyre. Positive and negative caster angle set in vehicle depending upon the suspension system geometry requirement and overall vehicle performance. Caster value varies if strut top point and lower ball joint contributor parts are not in specified tolerance limit which changes the king pin inclination. To check maximum or minimum caster variation as per the tolerance given in part like control arm, chassis, wheel end, strut etc., a tolerance stackup analysis is performed which helps to get maximum and minimum caster value. Caster angles are generally used to improve vehicle's steering balance at time of high speed and cornering. Positive caster increases steering effort also the amount of caster set into vehicle's suspension system is a balance between stability and steering effort.[5].*

Key Words: Tolerance stackup analysis for caster angle and KPI variation.

1.INTRODUCTION

In field of automobile engineering, suspension plays an important role in terms of ride comfort, cornering etc. To maintain all the vehicle performance, all the suspension parameter to be designed in such a way that it maintain its quality like design, drafting, manufacturing and inspection. Suspension design is very complex structure which is the combination of both kinematics as well as it should also bear all road load. The kinematics of suspension includes many suspension real time travel and turn via rack and pinion. Kinematics plays a major role in suspension desired application besides the kinematics suspension system should bear the road load condition which includes 1G, 2G, 3G, load which generates through articulation, cornering and weight shift while braking and accelerating.

This complex suspension design requires an inspection of all components to be 100% defect free. Suspension components should be defect free from design, CAE, manufacturing. This topic focuses mainly on the component and assembly level tolerances. Defining tolerances is the good practise before part manufacturing. Here, tolerance are the most common parameter that are available and to be given in the drawing as per the best practises of designer but how the tolerance of component will affect the tolerance of assembly? The purpose of providing tolerance is to ensure functionality, improves communication between designer and manufacturer.

The tolerances in the drawing are to be defined in such a way that the suspension parameter such as caster angle nominal values remains into the specified tolerance zone, Ideally the caster angle in passenger vehicle are kept as 3 to 5 degree which varies as per change in vehicle weight at front axial and rear axial. In this exercise all the tolerance are defined with following ASME Y14.5 standard, While designing the kinematics, testing road load and providing tolerance in the drawing, the tolerance stackup are need to be performed. The tolerance stackup is proven method to resolve the upcoming issues to allow the application of any assembly. It also includes the process of assembling the assembly to make suspension work.

Fig. 7 Lower control arm weldment assembly and its contributors

Let's take a lower control components from zone 2 for example, the tolerance of LCA front mounting (2'), LCA rear mounting (3'), LCA ball joint (4'), all bush compliance and all zone component to higher level assembly tolerance are taken into consideration to perform the stackup.

3. Mathematical Expressions and Symbols

Variation in camber angle is calculated by two methods:

1. Worst case Method
2. RMS (Root mean square)

Maximum and minimum tolerance are calculated which may affect the Caster angle.

The result of adding the means and taking the root sum square of the standard deviations provides an estimate of the normal distribution of the tolerance stack and the Worst base and RSS can be calculated by below formula.

1. Worst case scenario - Maximum and minimum gap/dimension/holes size can be calculate with using below example; suppose five part are such as P1, P2, P3, P4 and P5 are resting on a base plate and the thickness, tolerance of each part and base plate inner height i.e. 55mm are given. Maximum and minimum gap with using worst case scenario is calculated (All dimensions are in mm).There are three type of caster angle, all three types of caster angle used for different purposes. In this study primary focus is to check the positive caster angle which is being used in almost all type of on-road vehicle.

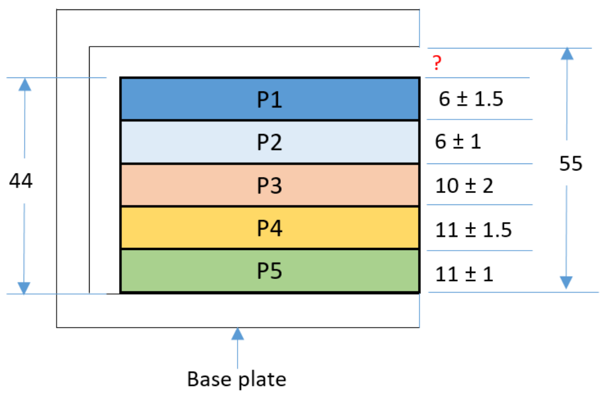

Fig. 8 Worst case scenario of plates

Table 3 – Worst case scenario of plates					
SR.NO.	Nominal dimension	Tolerance Maximum	Tolerance Minimum	Plate thickness Maximum	Plate thickness Minimum
1	6	1.5	-1.5	7.5	4.5
2	6	1	-1	7	5
3	10	2	-2	12	8
4	11	1.5	-1.5	12.5	9.5
5	11	1	-1	12	10
Total				51	37
Gap				**55 - 51 = 3**	**55 - 37 = 18**

With using the worst case scenario the maximum and minimum gap are as 18 and 3.

2. RMS (Root mean square) : below is the mathematical expression is used to find out RMS value for example

$$RMS = \sqrt{\sum_{i=0}^{n} \sigma^2} \quad (1)$$

Table 4 – Root mean square of plates			
SR.NO.	Nominal dimension	Tolerance Maximum	RMS
1	6	±1.5	2.25
2	6	±1	1
3	10	±2	4
4	11	±1.5	2.25
5	11	±1	1
Total			**3.24**

σ is the standard deviation, so the total tolerance of ±3.24mm in nominal dimension of all plate will be applied as per RMS. With using same method the contributor part tolerance are taken into consideration to find out the KPI and caster angle variation.

4. RESEARCH METHODOLOGY

The main component which affect Caster angle directly is strut top hard point and lower ball joint. To optimize the tolerances below exercise is also been done where the part level tolerances are considered to find out float to mount fasteners.

The calculated worst case and RSS case value from zone 1 and zone 2 are given as below. The cross addition of maximum variation from zone 1 and minimum variation from zone 2 vice versa gives the total camber angle variation in which it can be converted to degree and degree to minutes as per formula (2).

NOTE: Below dimensions tolerances in result table 5 are taken for case study and are for example only.

The total tolerance of Zone 2 denotes the lower ball joint point movement in X direction that changes the KPI angle as well as the caster angle. Vice Vera the total tolerance of Zone 1 denotes the possibility of strut top point movement in X direction which changes the KPI as well as the caster angle.

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Table 5 – Worst case analysis and root mean square of front suspension zones						
Direction	Components	Size	Tolerance		SQRT (Squared Tol)	
			Max	Min	Max	Min
Zone 2						
BIW PLP to subframe mounting holes	BIW	From datum	1.500	1.500	2.250	2.250
Subframe BIW mounting hole diameter (Clearance hole)	Subframe	18	0.100	0.100	0.010	0.010
LCA front pivot mounting	Subframe	60.5	0.400	0.400	0.160	0.160
LCA front pivot bush width tolerance	Lower link	60	0.150	0.150	0.023	0.023
LCA front mounting and LCA front bush width difference	Lower link	60.5 - 60	0.250	0.250	0.063	0.063
Front bush to LBJ	Bush	33.6	0.500	0.000	0.250	0.000
Total Tolerance in X direction			2.900	2.400	1.660	1.583
Zone 1						
Strut mounting BIW	BIW	From datum	1.500	1.500	2.250	2.250
Strut mounting point from BIW PLP	Strut	12.2	0.550	0.550	0.303	0.303
Strut top mounting bolts with BIW tower (Clearance hole)	Strut	12.2	1.710	1.710	2.924	2.924
Total Tolerance in X direction			3.760	3.760	2.340	2.340

Considerations – The maximum tolerance in mm meaning is the hard point will get shifted towards vehicle front vice versa minimum tolerance in mm will shift the hard point towards vehicle rearward.

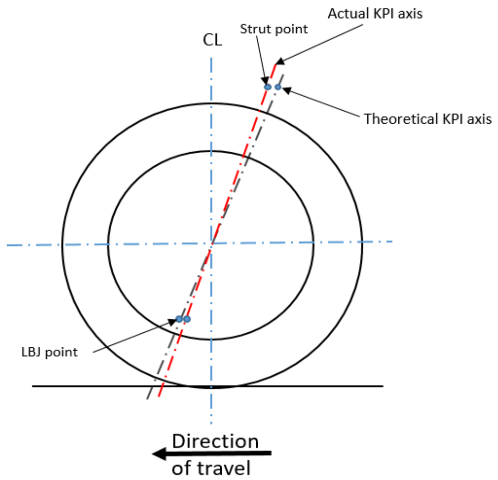

Fig. 9 Variation of strut top, lower ball joint hardpoints in front suspension

The movement of strut top and bottom point with some instant changes the KPI (marked in above figure) which clearly shows the sensitivity of hard points.

5. CONCLUSIONS

Above example of tolerance stackup analysis is applicable for one dimensional analysis only, which is having the optimal limitations for this particular case study. In this case study the geometry dimensions features, primary, secondary and tertiary datum's, modifiers such as LMC & MMC, RFS (if applicable), basic dimensions in parts, all linear and bilateral tolerances are taken into consideration to perform the tolerance stackup analysis to find out maximum and minimum camber angle variation. And as per the result and method followed from flow diagram Fig. 1, loop methods, it can be seen that the major contributor's which affect the caster angle are [6];
1. BIW
2. Strut