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

---***---

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.

The flow diagram 1 of research has given below for in depth details.

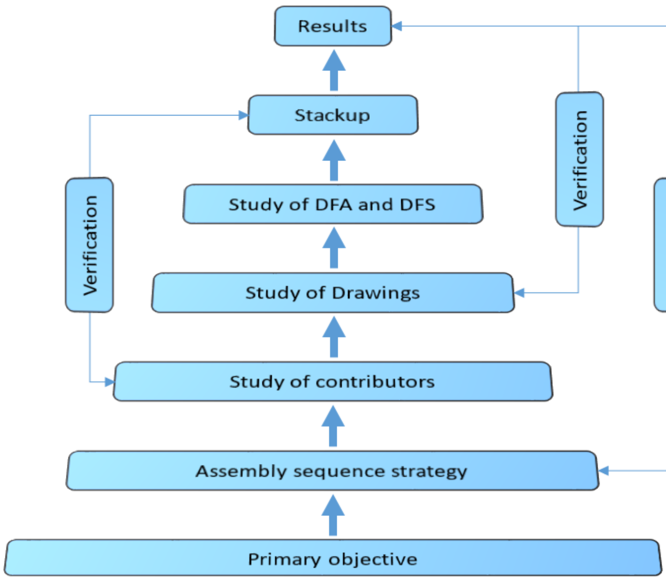

Fig. 1 Flow diagram

2. RESEARCH METHODOLOGY

First stage is to identify primary objective of the exercise which include the requirement of caster angle variation, hardpoint such as strut top point and lower ball joint, Second stage is to look out the assembly sequence strategy, third stage is to study the contributors which plays an important role to check hard point such as strut top and lower control arm, lower ball joint and king pin inclination. Fourth stage is to do study of all front suspension component, assembly drawing tolerances and GD&T, as the fourth stage is very sensitive and critical to do this study which requires to write all part tolerances at one place for verification with the result. Study of DFA and DFS is also important as when vehicle goes for servicing at customer end then there are possibilities to do incorrect fitment this fitment issues to be considered in study of tolerance stackup analysis. Final stage is to start doing stackup with considering all variation like process, drawing tolerances, part variation through service and this stage also requires to verify the result, recheck the drawings, wheel geometry machine variation. The tolerance stackup is done with following above steps. The tolerance stackup are done to follow loop method and this loop method divided into two loops which show the RSS and worst case of imaginary line which is called as king pin inclination i.e. axis passes from strut top to lower ball joint of LCA (about which wheel rotates at time of steering).

A. Caster angle is positive if top upright mounting point (strut top point) is more rearward of the car than the bottom mounting point (lower ball joint of LCA) when vehicle seen to side view (see image below).
B. Caster angle is neutral or zero if top upright mounting points and bottom mounting point are lies on the vertical line of hub and wheel (see image below).
C. Caster angle is negative if the top mounting point of the lower ball joint is rear of the hub and strut top point is at front of the hub center line (see image below).

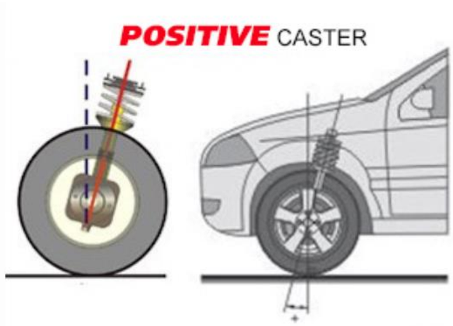

Fig. 2 Positive caster

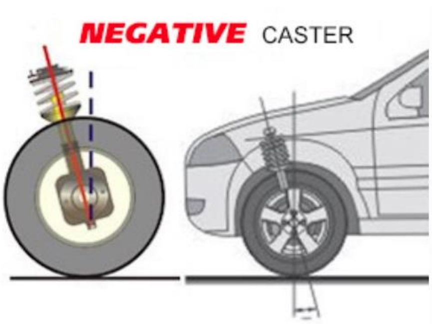

Fig. 3 Negative caster

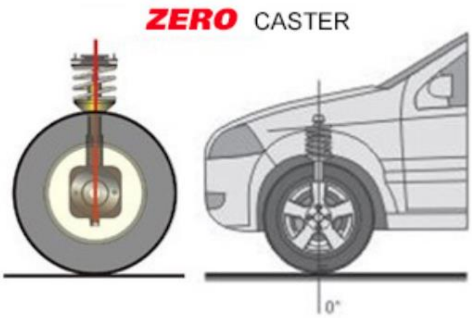

Fig. 4 Zero caster

Below is the example of tolerance stackup analysis method and the compact front suspension assembly structure component nomenclature as well as contributor of king pin inclination (steering axis) and caster angle variation.

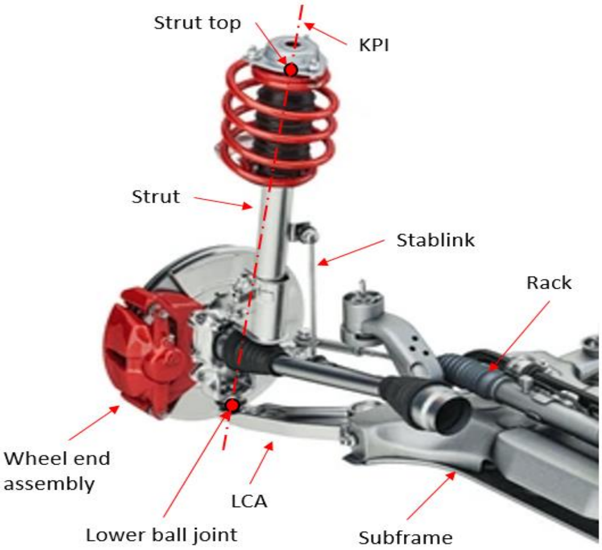

Fig. 5 Front suspension layout and its nomenclature

As the contributor for caster angle are strut top and lower ball joint so the direction of loop will be towards the X direction of vehicle co-ordinate system. And the total variation can be found out with creating loops of dimension as shown in Fig. 6. This zones has been divided in to two parts which are as below;

Zone 1 (refer Fig. 6)
All components in zone 1 are analyzed and moved towards X direction to calculate worst case scenario.
BIW
BIW to Strut top mount
Strut top mount to wheel end assembly

Zone 2 (refer Fig. 6)
1' Subframe front and rear mounting
2' Subframe to LCA mounting
3' LCA rear mounting to front mounting
4' LCA front and rear mounting to lower ball joint mounting

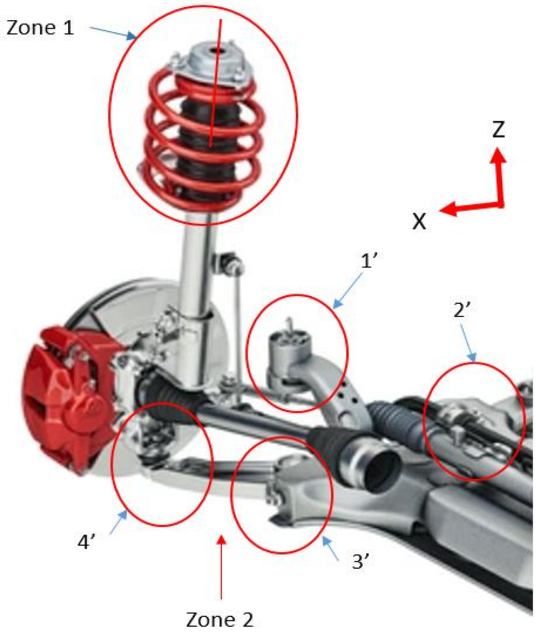

Fig. 6 Illustration of front suspension tolerance stackup zones

The purpose of dividing tolerance stackup zones are that the primary, secondary and tertiary contributors can be focused to calculate variation of strut top point and lower ball joint point. And according to the variation the caster angle can be found out for finalizing caster angle value. The zones are cascaded into part level and their dimensions and tolerances are considered as below table 1 and table 2.

Table 1 - Zone 1		
0’	BIW	1. BIW mounting holes tolerances 2. Strut top mounting pins tolerances 3. Fasteners size and tolerances
1’ to 2’	Strut top mounting to knuckle	1. Strut top mounting to knuckle width tolerances towards X direction (refer fig 3)

Table 2 - Zone 2		
1	Subframe	a. Subframe mounting holes tolerances b. BIW mounting holes tolerances c. Fasteners size and tolerances
2	Subframe to Lower control arm	a. Subframe holes tolerances for lower control arm mounting b. Lower control arm holes tolerances c. Lower control arm welding tolerances d. Lower control arm fastener tolerances e. Lower control arm bush tolerances
3 & 4	Lower control arm to	a. Lower control arm to lower ball joint part tolerances b. Lower ball joint tolerances c. Knuckle hole tolerances for mounting lower ball joint

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.

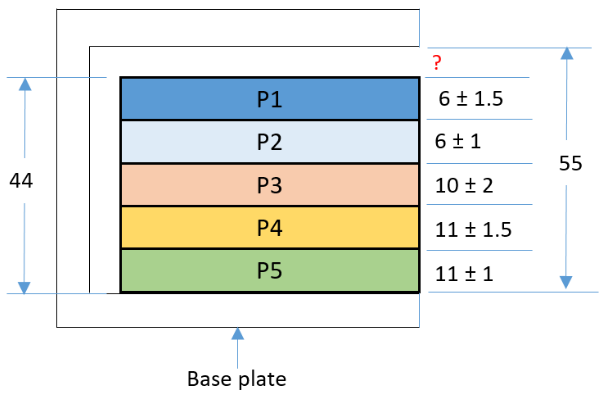

Fig. 8 Worst case scenario of plates

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.

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.

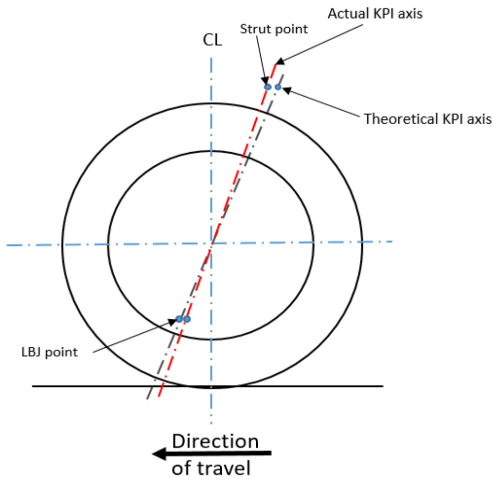

Fig. 9 Variation of strut top, lower ball joint hardpoints in front suspension

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

3. Lower control arm
4. Subframe

These contributors' geometry dimension and tolerances can be modify to get the caster angle within the acceptable range which is defined as per vehicle dynamics [4, 5, 6].

REFERENCES

[1] ASME Y14.5 (2018) Dimensioning and tolerancing. American Society of Mechanical Engineers, New York
[2] Rami A. Musa and Samuel Huang, Y. Kevin Rong "Simulation-based tolerance stackup analysis in machining"
[3] Chase KW (1999) Tolerance allocation methods for designers. ADCATS Rep 99–6, Brigham Young University
[4] Numerical Analysis of the Wheel Camber of the Front Axle of a Passenger Car During Cornering Denis Molnára* , Miroslav Blatnickýa , Ján Dižoa , Vadym Ishchuka
[5] Simulated Study on the Effect of Camber and Toe on the Handling Characteristics of a Car during Cornering T. Vijayakumar and V. Ganesh
[6] "Maximum and Minimum Variation of Wheel Geometry through Worst Case & RSS Method" Mohan Patwari , Ravindra Kachare & Sujeet Kumar

BIOGRAPHIES

Ravindra Kachare, Team Lead, Tata Technologies, ERC, Chassis, Tata Motors, Pune Maharashtra, India

Mohan Patwari, Tech Lead, , Tata Technologies, ERC, Chassis, Tata Motors, Pune Maharashtra, India