Maximum and Minimum Variation of Wheel Geometry through Worst Case & RSS Method

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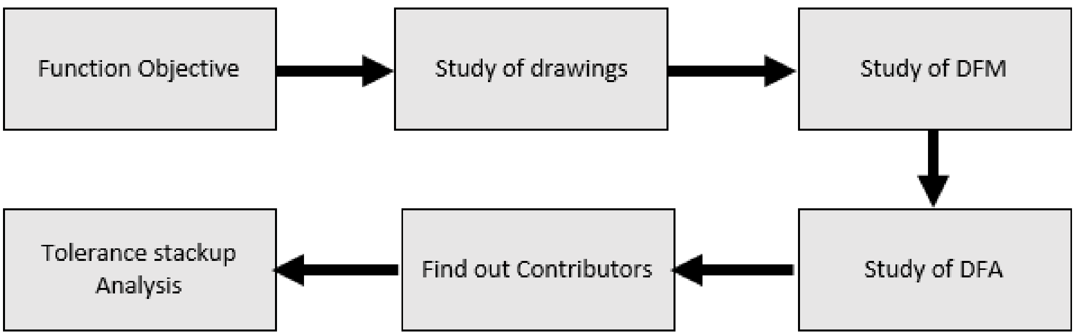
Abstract – *Camber angle is one of the main parameters of suspension system which affects, tire wear and handling of the vehicle. Camber angle is formed when vertical axis or top corner of tire is inclined outward or inward when seen from front or rear. Camber angle is said to be positive if top corner of the tire is outward and bottom corner of tire is inward. Camber is negative if top corner of tire is inward and bottom corner of tire is outward. Positive and negative camber set depending upon the suspension system geometry requirement. Static camber value varies if camber contributor parts are not in specified tolerance limit. To check maximum or minimum camber variation as per the tolerance given in part like control arm, chassis, wheel end etc., a tolerance stackup analysis is performed which helps to get maximum and minimum camber value. Vehicle behavior as per camber variation can be forecasted and it also shows the tolerance which to be controlled to minimize camber thrust, tire wear and poor ride handling [5].*

Key Words: Tolerance stackup analysis for camber variation.

1. INTRODUCTION

For ease of assembly and to manufacture the part in first time right and to maintain its quality, the tolerances of parts, assembly, fixtures and quality measurement components to be defined in such a way that the defined tolerances fulfil the primary and secondary function of the component, assemblies and fixture. The manufacturing cost of the tolerance depends up on the process of defining tolerance in the drawing as tolerance of assembly depends on the tolerance of sub-assembly and that sub-assembly tolerances depends on the tolerance components to make the system work. To make the function first time right, proper allocation of tolerance to be required to fulfil assembly function. Tolerance can be given as per the designed practise by designer and the defined tolerances. The tolerances is provided by designer in the drawing in such a way that the variation of dimension, angles and flush comes in the acceptable range. Hence the proper tolerances as per ASME Y14.5 to provide that camber angle affecting contributor's variation comes within the acceptable limit. And the acceptable limit is depends on the overall vehicle dynamics. The acceptable variation is 0 to 2 Degree negative camber which can varies to meet vehicle dynamics, overall performance of vehicle tyre wear and car handling and to meet vehicle targeted lifecycle [5]. Maximum and minimum of tolerance stackup variation is to be to find out to meet all functional requirement. This camber angle variation methods or workflow can be get with following steps given in block diagram (A1), after which the effect of tolerances can be seen. This variation can be controlled with controlling tolerances, design for assembly, and design for manufacturing process.



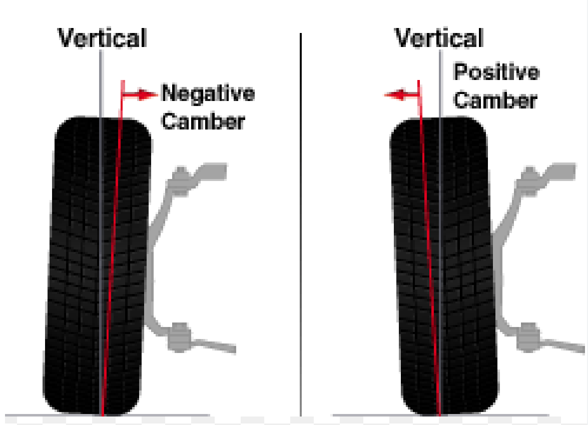
Block Diagram (A1)

1.1 Research Methodology

With following the process of block diagram the one exercise is done to understand the variation. It is been observed that major factor for contributing camber angle variation are control arm, damper, chassis, body in wide and wheel end assembly. With the help of application of worst case method and RSS method and with creating loop of dimension tolerance maximum and minimum variation in the part can be found out. Contributor tolerance, which includes linear tolerance, bilateral tolerance or any other specified GD&T, modifier such as MMC and LMC are considered and followed the loop in one direction. So the total tolerance of part in mm then converted to degree which shows the maximum and minimum variation in camber angle.

All the parameters vary the camber angle as shown below which is an Inclination of tire inward or outward from vertical plane when wheel viewed from front.

A. Camber angle is **positive** if tire top corner is inclined towards outside of car (see image below).
B. Camber angle is **negative** if tire top corner is inclined towards inside of car (see image below).



Refer below example to understand the camber angle variation and the nomenclature of part which are the major contributing factor for camber angle.

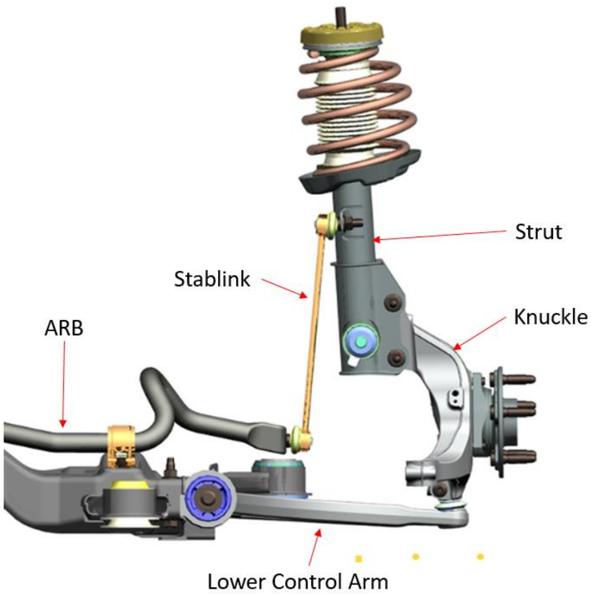


Fig. 2

The variation can be found out with creating loops of dimension in lateral direction as shown in Fig. 3. This loop has been divided in to two parts which are as below;

Loop 1 (refer Fig. 3)
0 Subframe
0 to 1 Subframe to Lower control arm mounting
1 to 2 Lower control arm mounting to knuckle assembly

Loop 2 (refer Fig. 3)
0' BIW
0' to 1' BIW mounting to Strut tube
1' to 2' Strut tube to strut mounting on knuckle

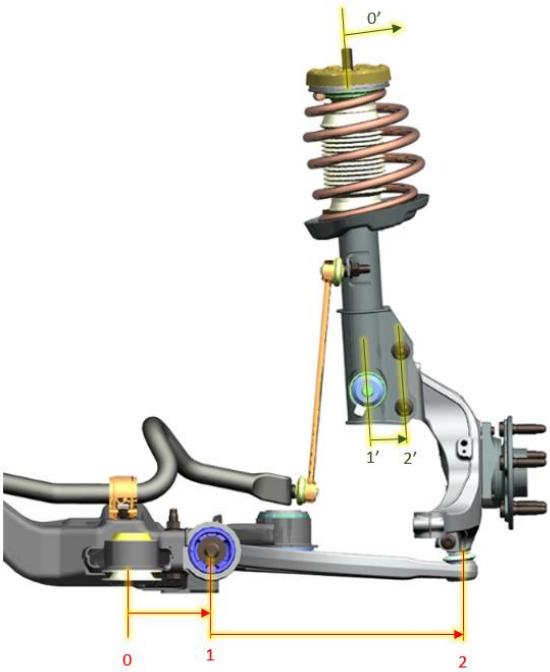


Fig. 3

The aim of dividing the loop into two parts is to find the maximum variation by which the camber angle can be finalized and also it can be controlled with modifying major contributor tolerance. The loops are cascaded into part level and their dimensions and tolerances are considered as below table A and table B.

Table –A

Loop 1		
0	Subframe	1. Subframe mounting holes tolerances 2. BIW mounting holes tolerances 3. Fasteners size and tolerances
0 to 1	Subframe to Lower control arm	1. Subframe holes tolerances for lower control arm mounting 2. Lower control arm holes tolerances 3. Lower control arm welding tolerances 4. Lower control arm fastener tolerances 5. Lower control arm bush tolerances
1 to 2	Lower control arm to	1. Lower control arm to lower ball joint part tolerances 2. Lower ball joint tolerances 3. Knuckle hole tolerances for mounting lower ball joint

Table –B

Loop 2		
0’	BIW	1. BIW mounting holes tolerances 2. Strut top mounting pins tolerances 3. Fasteners size and tolerances
0’ to 1’	BIW mounting to strut tube	1. Strut top to strut tube tolerances
1’ to 2’	Strut tube to Knuckle mounting holes	1. Strut tube to knuckle mounting holes tolerances. 2. Knuckle mounting holes tolerances. 3. Knuckle holes tolerances. 4. strut to knuckle mounting fastener tolerances

1.2 Theory and Calculation

Worst-case tolerance analysis is the traditional type of tolerance stackup calculation. The individual variables are placed at their tolerance limits in order to make the measurement as large or as small as possible. The worst-case model does not consider the distribution of the individual variables, but rather that those variables do not exceed their respective specified limits. This model predicts the maximum expected variation of the measurement. Designing to worst-case tolerance requirements guarantees 100 percent of the parts will assemble and function properly, regardless of the actual component variation. The major drawback is that the worst-case model often requires very tight individual component tolerances. The obvious result is expensive manufacturing and inspection processes and/or high scrap rates. Worst-case tolerance is often required by the customer for critical mechanical interfaces and spare part replacement interfaces [4]. When worst-case tolerance is not a contract requirement, properly applied statistical tolerance can ensure acceptable assembly yields with increased component tolerances and lower fabrication costs.

The root sum squared (RSS) method is a statistical tolerance analysis method. In many cases, the actual individual part dimensions occur near the centre of the tolerance range with very few parts with actual dimensions near the tolerance limits [2]. This, of course, assumes the parts are mostly cantered and within the tolerance range. RSS assumes the normal distribution describes the variation of dimensions. The bell-shaped curve is symmetrical and fully described with two parameters, the mean, μ, and the standard deviation, σ. The variances, not the standard deviations, are additive and provide an estimate of the combined part variation.

1.3 Mathematical Expressions and Symbols

Variation in camber angle is calculated by two methods:

1. Worst case Method
2. RSS (Root sum square method)

Maximum and minimum tolerance are calculated which may affect the camber angle. We have added all part tolerance and converted it to degree.

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 RSS can be calculated by below formula.

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

σ is the standard deviation

Conversion of degree to minute is $1° = 60$ minutes (2)

2. Results and Discussion

The main component which affect camber angle directly is knuckle and strut mounting holes. 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 tolerance are taken for knuckle and strut holes opposite to see the worst case in both positive and negative side (refer worst case 1) and vice Vera worst case 2.

Parameter	Nominal	Tolerance		Knuckle and strut hole center matched		Upper edge of knuckle and strut matched	
		Min	Max	Worst case 1	Worst case 2	Worst case 1	Worst case 2
Strut hole center distance	55	-0.1	0.1	54.9	55.1	54.9	55.1
Knuckle hole center distance	55	-0.1	0.1	55.1	54.9	55.1	54.9
Strut hole Diameter	12.3	-0.1	0.1	12.2	12.2	12.2	12.2
Knuckle hole Diameter	12.5	-0.1	0.1	12.4	12.4	12.4	12.4
M12 Bolt	12	-0.3	0	12	12	12	12
Strut and Knuckle hole clearance in mm				12.1	12.1	12	12
Float				0.1	0.1	0	0
Float each side in mm				0.05	0.05	0	0

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

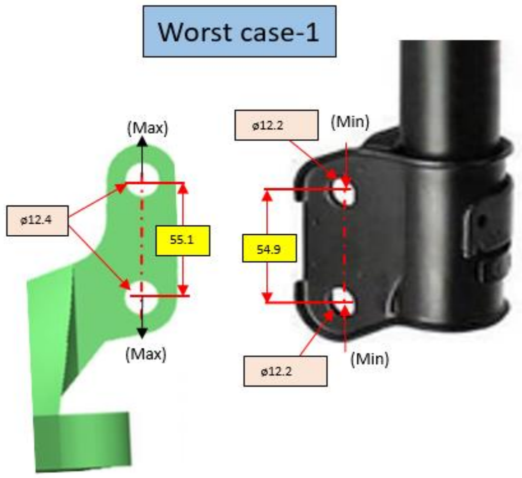


Fig 4 (A)

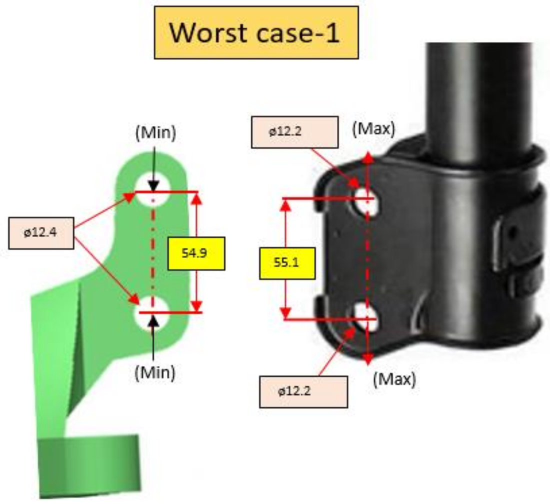


Fig 4 (B)

The calculated worst case and RSS case value from Loop 1 and loop 2 are given as below. The cross addition of maximum variation from loop 1 and minimum variation from loop 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).

	Component	Worst Case		SQRT (Squared Tolerance)	
		Max	Min	Max	Min
Loop 1	BIW to Subframe mounting holes	1.50	1.50	2.25	2.25
	Subframe mounting hole dia (Clearance hole)	2.00	2.00	4.00	4.00
	Subframe mounting pin	0.27	0.00	0.07	0.00
	Subframe to LCA rear pivot mtg hole	0.75	0.00	0.56	0.00
	LCA rear pivot mounting hole dia(Clearance hole)	0.90	0.90	0.81	0.81
	LCA rear pivot point to rear pivot bush (clearance hole)	0.50	0.20	0.25	0.04
	LCA front pivot pin : (LCA pivot axis)	0.27	0.00	0.07	0.00
	Lower link front pivot to lower ball joint mtg hole	0.00	0.00	0.00	0.00
	Total Tolerance	6.19	4.60	2.83	2.66
	Camber variation in degree	0.47	0.35	0.22	0.21
	Camber variation in min	28.14	20.91	13.18	12.41
Loop 2	Strut mtg point from BIW	1.50	1.50	2.25	2.25
	Strut top mtg bolts with BIW tower (Clearance hole)	1.21	1.21	1.46	1.46
	Strut -knuckle mounting hole distance	0.40	0.40	0.16	0.16
	Strut -knuckle mounting hole clearance hole	0.10	0.10	0.01	0.01
	Knuckle hole (Radial) clearance hole	0.043	0.043	0.00	0.00
	Total Tolerance	1.50	1.50	1.22	1.22
	Camber variation in degree	0.11	0.11	0.09	0.09
	Camber variation in min	6.80	6.80	5.53	5.53

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

3. 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 block diagram (A1), loop methods, it can be seen that the major contributor's which affect the camber angles are;

1. Knuckle
2. Strut
3. BIW
4. Subframe

These contributors' geometry dimension and tolerances can be modify to get the camber angle within the acceptable range which is defined as per vehicle dynamics, tyre wear and overall performance of vehicle [4, 5].

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