FRI-ONLINE-1-ID-06

CONCEPT FOR SUSPENSION GEOMETRY WITH DOUBLE WISHBONE

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Abstract: *When it comes to design suspension geometry from scratch, you need to understand every suspension parameter influence to get a good result. Once understood, the design process begins by choosing target values to get to the expected behavior. After the design process comes the validation step to check suspension parameters variations with suspension motions. All these steps of the design process are explained in a small set of articles. This one is the second and it is relative to the suspension geometry design.*

Keywords: *Design, Suspension Design, Automotive engineering, Double wishbone suspension*

INTRODUCTION

Suspension is a really important system as it is responsible of the handling, the safety and the comfort of a car. It is also a really complex system as there are lots of different parameters to take in account. Each parameter has an influence on a certain driving situation (cornering, braking, over bumps …) that will define the final handling of the car. The designer role is to create a solution that makes all parameters working together without one influencing another (except if being wanted and under control). These articles will first define the different important suspension parameters and their influence on the car behavior. Then will be explained the whole conception process to see step by step which parameters are defined. Finally, we will show the checking and validation of the suspension geometry using 3D CAD software Solid Works.

SUMMARY

This article has the aim of explaining step by step the geometry design process. Firstly, target values will be chosen for static position and dynamic motions. Then, the geometry of the suspension will be designed according to the expectations. It means defining wishbones length, inclination and mounting points to stick to the target values. The same work is done for the tie-rod and gives the suspension geometry.

1) Pre-design and specifications

Before going straight ahead into suspension design, it is important to think about the main purpose of the vehicle and what handling is expected from the car. The suspension types and settings will obviously not be the same for a race car and a family car. So you need to define the suspension type and the expectations in term of static target values and dynamic target variation for both parameters. Like in the previous article (Part 1), we will be focusing on a double wishbone suspension. The suspension type choice is made looking at space available, price of the solution, performance, comfort expectations.

By static target values are considered:

- Initial toe, camber, caster and steering axis angle
- Initial scrub radius length, roll center height, type of Ackermann steering, static ride height

All these values are taken when the vehicle is in static position, on a flat floor, under its own weight in state of work, without any external stress or input. The value of these parameters needs to be known before starting drawing the suspension geometry as it has got influence on it.

By dynamic target variations are considered:

- Bump steering, camber and caster gain

While travelling, static suspension settings are changing due to the geometry. These changes need to be controlled to provide a safe and good vehicle handling. Like for static values, you need to set targets for dynamic variations to design a suspension that can get to these expectations.

For a rear wheel drive road car, here is what could look like the target values:

Table 1

Settings	Front	Rear
Static target values		
Toe	2mm (toe out)	1.5mm (toe in)
Camber	-0.5^o	-0.8^o
Caster	+5^o	Not important
SAI	+11^o	+9^o
Scrub radius	-10mm	+4mm
Roll center height	+50mm	+80mm
Type of Ackermann	Ackermann	-
Ride height	160mm	165mm
Dynamic variations targets		
Bump steering	Compression: +0.5mm (toe out) Rebound: -0.5mm	Compression: -0.5mm (toe in) Rebound: +0.5mm
Camber gain	Compression: -0.5^o Rebound: +0.5^o	Compression: -0.7^o Rebound: +0.5^o
Caster gain	Maximum variation : ± 0.5^o	Maximum variation : ± 0.5^o

The compression and rebound targets are related to the values measured when the dampers is in full compression or rebound.

2) Drawing area

Before going into any drawings, you need to know the amount of space that is free for the suspension parts. At this step of a car project, at least the main dimensions of the car are set and ready to use. You will at least need the track, the size of the wheels and tire assembly, the free room inside the wheel, the width of the chassis and an idea of the expected ride height. It is also good to keep in mind that other parts will also need to fit in this area like driveshaft, spring and damper, anti roll bar, brake disc and caliper. Considering these parts during the drawing is important to avoid interferences between parts later in the process

As the suspension links the wheels and the chassis, we need to model them both to begin the drawing process. For each axle of the car, position the cross section of the chassis to the supposed static ride height. Then model the wheel symmetrically to the chassis and respecting the axle track. The images used all along parts 2) and 3) are used for understanding the process.

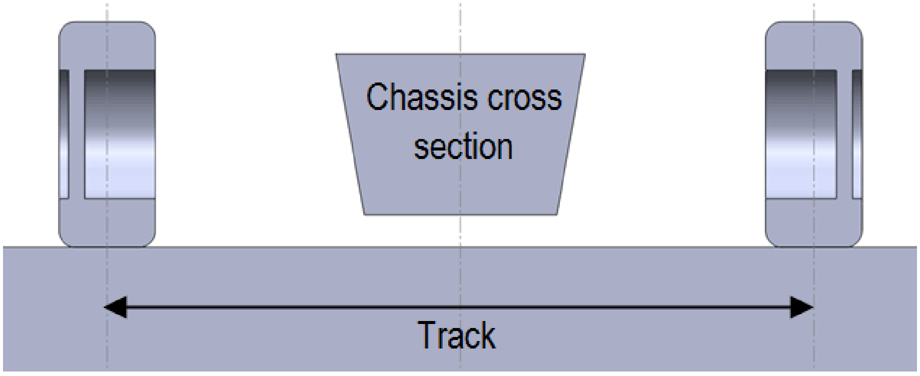

Figure 1: Chassis and wheels modelling

The dimensions used can be oversized in order to give a more visual impact and a better understanding.

For the next steps, we will only use half of this model as the suspension geometry will be symmetrical. We can draw a delimited area that will represent the room available to fit the suspension parts. You will notice that a gap has been left inside the wheel to be able to fit the braking system.

Until now, there is no difference in the process between front or rear axle, both drawing areas are done the same way. It comes a bit different for the next step. Defining the suspension components mounting points will not be the same as both axles have a different role. For the example, we will explain the process for a front axle. Because it is the axle that steer the car, a few more parameters needs to be considered like Ackerman steering or steering rack position.

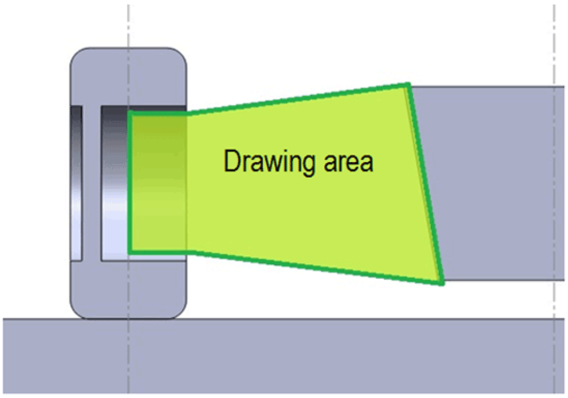

Figure 2: Drawing area, transversal plane seen from rear

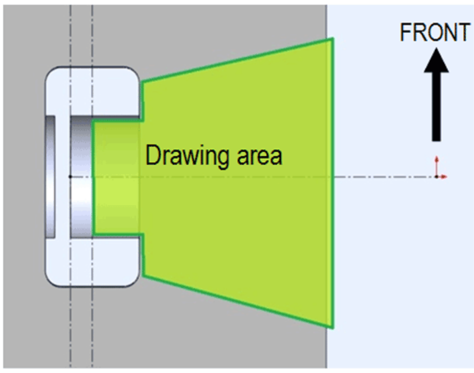

Figure 3: Drawing area, transversal plane seen from top

3) Suspension geometry design

Once that the drawing area is done, we can place on the model our target roll center and scrub radius. We are now able to draw the SAI (Steering Axis Inclination) from the scrub radius point and the target angle. It gives us a line where will be located the wishbone to upright upper and lower ball joints. The ball joints are placed next to the extremities of the drawing area, on the SAI axis. A little gap is left with the drawing area outline to be able to move the ball joints up or down during the verification process. This gap will also avoid the wishbones to hit the inside of the wheel during full compression or rebound.

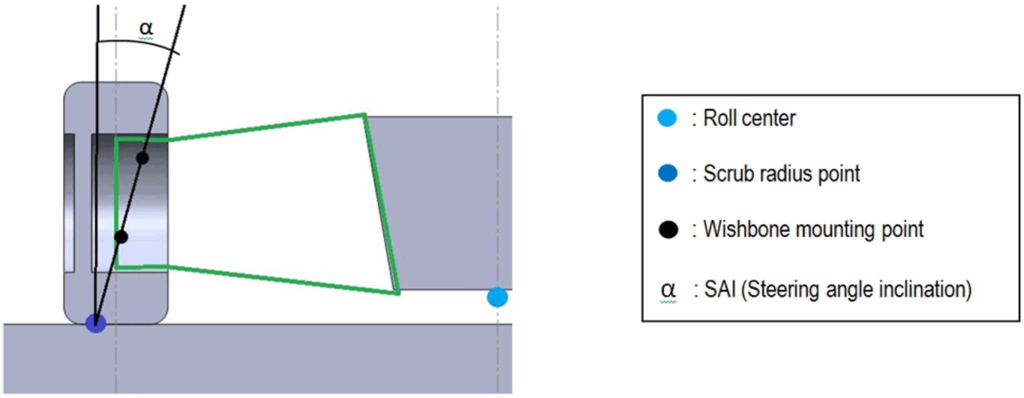

Figure 4: Wishbones outer points' positioning

We can then start to draw the wishbone lines. We will start with the lower wishbone and make it nearly parallel with the ground. The mounting point on the chassis will be placed on the outline. We can now find the instant centre of rotation of the wheel relative to the chassis. It is located at the intersection of the tire contact patch centre to roll centre line and the wishbone guideline.

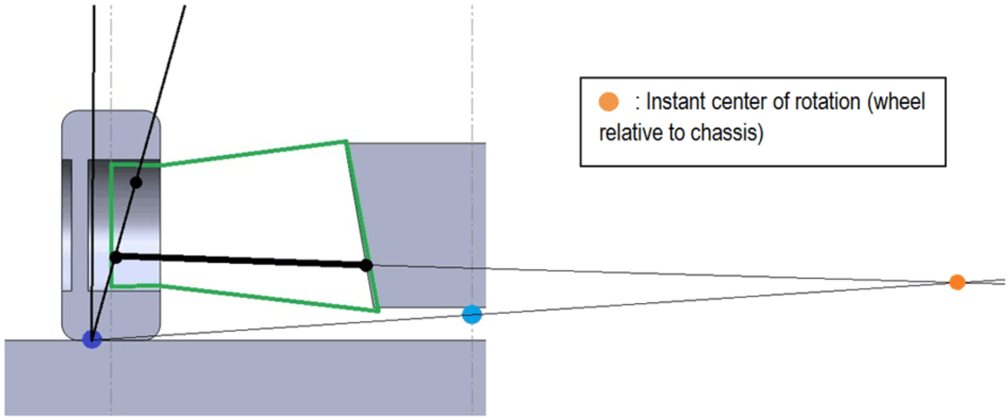

Figure 5: Lower wishbone positioning

We want the upper wishbone to rotate around the same instant center of rotation. Joining the already drawn upper ball joint to the instant center of rotation will give the upper wishbone guideline. The first important choices come now with choosing the upper wishbone length. It will influence the camber gain during suspension motion. The shorter the wishbone will be the more negative camber the wheel will get under compression (and positive camber on rebound).

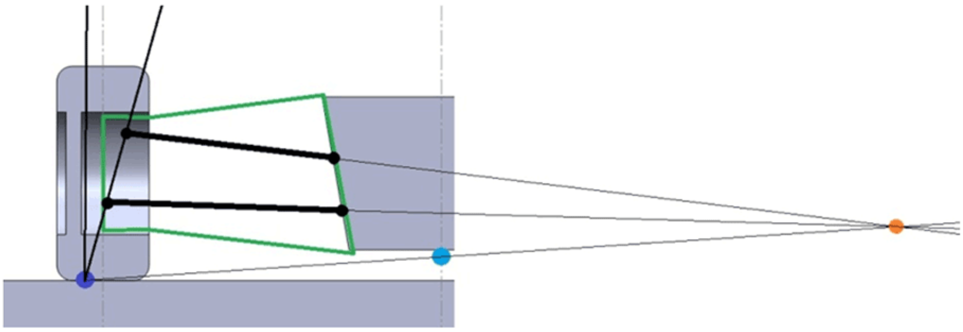

Figure 6: Long upper wishbone, small camber gain

This needs to be chosen according to the target variation values set at the beginning of the design process. Getting a shorter wishbone will also include a chassis modification (extended mounting plates) in order to attach the wishbone.

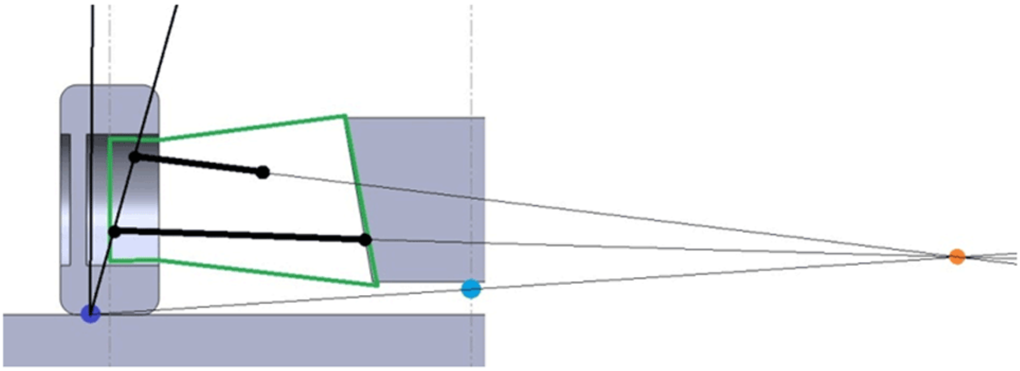

Figure 7: Short upper wishbone, high camber gain

We will choose a shorter wishbone to get more camber gain with suspension motion. Now that we have an idea of the wishbone position and length, it is time to find the position of the tie-rod to upright connecting point. To choose this point, we are using the Ackermann steering static position. The top viewing will be used for this case, place the upright ball joints points according to caster angle and position determined before with the transversal view. The upright pivot point to tie-rod connection point lines of each front wheels must cross at the middle of the rear axle to create Ackermann steering. The upright pivot point is located on the SAI and caster axis, at the intersection with the wheel center line. Then, the tie-rod to upright point position depends on the steering rack position (in front or behind the wheel center). Having the steering rack behind the wheel center allows more freedom in placing the upright connecting point as it is not limited by the brake disc position. We will keep the point behind the wheel center line as the steering rack is behind as well in our case.

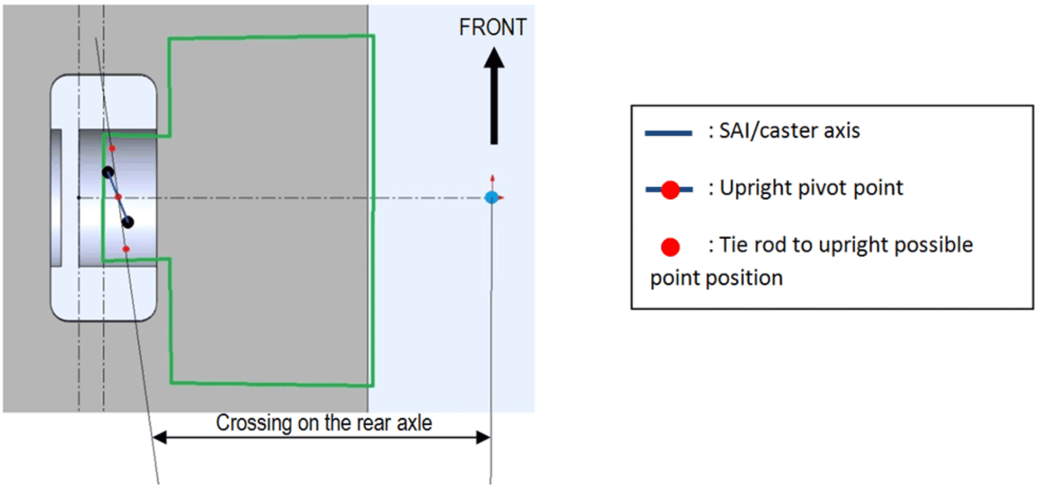

Figure 8: Tie-rod connection point choice

Having found the tie-rod outer connection point, we can come back in the transversal plane to draw the tie rod. To avoid bump steering phenomenon (or at least reduce it), the tie rod must have the same instant center of rotation than the wishbones. Joining the tie rod outer connection point and the wishbone instant center of rotation will create the tie rod guideline. In the example, we have been placing the inner point on the joining line between the two wishbone ball joints. It is not a zero bump steering position but a good point to start though.

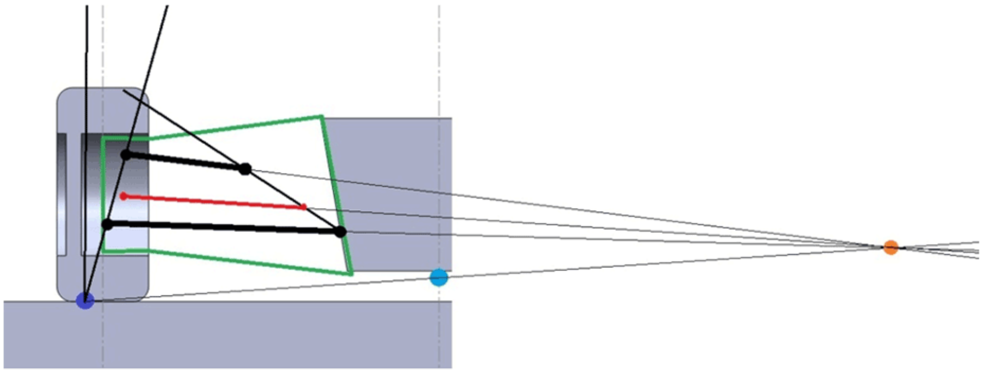

Figure 9: Tie-rod positioning, crossing wishbones instant center of rotation

There is then a point on this line that can avoid the maximum amount of bump steering; it can be found using “Bobillier lines” method. Changing the tie-rod length relative to this point will influence the amount of bump steering generated. A longer tie-rod will provide less bump steering than a shorter one.

If the tie-rod is not aligned with the wishbone instant centre of rotation, it will create “asymmetric” bump steering. In our case (steering rack behind the wheels centreline), having the tie-rod over the line of the centre of rotation will give toe-in on compression and toe-out in rebound. The contrary happen when the tie-rod is under the centre of rotation line.

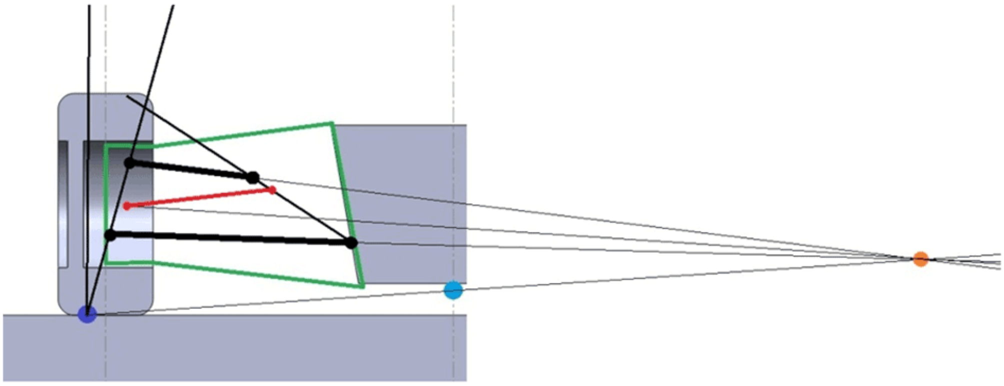

Figure 10: Tie rod position, generates toe-in in compression/toe-out in rebound

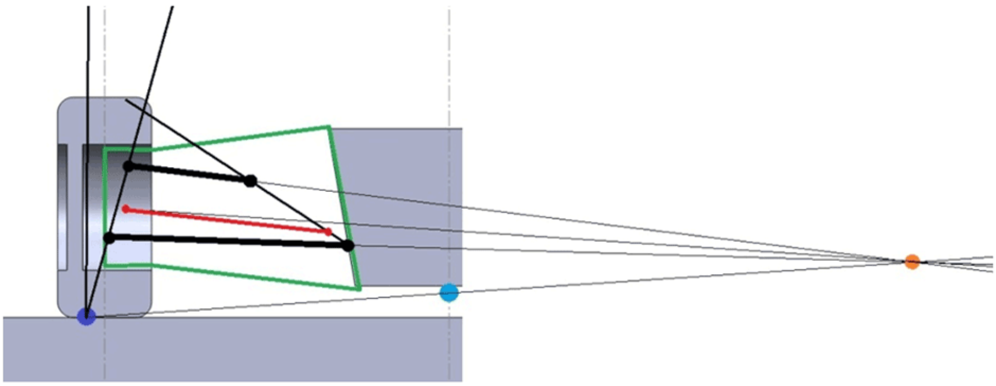

Figure 11: Tie-rod position, generates toe-out in compression/toe-in in rebound

The tie-rod position can now be decided according to the amount of bump steering wanted and the way it acts on compression and rebound. Once the tie-rod position is set, you know the static distance between the two sides and can determine the length of the steering rack.

Another approach for defining the tie-rod mounting points is to start with the sterring rack size if the part is already designed. The tie-rod positioning comes then as a combination of steering rack height, Ackermann steering conditions and bump steering expectations. Seen from the top, the tie-rod can be positioned freely as long as it stays on the horizontal line passing by the inner ball-joint point defined earlier. As the bump steering effects will be negligible, the tie rod position seen from the top will be chosen to fit the better way with all other components.

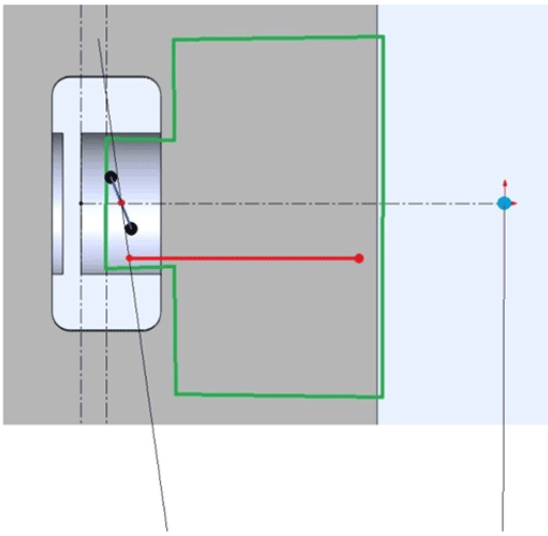

Figure 12: Tie-rod position, seen from top

Concerning the wishbone mounting points to the chassis, they can influence caster changes and can create anti-dive, anti-lift or anti-squat features. To avoid caster variations, each wishbone chassis mounting points must be located in the same flat plane. Concerning anti-dive/lift/squat features, they are obtained with the wishbones angle seen from the side. If both wishbones mounting points are parallel with the ground, no counter effect will be created.

Now, all the mounting points of the suspension parts are defined according to our target values and variations. Before getting into designing the real parts, the geometry needs to be tested to check the evolution of the parameters relative to the suspension motion. The test procedure will be explain in the next article (Part 3). After testing, you analyse the results by spotting the differences with your expectations. Once identified, the differences must be reduced by changing some parameters such as tie-rod length or wishbone length or inclination. The main parameters to care about are bump steering and camber and caster variation. The final result comes generally as a compromise.

Even after the analysis and the geometry validation process, our suspension is still made of lines and points. The component design can begin. It includes designing the shape of the component, choosing the right material, thinking about the fabrication process, choosing the technical solutions for mounting points (ball joints or bushings for example) … The upright will also need to be designed or at least modified to match with the defined mounting points.

CONCLUSION

You now have the basics to design suspension geometry in relation with settings expectations. Taking time defining the target values is important as they will be your development guidelines through all the process. Most of the time will certainly be spend modifying the first geometry sketches to get to your expectations according to analysis. The method shown here is one way of seeing the design process and there are certainly other ways of doing it. The method showed here is based on fixing first the roll center height and scrub radius. in the othrer article is explain the analysis process based on suspension 3D model via CAD software as Solid Works.

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