Loaded questions

OptimumG's series on tuning springs and dampers continues with an explanation of the importance of tyre load variation

By CLAUDE ROUELLE

A TCR racer loads up its front right tyre in a corner. The relationship between vertical load and mechanical grip is a key factor when it comes to damper spec and spring rates

In the previous edition of *Racecar* (V30 N3), we tried to answer the question: how do we determine suspension spring rates and damping for a vehicle?

To answer this, it was necessary for us to first define the purpose of the suspension. We looked at how the suspension plays an important role in improving the driver and passenger comfort, handling, aerodynamics, mechanical grip, vibration and transient response.

With the purpose of a suspension defined, the next step was to select our spring and dampers. It was explained that to choose these it is necessary to first define the goals for the suspension system: driver comfort, tyre comfort, body control.

We then closed the loop by discussing how you should define your goal based on the track scenario: bumpy or smooth circuit, off-road, passenger vehicle or high/low downforce vehicle. This month we will be looking at one of these goals: tyre comfort.

As previously mentioned, tyre comfort is important for mechanical grip. Mechanical grip refers to the efficiency (friction factor) of the tyre. **Figure 1** shows a typical lateral force (*Fy*) versus slip angle (*SA*) curve, for five different vertical loads at zero degrees of camber, and a constant pressure. When testing a tyre, a typical chart used to understand the tyre's lateral performance is an *Fy-SA*, like this. In this article we won't delve into analysing the tyre's lateral performance based on this chart. Instead, we will use this to help illustrate mechanical grip.

Loading up

In Figure 1 we have plotted the same tyre at five different conditions (five different loads), and for each increase in vertical load we measure the lateral force. What we can observe is that as we increase the

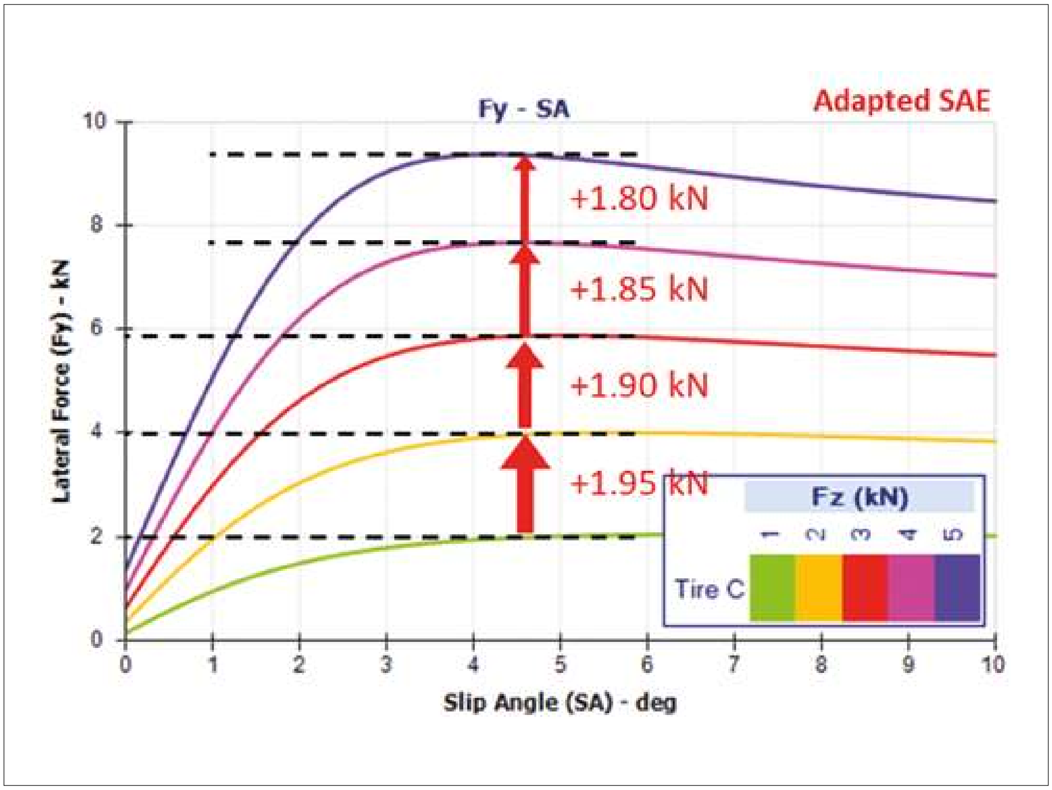

Figure 1: This shows lateral force (*Fy*) *vs* slip angle (*SA*) for five different vertical loads (*Fz*). It is the classic *Fy-SA* tyre chart

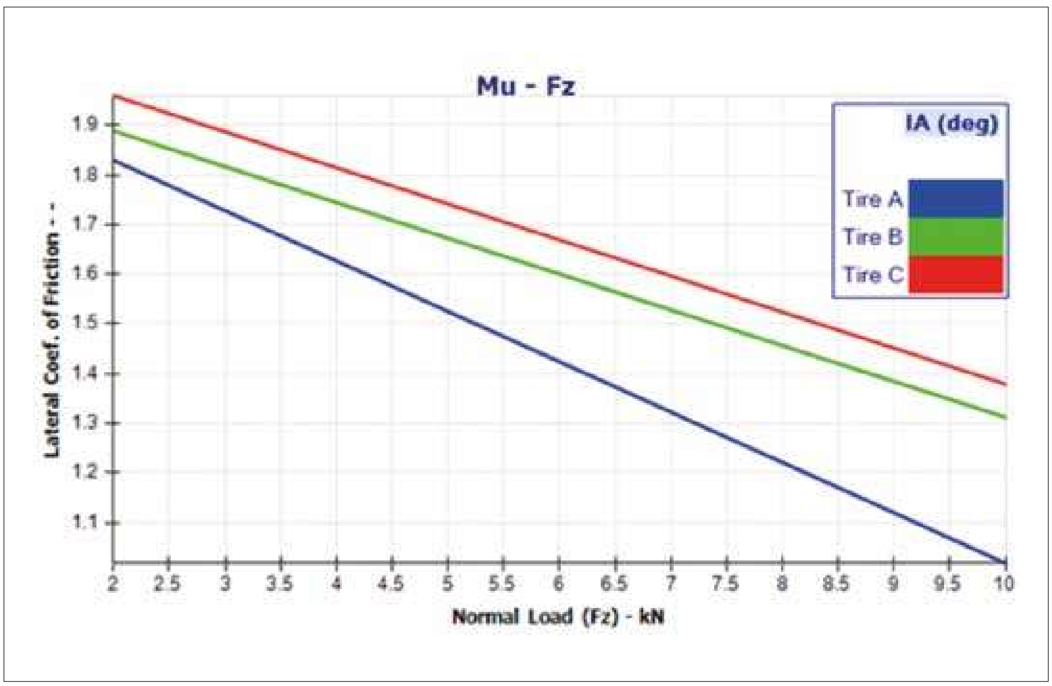

Figure 2: Lateral coefficient of friction *vs* vertical load for three different tyres plotted at zero degrees camber and a constant pressure

vertical load, from 1kN to 2kN; 2kN to 3kN and so on, we effectively have more lateral force. But looking closely you can see that the lateral force net gain is decreasing as we increase the vertical load. From a load of 1kN to 2kN the tyre lateral force increased by 1.95kN, from a vertical load of 2kN to 3kN the tyre net lateral force gain was 1.90kN. Effectively the tyre's lateral force increased, but the total amount decreased. That's why a tyre loses efficiency as you increase load.

Table 1: Table representation of Figure 1

Vertical load (kN)	Lateral force (kN)	Lateral force gain (kN)	Friction coefficient
1	2.00	-	2.00
2	3.95	1.95	1.97
3	5.85	1.90	1.95
4	7.70	1.85	1.92
5	9.50	1.80	1.90

Table 1 shows the same as in Figure 1. If we display it in a table, we can see more clearly that the friction coefficient is decreasing as we increase the load. The friction coefficient is calculated by dividing the lateral force per the corresponding vertical load (column two divided by column one).

A common chart used to investigate the tyre efficiency is the tyre efficiency versus the vertical load, which you can see in **Figure 2**. As an example, we have plotted the tyre coefficient of friction for three different tyres. You can see that, depending on the tyre, their load sensitivity will be different, in this case tyres B and C have almost the same tyre load sensitivity, although tyre C has more grip. Tyre A is the most load sensitive.

Knowing your tyre load sensitivity is important, because it will give you an idea of the set-up change sensitivity, as you change your weight transfer ratio. An example of doing this is by changing your spring stiffness.

Unsteady state

Up until now we have been discussing load sensitivity and mechanical grip. At this point we have understood that as we load the tyre more, we effectively have more lateral force, but this lateral force gain is smaller as we increase the load. This conclusion was made under the assumption the tyre was in a steady-state condition. The vertical load is applied, we wait until the load reaches a constant value and we measure the lateral force. Unfortunately, with the unevenness or bumpiness of the track, the vertical load is not constant.

As we have shown in a previous article (see November 2018, V28 N11) if the normal load on the tyre varies then the tyre coefficient of friction will decrease overall. The decrease in friction is due to the tyre load sensitivity and the delayed

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response of the tyre to load changes (relaxation length/response lag). The decrease in friction factor corresponds to less lateral and longitudinal grip, the overall effect being slower lap times.

If a tyre is held at a steady operating condition and the normal load is increased, the friction factor of the tyre will decrease. When it is decreased the friction factor of the tyre will increase. But you always end up gaining less from the additional load at a lower friction factor than you lose from the decreased load at a higher factor. We can see the size of this effect if we have a good idea of the lateral friction factor of the tyre at different loads (as in Figure 1). In **Figure 3** we see a possible time-based load variation on a race tyre. In the plot we have a static reference load (average load) of 3000N and we are varying the load by 75 per cent (750N to 5250N) either way.

At each point on this curve we measure the lateral force. We then plot the lateral force (**Figure 4**).

Additionally, in Figure 4 we have calculated the average lateral force and the average lateral force without the sinusoidal vertical load input. If we then calculate the average lateral force based on the sinusoidal vertical load input, the difference between the two is how much we lost due to the tyre load variation.

To understand how minimising the tyre load variation plays an important role on the mechanical grip, **Figure 5** is a summary of the lateral force loss for different amounts of tyre load variation for this particular racecar and tyre. As the load variation increases the lateral force loss becomes greater and greater. The effect is significant at high levels of tyre load variation.

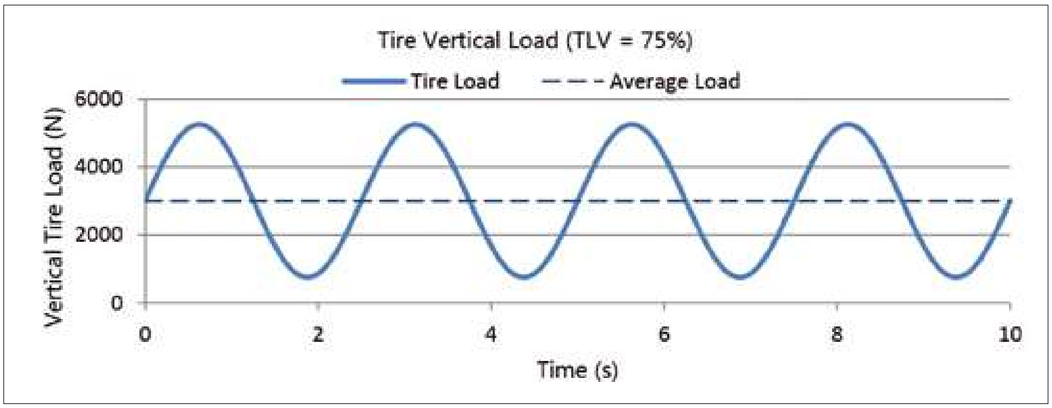

Figure 3: Load on a racing tyre for a sinusoidal profile. Variation is shown as the blue wavy line, with the average running through it

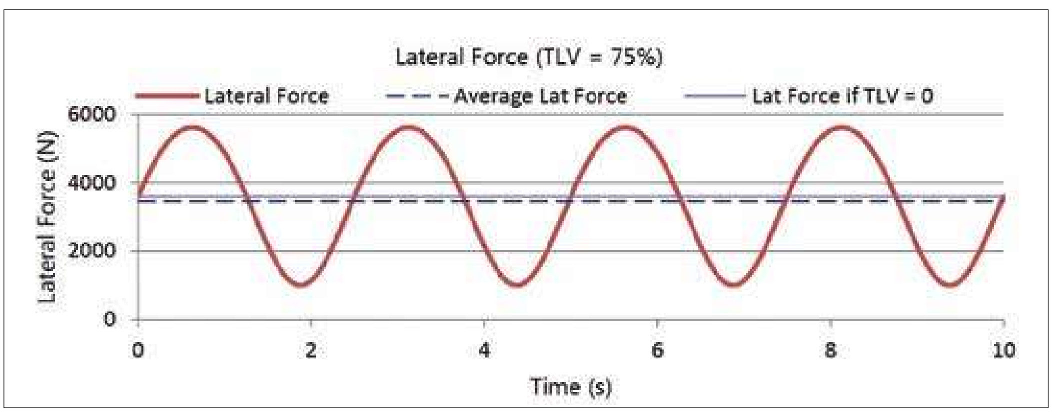

Figure 4: Here we have calculated the average lateral force and the average lateral force without the sinusoidal vertical load input

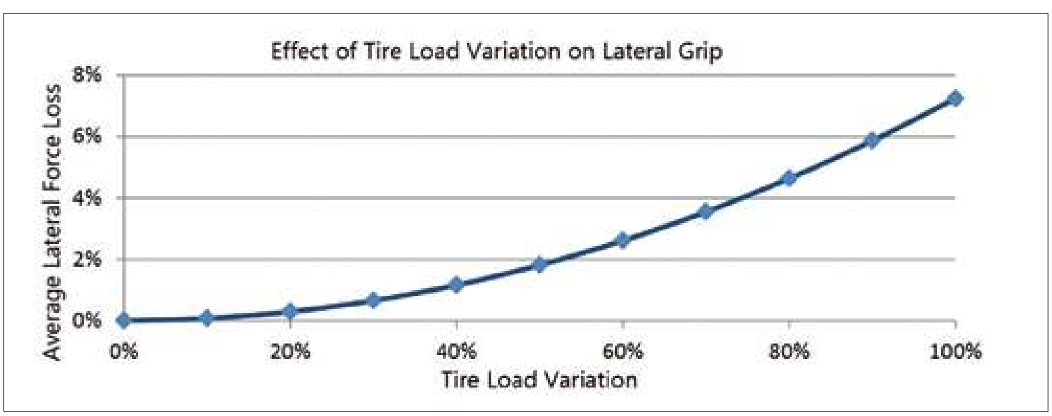

Figure 5: This is a summary of the lateral force loss for different amounts of tyre load variation for this particular racecar and tyre

Higher frequency

If a tyre is held at a constant operating condition but the normal load is varied, then the tyre will take time to gradually build up to the maximum steady-state force that is possible. Unfortunately, at higher frequency the load is constantly varying and the peak steady-state value is never achieved. The quicker the load is varying the worse the effect is. At high frequency and high amplitude of tyre load variation, the grip capacity is greatly diminished.

For that reason a lot of time is spent on four- and seven-post rigs minimising tyre load variation, which in turn minimises the tyre contact patch variation. What we've seen is that minimising it reduces the tyre load sensitivity, which in turn increases the performance of the racecar. Minimising the tyre load variation can be achieved by tuning your damper response and/or changing your spring stiffness.

Slip Angle is a summary of Claude Rouelle's OptimumG seminars.

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CONTACT
Claude Rouelle
Phone: + 1 303 752 1562
Enquiries: engineering@optimumg.com
Website: www.optimumg.com

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