Traction Engineering
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Lecture 39: Classification of steady state handling characteristics and handling diagram

Hi everyone, this is Professor H. Raheman from Agricultural and Food Engineering Department. I welcome you all to this NPTEL course on Traction Engineering. This is lecture 39, where I will try to cover the classification of steady state handling characteristics and particularly the handling diagram. And the concepts which will be covered in this class is neutral steering, over steering, under steering and the handling diagram. This neutral steering, over steering and under steering these are the classification of handling characteristics.

So, in the previous class we defined a terminology called understeer coefficient K_{us} which is nothing, but

$$K_{us} = \left(\frac{W_f}{C_{\alpha f}} - \frac{W_r}{C_{\alpha r}}\right)$$

So, that difference is indicated as understeer coefficient. When this bracketed term is equal to 0, that means, K_{us} is equal to 0. The steer angle δ_f, which is required to negotiate a given curve is independent of the turning radius or the forward speed. That means, when delta that is the steer angle required to negotiate a given curve is independent of the forward speed.

So, the relationship which that the fundamental equations, which we derived in the previous class,

$$\delta_f = \frac{L}{R} + \frac{V^2}{gR} K_{us}$$

So, when K_{us} is equal to 0 so obviously, this component will be 0 and $\delta_f = L/R$. So, that is reflected in this figure, neutral steering, the central curve. So, for a neutral steer vehicle, when it is accelerated in a constant radius turn, the driver should maintain the same steering wheel, steering wheel position or in other words you can say, when it is accelerated with the steering wheel fixed, the turning radius remains the same ok. So, let me repeat this, in a neutral steer vehicle, the turning radius is to be maintained constant then we have to maintain the steering angle constant ok.

So, when a neutral steer vehicle, which is originally moving along a straight line and it is subjected to a side force acting at the centre of gravity, so, equal slip angles will be developed at the front and the rear tires. As a result, the vehicle will follow a straight path at an angle to the original. So, I will show this thing at the end, how it is acting against the side force. Now, I will go to the other classification which is the understeer.

When the understeer coefficient K_{us} is greater than 0 that means,

$$\frac{W_f}{C_{\alpha f}} - \frac{W_r}{C_{\alpha r}} > 0$$

That means, this cornering stiffness and the weight coming on the front wheel, that ratio is more than the ratio of weight coming on the rear wheel and the cornering stiffness of the rear wheel then K_{us} will be equal to more than 0. So, this, under that condition the steer angle del f required to negotiate a given car increases with the square of the vehicle forward speed. So, that is indicated here in this. This is the situation. For an understeer vehicle, when it is accelerated in a constant radius turn, the driver must increase the steering angle. If you want to get the constant steering radius then at the turning radius, then the driver has to increase the steering angle or in other words when it is accelerated with the steering wheel fixed, the turning radius increases, it does not remain constant.

So, when a side force is acting at the centre of gravity of an understeer vehicle originally moving along a straight line, the front tyres should develop a slip angle which will be greater than the rear tyres, as a result a yaw motion will be developed and that will turn the vehicle away from the side force. Now, I will go to the third condition. Third condition is your oversteer. When the understeer coefficient K_{us} is less than 0, that means, the front wheel is developing less slip angle then the steer angle δ_f which is required to negotiate a given curve decreases with an increase in forward speed. So, that is indicated by this line in this figure. For an oversteer vehicle when it is accelerated in a constant radius turn, the driver must decrease the steering angle, or in other words when it is accelerated with steering wheel fixed, the turning radius will decrease.

So, if you look at the figure, initial turning radius is R now if you follow this over steer condition then the whatever turning radius is coming so that will be less than the capital R. So, when a side force is acting at the centre of gravity of an over steer vehicle originally moving along a straight line, the front tyres will develop a slip angle which is lesser than that of the rear tyres, as a result a yaw motion will be initiated and the vehicle will turn into the side force. So, I will show you what is the turning into the side force or what is the turning away from the side force. When a side force is acting a phase under neutral steer, it will move at an angle whereas, in case of under steer it will move away from the original condition and the over steer condition, it will move towards the side force ok. So, this is oversteer, this is understeer, this is neutral steer.

So, this figure shows the directional response of neutral steer, oversteer and understeer vehicle to a side force at the centre of gravity. So, whether it is understeer or oversteer, they are created, they will be creating directional instability after certain speed. So, let us see we will try to find out some characteristic speed. For an understeer vehicle, I have defined a speed called characteristic speed which is denoted as V_{char} this has to be identified. What is this? This is the speed at which the steer angle required to negotiate a turn will be equal to

$$\delta_f = \frac{2L}{R}$$

Where L is the track width as wherever L is the wheel base and R is the turning radius and

$$V_{char} = \sqrt{\frac{gL}{K_{us}}}$$

K_{us} is the understeer coefficient and that represents this point.

Your forward speed is exceeding this one, then there will be directional instability. The similar to characteristic speed which is associated with understeer vehicle, we will also define a terminology called critical speed. This is associated with oversteer condition or oversteer vehicle which I denoted as V critical (V_{crit}) and that has to be identified because beyond this speed that will give you directional instability. So, it is the speed at which the steer angle required to negotiate a turn is 0. So, this is the condition.

If you increase the speed that means, this is a plot of steer angle δ_f versus forward speed, I have just given an example. So, when the speed reached to this point, that means, steer angle is 0, then there is a possibility that V critical will be arrived and

$$V_{crit} = \sqrt{\frac{gL}{-K_{us}}}$$

So, whether it is characteristic speed or whether it is critical speed, if we cross these limits then there will be directional instability, and the neutral steer is achieved at 0 when K_{us} is equal to 0 that means, $\delta_f = L/R$. So, these are the three conditions which I have indicated for understeer, oversteer and neutral steering. Now, let us see the prime factors which are controlling, now if you look at the steady state handling characteristics of a vehicle these are the weight distribution of the vehicle and the cornering stiffness of the tyres.

So, that will control the K_{us} factor and whether K_{us} is 0, Kus is negative, or K_{us} is positive. So, that will decide whether the vehicle is in neutral steer whether the vehicle is in understeer condition or that the vehicle is in oversteer condition. So, there is another way of representing this handling behavior of vehicles with respect to operating conditions that is called handling diagram. So, this is a plot of a_y/g vs $(\omega_z L/V)-\delta_f$. I will come to this factor what is this a_y/g and what is this $(\omega_z L/V)-\delta_f$. In the previous class we have defined the steering angle requirement there is an expression of steady state handling behavior.

So, I have written as this one,

$$\delta_f = \frac{L}{R} + \frac{V^2}{gR} K_{us}$$

So, now, this I can write as

$$\delta_f = \frac{L}{R} + \frac{a_y}{g} K_{us}$$

Where a_y is called the lateral acceleration which is nothing, but V^2/R. And now if I rearrange this one so,

$$\frac{a_y}{g} K_{us} = -\frac{L}{R} + \delta_f$$

$$\frac{a_y}{g} K_{us} = -\left(\omega_z \frac{L}{V} - \delta_f\right)$$

So, ω_z is called the yaw velocity and is represented by V/R.

So, instead of V/R, I am writing ω_z. So, I have divided by V. So, I am replacing basically R with V/ω_z. So, now, the equation becomes $\omega_z L/V - \delta_f$. Now, if I plot a_y/g versus $\omega_z L/V-\delta_f$, then I will get a curve like this.

So, what you inform, inform from this figure? When the slope is positive, if you look at this curve when the slope is positive that means, here, so, K_{us} will be negative because

$$\frac{d\left(\frac{a_y}{g}\right)}{d(\omega_z \frac{L}{V} - \delta_f)} = -\frac{1}{K_{us}}$$

When the slope is negative that means, K_{us} is positive. When slope is negative like here, so, this refers to understeer coefficients when slope is negative. So, K_{us} is positive this indicates K_{us} is positive.

So, when K_{us} is positive, means your front wheel is giving you more side force. So, that is why $W_f/C_{\alpha f} > W_r/C_{\alpha r}$. So, that is why K_{us} is positive so that means, this will refer to understeer condition. When the slope is positive that means, K_{us} is negative. So, the negative-negative becomes positive.

So, when slope is positive, K_{us} will be negative. So, negative means the front wheel is developing lesser force as compared to the rear wheel ok. So, and when the slope is infinite, so this is the condition, so, K_{us} will become 0. So that means, this is the neutral steering. So, this is another way of representing the handling characteristics taking into consideration the lateral acceleration and the yaw velocity.

But the problem here is the measurement involves ω_z, measurement involves δ_f, measurement involves R. So, there are 3 parameters to be measured, hence with a slight error may lead to some difficulty, otherwise this is another way of representing the handling characteristics. So, basically handling characteristics we have considered 3 conditions: one is neutral steer, the other one is over steer this third one is under steer. And all these 3 components they are classified based on the K_{us} value, is the understeer coefficient which is going to give you or which is going to decide which one will, with the condition for taking a turn by the vehicle. Now K_{us}, if you look at, it depends on the weight coming in the tyre, it depends on the stiffness of the tyre at the front as well as at the rear.

If the front tyre gives you more W_f /$C_{\alpha f}$ value then, obvious then the rear tyre then obviously, K_{us} will be positive that means, these are understeer condition. Now, when front weight by the cornering stiffness is lesser than the rear weight and the cornering stiffness, they will lead to over steering conditions. Whether it is understeering or over steering both will lead to directional instability. So, we have defined 2 critical velocities: one is V characteristic and the other one is V critical and we have also defined expression for V characteristics which is nothing, but $\sqrt{\frac{gL}{K_{us}}}$ and the other critical speed which we defined for oversteer vehicle is $\sqrt{\frac{gL}{-K_{us}}}$. So, this will decide whether the vehicle is going to have a directional instability or not.

So, in brief, we have discussed about 3 conditions, steering conditions: which is neutral steering, understeering and oversteering and also discuss along with characteristic speed and critical speed. Then we have also discussed about the handling diagram which is another way of representing the handling behavior of a vehicle with operating conditions, where we have taken into consideration the lateral acceleration and the yaw velocity. We can refer to Wong's book on Theory of ground vehicles to give you some more information. Thank you.