Fundamentals of Automotive Systems
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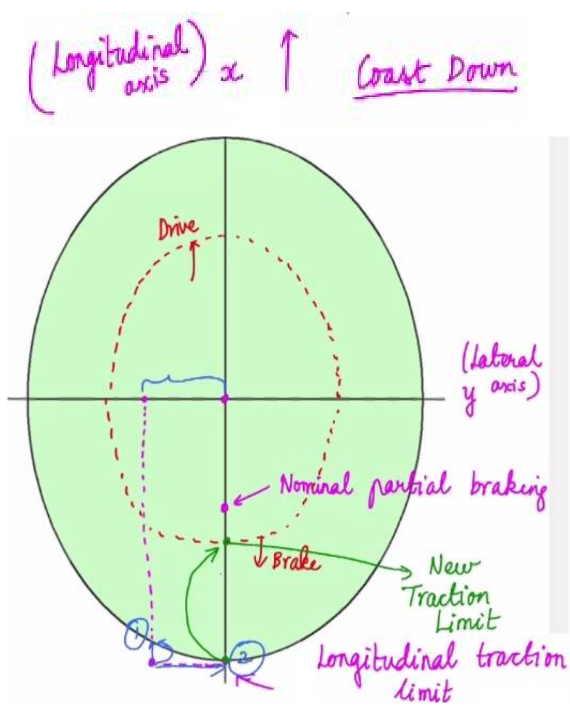
Air Brake System1 Part – 02

The tyre road interface essentially behaves in the same manner right the analogy I gave for about as walking.

So this brings us to the question of what are traction limits at a tyre road interface of course it is a different thing to figure out how to determine them okay we are not going to come to that topic in this course right but we are only going to learn what happens if we exceed those limits right. So what happens if these limits are exceeded okay so those are the 2 important questions that we would know look at.



FRICTION ELLIPSE

So to answer this we will look at what is called as a friction ellipse ok so this is a very common concept you know like use to explain this idea of this traction limits okay. So what is his friction ellipse and what does it gives okay. So the friction ellipse is nothing but a plot of the longitudinal and lateral traction available at a particular tyre road interface. So typically in a plot you know we label the horizontal axis as x and vertical as y right.

In this case we will label it other way around so we learned a label this as x and this as y right because we are looking at the tyre road interface from the top so this is the longitudinal axis the vehicle is moving in this direction and this is the lateral axis. So x is given for the longitudinal axis x represent longitudinal axis Y represents the lateral axis right. So, that is the reason why we mark x and y in this fashion.

So what is this what does this friction ellipse give us so the concept of friction ellipse or this friction ellipse now provides the limits of longitudinal and lateral traction available at a tyre road interface okay. So that is the purpose of a friction ellipse right okay so if you look at this ellipse the boundary of the ellipse gives me the limit okay those are what are called as traction limits so that is how much force it is there you know like that is about it right so in the particular tyre road interface.

Now let us say I am at the origin of this ellipse okay I am in the origin of ellipse that means that what happens you know like I am neither asking the powertrain to generate any force nor asking the brake to generate any force and you know like I am not turning the vehicle either right fx is zero fy is zero. So what will happen this will correspond to what is called as coast down because as we already know even if am going on a flat road we will have rolling resistance and aerodynamic drag acting on the vehicle right when we did that powertrain analysis.

So, what is going to happen I am neither commanding my powertrain nor commanding brake so slowly the vehicle will start to slow down and it will stop after some time okay that is what is called as a coast down maneuver okay. So this origin corresponds to what is called as coast down all right if nothing happens right. Now if you look at this axis themselves this positive x axis corresponds to drive and this negative x axis corresponds to braking right.

So depending on the sign of the force that is developed right okay so with that understanding let us go forward. Suppose let us say I this let us say we assume that this ellipse corresponds to a dry road surface condition right and I brake nominally what happens? Let us say I am commanding this much of braking force okay so this is like nominal partial braking right. So I am commanding this much of force so you know let us say I am going in city traffic you know I see a signal I brake slowly with some force which gets applied and I come to stop alright decelerate depending on then everything is fine alright.

Now let us say I am driving my vehicle and suddenly a child runs in front of me right what do we do? We slam the brake pedal correct? So the brake system is designed to give us the maximum possible brake force when we completely press it right. And let us say that point is this and everything is working perfectly we are at the limit okay so this is the maximum braking force that we can get at this particular tyre road interface so this is the longitudinal traction limit.

So now I hope it is clear what is called as a traction limit does not matter which direction we are talking about the question is traction limit conveys to us you know what is the maximum force that we can get at a particular tyre road interface right. So that is the longitudinal traction limit during braking all right of course this is the longitudinal the top point indicates the longitudinal traction limit during drive we are looking at braking so we look at this.

So now we are still on the surface right but then we have to be now careful suppose let us say a child is running in front of me right when I am driving the car straight. So I panic and then press the brake pedal completely but sometimes you know we may also try to steer right our natural reaction would be to not only brake but also try to steer so that like we can avoid the child right. So what happens now not only am I braking completely I am also asking for some steering force or force along the lateral direction not completely.

But let us say know that is this point right, so this is like some steering partial steering and I am doing complete braking. Now where will the resultant be the resultant force is going to be here is a resultant going to be inside the ellipse or outside the ellipse this is outside the ellipse alright. So you can immediately see that under this I am just constructing a scenario where things can go out of control right what is happening is that in this scenario at this particular tyre road interface does not matter it is front or the rear the situation is such that you know like I have gone outside the ellipse.

That means that my tyre road interface will no longer be able to sustain the force that I am demanding right both along the longitudinal and lateral direction. Suppose and then you know like the way we are going to lose some we are going to pay a price you know like we will see what that price is shortly. But then suppose if I want to bring the vehicle under control once again right what should I do? I should go within the ellipse right or to the boundary of the ellipse at least alright.

So you can immediate see that there are multiple ways by which I can go to the boundary of the ellipse but the 2 natural choices would be to go from here to here or here to here. Let us say we call this choice 1 choice 2 right if you look at choice 2 what I am doing? I am going from the point outside the ellipse to the limit of the longitudinal traction so that means Fy becomes 0. So what does it mean I cannot steer that is all the vehicles orientation is not going to change.

Although my intention is to change the vehicle's orientation slightly it may not change right what about point one? point one essentially, I am still changing my vehicle's orientation a little bit because I am giving a small steering angle right the path of the vehicle will still change because there is still a component of the force along the y direction but have I sacrificed. I have essentially ensure that I have reduced my Fx. Now if you want to reduce the Fx what do we do? I need to reduce the braking force now all of us know that braking force depends on the actuation force alright for a fixed brake factor actuation force is brake pressure times area of the actuator.

We cannot change the area of the actuator in real time it is fixed at least in traditional brakes and so the only thing which we can reduce is the brake pressure right and that is what the ABS does right it tries to detect this figure out how much brake pressure reduction should happen and reduces it. So that the brake pressure is lower that what is commanded by the driver okay. So the driver commands some brake pressure because in this experiment I slammed the brake right.

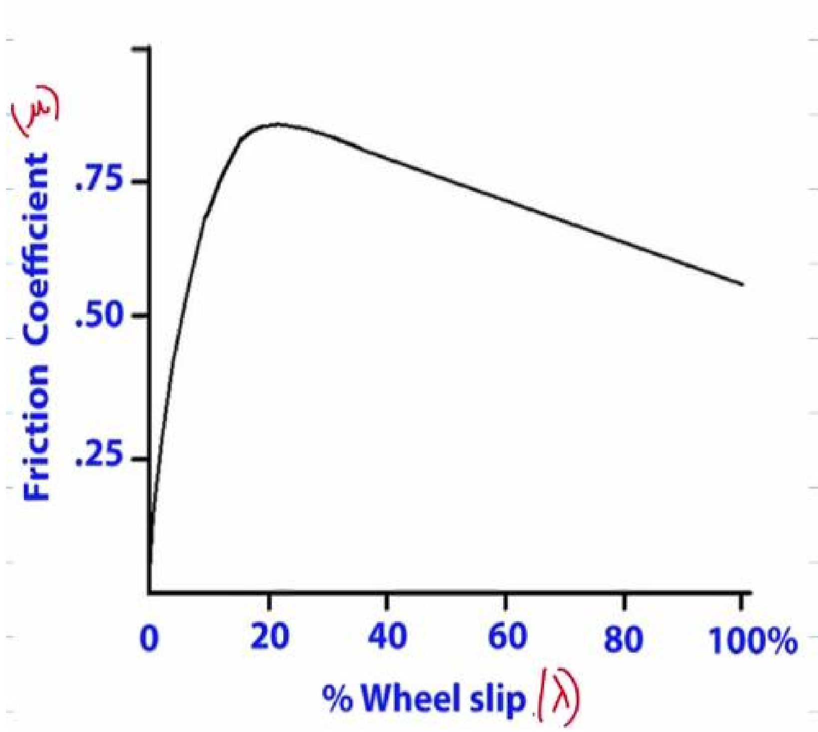
I want the maximum operating pressure but so happens, that I cannot sustain that right so it has reduced okay that is the task of an anti-lock brake system. But this is only one scenario there are other scenario's also I am going to present you 1 more scenario where this becomes important. Let us say now it rains same vehicle same driver same tyre everything remains the same but it rains what is going to happen the traction capacity or the traction limits are going to decrease.

Now what will happen is that this ellipse will now shrink so let us say I am just drawing this red dashed line showing that shrink shrunk ellipse alright. So this is the shrunk ellipse friction ellipse due to a wet surface. Now we have another problem right let us forget steering for the time being let us say we are going straight ahead right and let us say it is raining so suddenly I see a I have poor visibility and suddenly I see something some obstacle is in front of me what do I do ?

I once again slam the brake let us assume that we do not even steer right now when I am slam the brake what am I asking for? I am asking for this but the new traction limit is this then do we have a problem? Obviously we have right because I am already outside that ellipse right the new ellipse right which gets modified right. So I need to come here once again how do, I come here reduce the pressure okay.

So once again you know I am slowly getting to how the ABS works but of course all this is fine for explaining the concept but in real life do we know these things? Very difficult right so I do not know what this ellipse is right and this ellipse keeps on changing in real time how do I you know how much it has shrunk? Very difficult to find out how do I even find out the road condition in real time? See you and I the driver are the human being can look and then perceive the road is wet snowy it is icy and so on.

But this has to be automatic right how does it tyre figure out on it is own right what surface it is in right? So the ABS algorithm adds the smartness part to the entire system right how does it figure it off? Now that is a separate very active field of research okay so this is a, what to say this notion of this friction ellipse is used to explain the need for ABS right.



μ-λ CURVE

So but then how is that how can that be done I am going to explain what is called as a Mu lambda curve. So for the time being let us only look at straight line braking okay let us not even like look at you know steering right we are only going to look at straight line braking. So let us consider what is called as the Mu lambda curve or the traction curve and so on right. So what is plotted here is that on the y axis we have the friction coefficient Mu on the x axis lambda in terms of percentage obviously right.

So 1 means 100%, 0 corresponds to 0 by and large it has been found out that if you take a typical pneumatic tyre which is used in a road vehicle the maximum friction coefficient or that traction limit or the friction limit various with slip in this fashion right experiments have shown that this is the typical trend. So it so turns out that the peak once again you have to take these numbers in a qualitative sense alright even if you take a nice dry concrete road right the peak Mu you know comes around like let us say 15 to 20% of slip right.

So people say in this community you know like the region the operating region to the left of the peak curve is what is called as a stable region the operating region to the right of this is what is called as the unstable region. So what is stable and what is unstable to the right of the region please note that if we reach a point in the right of this vertical red line I drew. So let us say we are somewhere here what will happen is that I am already a pressing a brake too much but the wheel is slipping so the output brake force is going to be low right is not it?

So what will the driver think? The driver will think that my brake is not delivering enough force and may end up pressing even further and that is going to only make the problem worser right. So it is going to push it towards locking right one can visualize it from that perspective. But also for a given brake force if you do not take corrective action you know like when the operating state of the tyre goes beyond this goes to the right of this peak point you know; the it will tend to lock very fast okay.

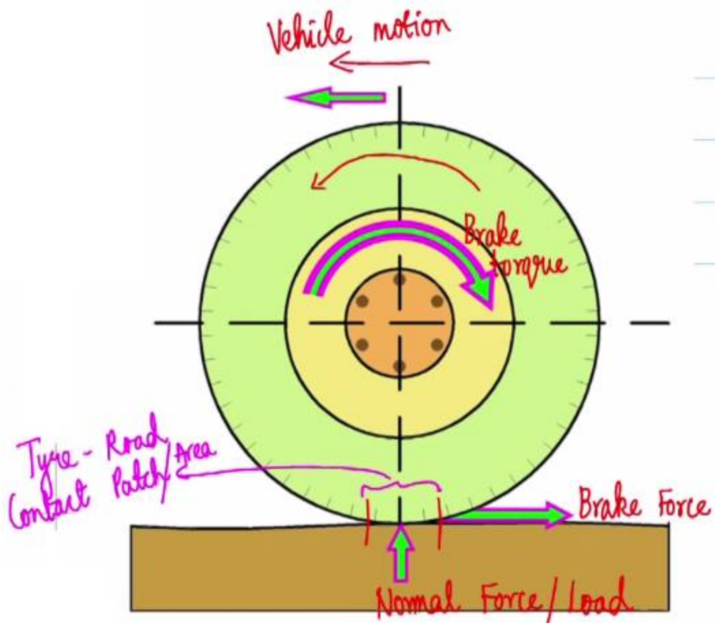
So this is the point where we have a wheel lock right and that is something which we want to avoid right why because you know like we lose stability amongst other things right. So we will see what is the consequence of course this is a very simplified notion as I told you when you go to advanced courses you will learn more right. So this curve first of all depends on lot of thing okay even for a particular surface depending on the normal load.

On the tyre you know there will be variations depending on the wheel slip angle there are going to be variations depending on the road surface this curve will change right. So figuring out this curve is a challenging process of figuring out this value of Mu is the challenging process.

So if you look at it from a controls perspective the problem of ABS can be also host as a problem of regulating lambda right is it not? See if I can regulate lambda let us say in a region around the peak let us say between 10 and 20% okay then the question becomes like would I get a nice stable braking right. So this problem of regulating lambda is what is called as wheel slip regulation okay which is a very,very important aspect for active vehicle safety system right which essentially work automatically in current generation vehicles right.

Anti-lock braking systems electronic stability control systems you know like all work on regulating the wheel slip you know like accurately but there is challenge right. If I want to regulate something I should know it is value at this instant of time let us say I will tell you, hey make sure my wheel slip ratio lies around 15% if I want to essentially ensure that wheel slip ratio lies around 0.15. First I should know what is the wheel slip ratio at this instant of time is it not see that is the whole philosophy of control right.

You calculate the difference between what we desire and what is the actual and take corrective action as I mean result but that is where another challenge comes.



<u>Wheel Slip Ratio (Longitudinal Wheel Slip),</u>

$$\lambda := \frac{v - r\omega}{v},$$

$v \rightarrow vechile' longitudnal\ speed,$

$\omega \rightarrow angularvspeed\ of\ the\ rotating\ wheel,$

$r \rightarrow tyre\ rolling\ radius.$

WHEEL SLIP RATIO

Because this if you look at the definition of wheel slip ratio I do not know what is the current value of lambda why? Because I do not know V so estimation of wheel slip becomes very very critical see only if I first estimate wheel slip properly would I know the value or the state at which the vehicle is then only I can control it right that is another problem I am just introducing you to the issues right there is another problem in wheel slip regulation is that like how do I find out what is the what we call us the reference wheel slip in control system you know like we would have what to say encounter the term reference input right.

That is the desired value right similarly here what is the reference wheel slip okay this will change based on you know the tyre road interface conditions amongst others okay. Dry road, wet road, snowy road, icy road okay it is going to change right. It may be 15% for dry road you know like it can come down to let us say 5% you know like 4% for a snowy or icy road right. So there is a range how do we regulate it right?

So I have to find out what is the reference wheels okay and then the people talk about Mu estimation there is another challenge because we do not know this wheel slip curve also alright. So, essentially what is the maximum Mu that we can get out of the tyre road interface right or the which is the indicative of maximum traction force at a particular tyre road interface right. So all these are very interesting problems in which you know like which are being investigated right.

Of course we have commercial ABS system ABS solutions, which work on their, own proprietary algorithms right. So but there are certain components which are standard components of various antilock brakes systems we look at those components we look at how they function and also we look at what is the impact of let us say locking of different wheels on vehicle stability in the next class okay thank you.