Fundamentals of Automotive Systems
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Module No # 11
Lecture No # 53
Antilock Brake System 2 – Part 01

So greeting, so let us get started with today's class. So a brief recap of what we were discussing? So we started our discussions on antilock brake systems and antilock brake system as the name indicates is a system that prevents locking of wheels. So we learned that a wheel is said to be locked if it stops rotating but a vehicle is still in motion right. So what we typically call as skidding and we defined a variable called wheel slip ratio which is given by this formula lambda equals v minus r omega by v.

Where v is the vehicle longitudinal speed omega is the angular speed of the rotating wheel and r is the tyre rolling radius and when the wheel is undergoing a pure rolling motion the wheels slip ratio will take a value of 0 and then it is fully locked it will take a value of 1. The main reason why we want to regulate this wheel slip ratio is that the longitudinal traction and the lateral traction available at the tyre road interface depends amongst other things on the wheel slip ratio lambda.

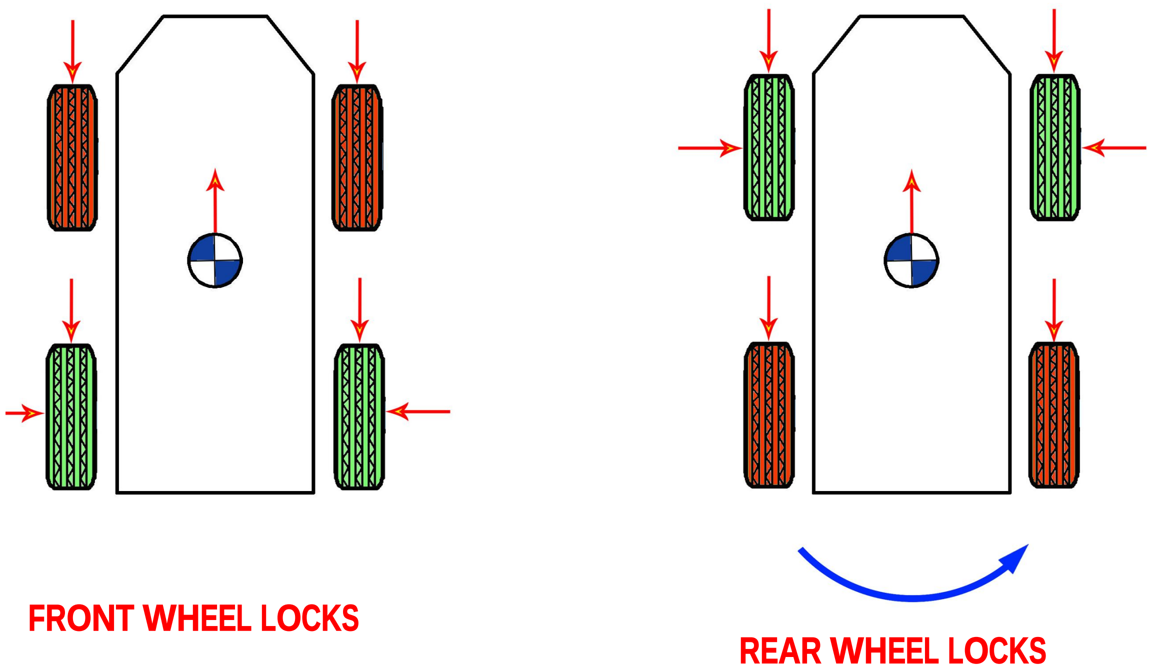
So we saw that you know typically the so called friction coefficient or the traction coefficient essentially varies with the wheel slip ratio in this manner and we can observe that we get a peak value at a in a very small range or at a particular value of wheel slip ratio. And we want to maintain the wheel slip ratio under panic braking conditions in this range okay where we get the maximum friction coefficient.

So, that we are able to get the maximum traction on the tyre road interface. We looked at the so called friction ellipse understood what were the issues related to tractions at the tyre road interface along the longitudinal lateral direction. And how change in tyre road conditions for example a wet surface as supposed to a dry surface is going to affect a brake performance in general.

So that motivated us to the so called process of the wheel slip regulation wherein we want to regulate this value of lambda to achieve in a broad sense 2 purposes. One is to ensure that a wheel does not lock while the vehicle is in motion. Second is also try and maximize the traction or the tractive effort available at the tyre road interface. So these are 2 broad purposes right. So now this is the concept, or this is the motivation behind the so called process of wheel slip regulation that forms the basis of an antilock brake system.

So now what happens if wheel locks you know why are we trained to regulate in the first place right? So to understand that first let us look at a single unit vehicle and see what happens when wheels lock ok. So let us consider a single unit vehicle like a passenger car, SUV or a typical bus and so on right. So and we consider let say a 4 wheel vehicle suppose let us say the front wheel locks ok. So this schematic on the left is for front wheel lock ok.

So if the front wheel locks or we apply the brake so hard at the front wheel that we are either reaching this point to or going beyond the friction ellipse right. So then we can immediately observe that there is hardly any lateral traction available at the tyre front tyre road interface.



EFFECT OF LOCKING

And by and large the front wheels are the one that are steered. So let us consider of course we are consider a single unit vehicle with the front wheel is being steered.

So we will look at this in greater detail when we go to steering system but in order to turn the orientation or heading of a vehicle we need lateral forces at the tyre road interface you know to essentially change the course of the heading of the vehicle. So now we have the front wheel lock for the front wheels are the one that are steered what happens is that like there are hardly any force along the lateral direction at the front tyre road interface. Then the driver loses the steerability of the vehicle.

So what it means is that even if the driver turns the steering wheel the front wheels may turn physically you know through the steering mechanism. But due to the absence of that lateral traction of the tyre road interface in the on the front the vehicle orientation would not change ok. That is what is called as loss of steerability ok.

So when front wheels lock you know there is a loss of steerability is loss due to absence of lateral traction at the front wheels ok which are steered. Of course that is why I am starting with the premises that the front wheels are the one which are steered which is the most common configuration that we observe today right. So that is what happens when the front wheel locks. So the consequence is that let say we are going along a direction and the moment front wheels lock the vehicle will continue to go along the same heading or a path or the direction unless otherwise a corrective action is taken place ok.

So that is the influence of front wheel lock. So what happens if the rear wheels lock? So here in this diagram what happens is that the rear wheels lock then we can observe that the lateral traction at the rear tyre road interface is absent ok because we have either met the traction limit or exceed at the traction limit at the rear tyre road interface. And that is completely taken up by the what to say for the braking process along the longitudinal direction.

So there is hardly any traction available along the lateral direction of the rear tyre road interface. So then what happen is that the direction stability of the vehicle is lost when a perturbation is given along the lateral direction. So this can be in the form of steering input given by the driver. This can be in the form of let say a lateral disturbance force that comes on the vehicle let us say due to side wind or one of the wheels hitting up bump which gives a force along the lateral directions.

You know you will have what to say a slope along the lateral direction you know which will which can give a perturbation and so on right. So there are so many reasons why you one can get the perturbation along the lateral direction. So the moment such a perturbation comes the vehicle will spin out of control ok. That is why people say that when rear wheels lock the chances of the vehicle losing its directional stability is high direction stability is lost of course in the presence of an appropriate lateral perturbation.

An appropriate lateral perturbation as I mentioned one can have steering you know next side wind ok so called road camber etc., ok. So these can create perturbations along the lateral direction and the vehicle will spin out of control ok. So that is why you know people say directional stability is lost right. So now we can immediately observe that this what happen in a single vehicle unit right. So we do not want any wheel to lock during, a vehicle operations that is the ideal scenario.

But however let us say wheel lock cannot be prevented you know like we are reaching some conditions you know like wherein you know we are in a position where some wheels have to go to lock right. If that is the case then the question arises you know which one would one prefer to lock first right. So the sequence of wheel lock becomes important. In this regard although the wheel lock is undesirable irrespective of the wheel the position of the wheel. If at all a wheel locks it is better that the front wheel locks before the rear wheel.

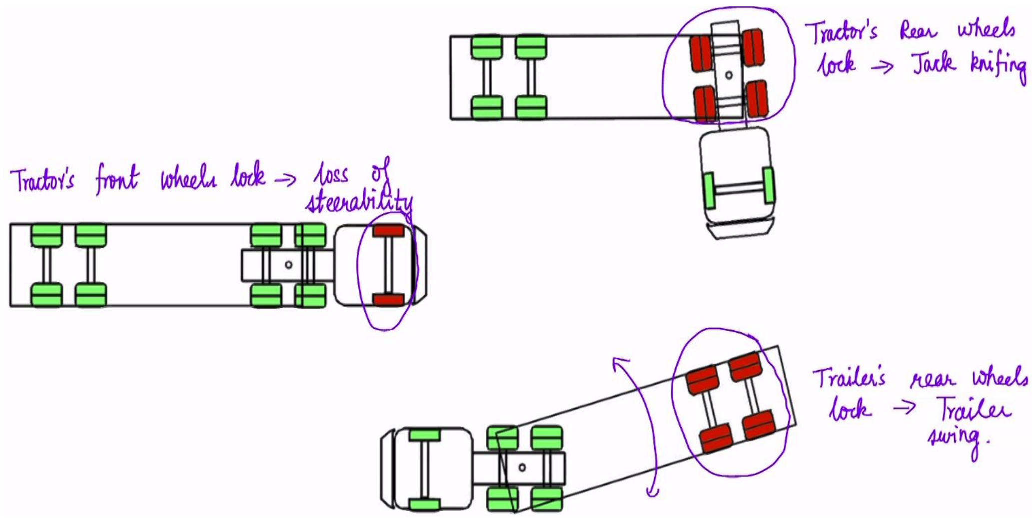
So that even when a front wheel locks and steerability is lost at least reasonably trained driver will be able to detect it and take corrective action you know before it is too late. On the other hand, a rear wheel locks and a corresponding loss of directional stability is relatively more difficult you know for a driver to detect and correct ok. So that for that reason you know like when people design even brake systems you know like they want to also ensure that what is the sequence of wheel lock.

You know if at all it happens in a vehicle. We are going to analyze it shortly right. So we are going to derive the expression like simple expression and then like we see which wheel would lock first. But however the sequence of the wheel lock is important for this particular reason ok.

So let me write down what I just told because this is very important though lock up of any wheel is undesirable ok loss of steering control or loss of steerability may be detected more readily by the driver. Of course the driver has to be trained right as to what to do. If the driver has not received proper training that when you have lost steering control while braking at least release the brake partially that training should have been given all right and the driver can regain control by releasing the brakes.

Hence rear wheel lock up is more critical ok and the sequence of wheel lock up becomes important for this reason alright. So we will we shall analyze what happens when different wheels lock sorry what is the condition under which front wheels will lock before rear wheels and vice versa when we do braking analysis ok. So this is a regarding you know like what happens when we have you know like wheel lock up in a single unit vehicle.

Now let us consider an articulated vehicle alright. So that means let say a tractor, a semitrailer or a tractor trailer and so on ok. So which are nowadays you know like used to carry goods right for goods transport. So if we consider such a vehicle and if we observe what happens when wheel lock occurs in such vehicles so broadly the effects are the following.



EFFECT OF LOCKING – ARTICULATED VEHICLE

So once again we consider that the tractor front wheels to be steered. So in such vehicles of course there are configurations where you have long chain vehicles right where even the trailer axles can be steered ok. So we are not considering those configurations now right. So let say a simple tractor semitrailer ok. So if the tractors front wheels lock which is this schematic then once again we have loss of steerability ok.

So the vehicle continuous to go along the same path right as the instant when the front wheels lock ok steering control is lost right. So now if the trailers rear wheels lock so here we have lock of this these wheels. Here these wheels are locking right. Then once again the lateral forces on the trailer's rear wheels are absent. So consequently, any lateral force that acts on the trailer any lateral disturbance will lead to what is called as trailers swing.

So you see that the trailer swings about an axis right and then you can observe the that trailer is going this way. Of course the driver can detect it and release the brakes but once again this is undesirable why? Because if you have a multilane roadway you know this is going to essentially sweep across the adjoining lanes right so and that is going to be harmful for vehicle coming in those lanes right. So this is also undesirable.

And if the tractor's rear wheel lock then what happens is that the any lateral disturbance the tractor and the trailer will swing into each other and they will just collapse like this right. And when most heavy vehicles what happens is it like due to what is called as a significant roll motion ok there is a tendency for the vehicle to roll over when there is a swing or a yaw motion ok.

We will look at that later when we come to suspension. But then there is propensity for the rollover. So the when the tractor rear wheels lock the tractor and the trail semitrailer will just fold like this into each other right and this very extremely critical and this is termed as jackknifing ok. So they just collapse and then flip over most likely right. So out of the 3 you know like the people essentially consider this jackknifing to be very critical something which the driver cannot even an experienced driver cannot easily come out of it right.

So that should be prevented. Of course once again you know like locking of any wheel is undesirable but here the tractor rear wheels are the most critical ok. So these are the physical effects of wheel lock. So that is why you know like today antilock brake systems are mandated. You know in fact interestingly although like antilock brake systems are available as standard features in many passenger cars SUV sold today.

Interestingly antilock systems are mandated in heavy road vehicles considering their safe operations ok. In India even ABS is now mandated in certain class of 2 wheelers right so to improve the operational safety ok. So now what is a typical ABS constituted off right.

What are the components of typical ABS? Then we will look at the broad concept of its operation. So if you look at a, components the list of components of a typical antilock brake system. So as we discussed you know ultimately the problem reduces to controlling that lambda the wheel slip ratio. And what does lambda v minus r omega by v right. So I need v I need omega right. But v is not easily measurable the level of fidelity required for this application in production vehicles then we at least need omega.

So for that reason we have wheels speed sensors that provide us the measurement of the angular speed of rotation of the wheel right. So wheel speed sensors are standard. And then we have an electronic control unit which essentially is more or less like the brain of the entire system wherein you know the data is processed and the wheels are continuously monitored, and action taken whenever required.

And the actuators which are used to typically take control action in this ABS currently which are used are what are called as modulators ok which are typically realized as a solenoid valves ok. So these are the 3 broad elements. So of course, there are other elements like a, what to say a proper cabling harness, connection connectors are all important ok. So I am not listening going to a very micro level here just a broad level. And these are the 3 items which are also required for implementing any control system right.

So if you recall our discussion on control system previously right we saw that you know if you want to have control with feedback we need measurements we need sensors to measure variables that we want to control. We need a controller which will try to reduce the error between what we desire and what is the actual variable and we need an actuator to realize the controller input which is calculated by the controller.

So you can see that even in ABS you follow the general you can map to a general controller structure right. We have sensors in the form of wheel speed sensors we have an electronic control unit where the control algorithm is running, and we have the actuators in the form of typically modulators solenoid valves right ok. So what are the different configuration which are available in passenger cars.

So let me consider a passenger cars you know like as a discussion point of course we can extend it to other types of vehicles. So just for essentially discussing ABS configuration let us consider 4 wheeled passenger car right. So what are the different configuration that are available. So we can have what is called as a 4 channel 4 sensor ABS ok. So what does this channel mean here? So the word channel here refers to the number of independently controlled valves ok controlled valves or modulators right.

So ok so that is the channel. So if you have a 4 channel 4 sensor ABS means obviously we can interrupt that there is 1 sensor and 1 modulator for each wheel alright. So obviously from a design perspective this is very good choice because we can really adjust the monitor each wheel independently and control them independently right. But the cost and complexity obviously go up right. So there is a tradeoff.

So what are the other configurations which are possible we have what is called as a 3 channel 3 sensor ABS right. So as the name indicates now we have reduced 1 channel. So what happens is that like each front wheel in the 3 channel 3 sensor ABS. Each front wheel has its own speed sensor and modulator because as we already discussed you know the front wheels have higher normal load in a typical passenger car that is why I am restricting this to passenger cars right.

So we can see that you know like we do not we want to maximize the traction from the wheels where which are loaded more right. So and we will shortly see that during braking there is going to be dynamic load transfer from rear to front. So consequently, the front wheels are going to be loaded even more right. So there is more potential for braking force right. So that is why we in this 3 channel 3 sensors ABS each front wheel is controlled independently ok.

And the 2 rear wheels have a common sensor and a common valve or modulator ok. So the most basic configuration in passenger cars is a 1 channel 1 sensor ABS that is if you want to say what is the most basic of course there can be multiple configuration these are the common configurations right. So 1 channel 1 sensor ABS suppose cost is of a constraint. So we want to have the least possible sensing and actuation you know we go for looking at the rear wheels right.

As we already discussed you know out of the 2 rear wheel lock is more critical. So consequently, in 1 channel 1 sensor ABS what happens is that the 2 rear wheels have a common sensor and the common actuator ok right modulator ok. So let me use the same term so essentially it is ok. So that is the 1 channel 1 sensor ABS.