Fundamentals of Automotive Systems
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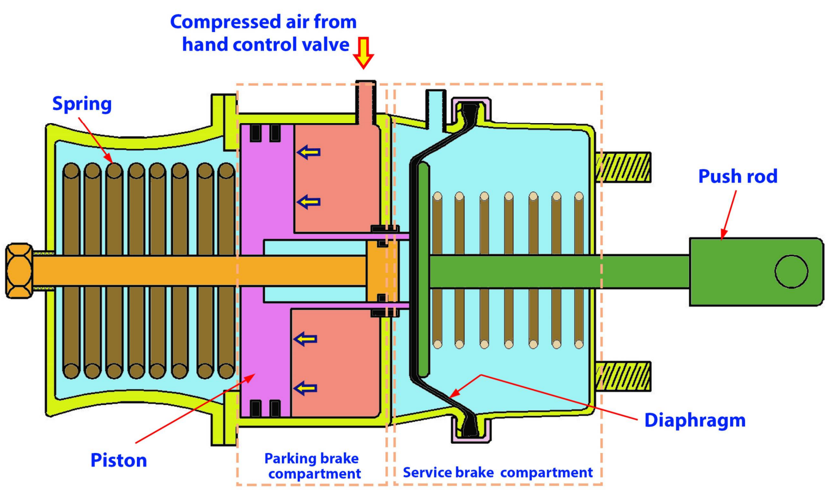
Module No # 11
Lecture No # 51
Antilock Brake System 1 – Part 01

Okay greetings so welcome to this lecture so let us quickly recap where we stopped, we were looking at the parking brake in a typical hydraulic brake with a drum brake on the rear the right in a passenger car. We learned that the parking brake is by and large achieved through mechanical means. Wherein the driver pulls the hand lever the parking brake cable is pulled and that essentially rotates this lever arm and the parking brake strut presses the brake shoe against the drum. That is how the parking brake functionality is realized ok.

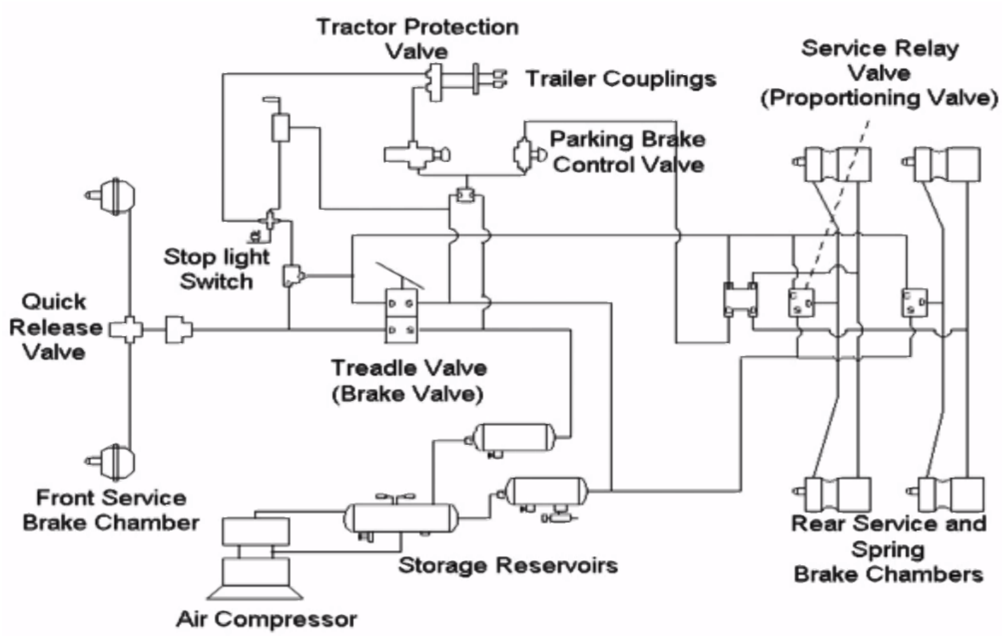
So today's class we will get started with figuring out how this parking brake works in an air brake system. So this was in the previous class we looked at the mechanical parking brake which is typically integrated in the drum brake in a



PARKING BRAKE-OPERATION

hydraulic brake. So today let us look at the air brake system which are used in heavy vehicle and see how the parking brake functionality is achieved. So what happens is that like in the air brake a particularly in the rear axles right so of let us say truck or a bus we have what is called as a spring brake chamber.

So if you recall the very simple schematic that we drew for the air brake and just going up so if you look at this you know like there was something called as a spring brake chamber right so if you look at this label typically mounted in the rear wheels right.



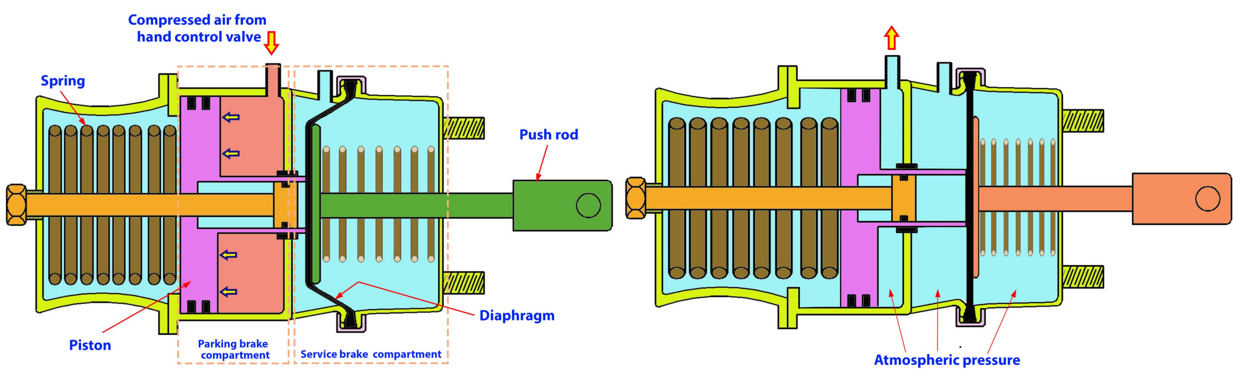
AIR BRAKE -LAYOUT

So and we can immediately see that this spring brake chamber appeared to be larger in size than these what to say service brake chambers mounted on the front wheels at least look at be wider or thicker depending on a perspective right. So that is what is also used to achieve this parking park and emergency brake functionality in air brakes ok. So that is what we are going to discuss are today.

So this spring brake chamber which is typically mounted on the rear wheels essentially consist of 2 chambers. One is the service brake chamber and a parking brake chamber. So these are the 2 chambers in the spring brake chamber right. So you can see that there is a what is labeled as a service brake compartment under a parking brake compartment. So what is this parking brake compartment?

So when the vehicle is in under operation right what happens is in the parking brake chamber is that there is a highly stiff spring ok a spring that has a pretty high spring stiffness which is held in a compressed state by the air which comes from the reservoir. So let say air at let say around 9 to 10 bars right enters this chamber it pushes this diaphragm or piston against the spring and holds the spring in a compressed state right.

Now we do the normal braking operation when the treadle valve is pressed air goes from the primary circuit of the treadle valve to the relay valve and into the service brake chamber and the diaphragm is pushed right the push rod strokes out it rotates the slack adjuster and then the S cam and the brakes are applied right that is the normal operation. Now what happens in the event that the driver wants to apply the parking brake or in the event that there is an emergency scenario right?



PARKING BRAKE – OPERATION SEQUENCE

So this schematic essentially corresponds to normal brake operation ok. So here service brake is engaged while the parking brake is not. So that is the normal operation right. So, of the service brake chamber ok. So as we just discussed you know like this spring is held in a highly compressed state by this compressed air and then the air enters from the relay valve and then pushes the push rod out ok. So that is the service brakes operation. What happens in the event of engaging the parking brake?

So when the parking brake is engaged the driver actuates a parking brake valve and what it does is that it exhausts the compressed air to the atmosphere right. So then what happens the force which was previously holding the spring the high-tension spring in a compress state is now released because compressed air is exhausted so what will happen? This spring would expand right and then it pushes this mechanism against the service brake diaphragm and the push rod is pushed out the slack adjuster rotates the S cam rotates and the brake shoes contacts the brake down.

So this is how the parking brake is engaged in an air brake chamber right. That is why it is called as a spring brake chamber right. So air is exhausted and the restoring force of the spring is used to engage the parking brake ok. This also serves as an emergency brake why? Because let us say you know like we are driving our truck or bus on a highway let say one of the main airline break, break away right breaks off right and I am just creating a scenario right.

So what happens there is no air supply to the treadle valve or the relay valve. And so the main airline breaks off even there will not be any air supply to the spring brake chamber is it not? Then the spring will automatically be released, and the brakes will be applied ok. So, that ensures that this also acts as a as an emergency break. If you have a tractor trailer system or a tractor semitrailer vehicle right even if the semitrailer or the trailer breaks away from the tractor right the airline are also disconnected.

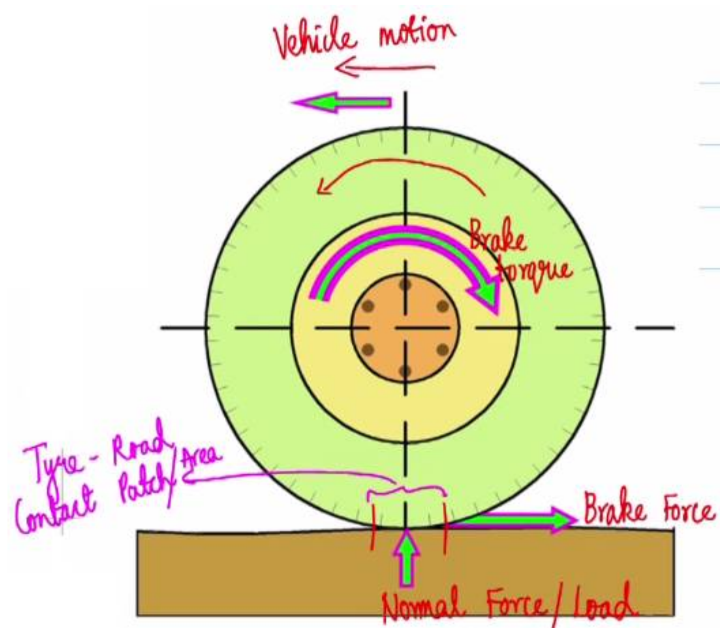
So the pressure would be lost in the spring brake chamber and the spring brake will get engage and the semitrailer or the trailer will stop because of this braking action ok. So that is one more way it is acts as an emergency brake in a tractor trailer or a tractor semitrailer combination right in multi-unit articulated vehicles ok. So that is how the parking brake is engaged right.

Of course if you want to disengage a parking brake obviously when the driver let say starts a parked bus or a truck they need to charge up the storage reservoir to a sufficiently high pressure and then pump pressurized air into this spring brake chamber so that the spring is pushed back and then the parking break is disengaged ok. So that is how it works. So that completes the discussion on hydraulic and air brakes.

So the next important topic which I am going to discuss in this lecture is on what is called as Antilock Brake System or an ABS right in short. So what is this antilock brake system as the name, suggest or the term suggest right. So this is the system that is supposed to prevent lock of a wheel that is why it is called antilock right. So it is major expectation is to prevent lock up of wheels during braking.

We will see why this should be prevented and what are the consequences shortly right. And what is this wheel lock right lock up of the wheels are wheel lock. So a wheel is said to be locked or wheel lock is a process where when in this case right the wheels stops rotating but the vehicle is still in motion ok. That is when a wheel is said to be locked see what we commonly called as skidding you know the vehicle skids right. So this is a proper definition of wheel lock right.

So why is this important you know like why it should be avoided right? So let us look at a broad set of reasons and discuss the science behind this right. So for that purpose let me introduce the simple schematic of a particular.



WHEEL SLIP RATIO

Let us say tyre assembly wheel assemble let us say that this is the direction of vehicle's motion so that is the longitudinal direction as far as the vehicle motion is concerned. And the wheel is rotating counterclockwise ok as far as this visualization is concerned. Now when we brake drum brake or disc brake right. So we are going to develop a clockwise brake torque. So that is what this thick arrow indicates in this picture right. So that is the clockwise brake torque, and this is going to generate a brake force at the wheel right.

And at the tyre road interface on the wheel assembly and there is a normal force or normal load acting on the tyre road assembly sorry tyre road interface right. At the tyre road interface on the wheel assembly correct. So these are the various aspects. Now if we look at a pneumatic tyre it does not undergo pure rolling motion. So what happens is that this pneumatic tyre is such that when it enters what we call as the tyre road contact patch or contact area ok.

Initially the tyre sticks to the surface then it starts slipping. So essentially there is a sticking process and a slipping process. So it does not undergo a pure rolling motion. See for example in many physics problem right high school physics problems you would have consider a rigid cylinder you know like undergoing pure rolling motion on a surface and so on right. In this particular case you know like the pneumatic tyres which are used in road vehicles they slip ok when they are subjected to motion.

Does not matter whether they are being driven or being braked ok either way. So then what happen is that there is something called as the wheel slip ratio or what is also called as longitudinal wheels slip which is denoted by the symbol lambda which is nothing but v minus r omega divided by v. Where this v is the vehicle's longitudinal speed it is a speed at which the vehicle is travelling along the longitudinal direction. Omega is the angular speed of the rotating wheel an r is the effective tyre rolling radius.

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

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

$v \rightarrow vechile' longitudnal\ speed,$

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

$r \rightarrow tyre\ rolling\ radius.$

So if the tyre or the wheel assembly; is undergoing pure rolling motion. What will happen this v will be equal to r omega right but it is not right. So v is the longitudinal speed of the vehicle r omega is the circumferential speed of the wheel along the longitudinal direction due to its rotation. There is a difference between the two ok. This wheel slip ratio or longitudinal wheels quantifies the difference. So v minus r omega is the difference and it is normalized by the parameter or the variable v.

And obviously this is going to be vary as the vehicle operates. So if we plot an axis of lambda; and mark the extreme value. See typically you know like this is how the definition of the lambda is taken during breaking ok during traction you know it is taken a little bit differently you know but we will we are considering braking so we will consider this particular definition. But the concept is the same that is the tyre road interface the tyre slips and this slip ratio is indicative of how much it is slipping ok.

So that is what we are interested right. So sorry if you look at the value of 0 when do you think the wheel slip ratio will be 0 it is essentially having pure rolling right. So we have a rolling wheel right v equals r omega. When do thing it would be 1? Of course for non-zero speeds right. So at when omega becomes 0 so the value of lambda becomes 1 for a locked wheel right. So when the wheel is purely rolling lambda is 0 when it is fully locked the value of lambda is 1 ok.

So the range of the lambda or the wheel slip ratio is between 0 to 1 ok during braking right. Is this important we are going to see why this become’s very critical, now in real life do we know lambda at each and every instant of time? No because even let say we measure the wheel speed using wheel speed sensors which are now available in most vehicle equipped with an antilock brake systems.

And even if we know r we do not know v the vehicle longitudinal speed is not known to us to the level of fidelity required for ABS applications right that poses interesting challenges which we will list them right when we discuss the overall system alright. So just a few more definitions and notations before; we look at the physics even further.

$$Let\ F_x\ represent\ the\ normal\ \frac{force}{load}\ on\ the\ tyre.$$

$$Thus, the\ longitudnal\ force\ (F_x)\ available\ at\ the$$

$$tyre\ road\ interface\ is\ gien\ by$$

$$F_x = \mu_x(\lambda, \alpha, \gamma)F_x, \quad \Rightarrow \quad \mu_x(\lambda, \alpha, \gamma) = \frac{F_x}{F_x}$$

Tyre slip angle

Camber angle

Longitudinal friction/traction/adhesion coefficient

So let Fz represent the normal force or what people call as load on the tyre ok. This particular tyre assembly that we are considering then the longitudinal force available ok at the tyre road interface you know for a particular tyre and a particular road condition. Let us say is given by Fz equal sorry Fx is the longitudinal force right. It is denoted as Fx ok Fx is the longitudinal force. This is denoted as some Mu x it is going to depend on many other parameters times Fz ok.

So this is going to depend on the wheel slip ratio then it will also depend on what is called as slip angle and it will also depend on wheel camber angle and so on ok. It may also depend on other factors ok. It is a complex quantity right. But for the sake of simplicity we are going to do a first cut analysis ok. So that is what we are going to do right.

Similarly, the lateral force available at the tyre-road interface is given by

$$F_y = \mu_y(\lambda, \alpha, \gamma) F_z, \qquad \mu_y(\lambda, \alpha, \gamma) = \frac{F_y}{F_z}$$

Lateral friction/traction/adhesion coefficient

So let me explain what this Mu x is but this alpha is what is called as the tyre slip angle ok. This Gamma is what is called as a camber angle. So when we come to steering we will look at all these quantities right. So but please remember this right. So this essentially gives me this Mu x to be equal to fx by fz. This is how this quantity is defined this quantity is what is called as the longitudinal friction or traction or adhesion coefficient ok.

So what this Mu x typically in longitudinal dynamics literature they would not put the subscript x ok. They will just say hey look this is Mu right and they will talk about the variation with respect to lambda that means that we are only considering pure longitudinal motion. That means we are looking at either braking or driving right what we call as traction right. So the subscript x does not come but this is what is called as longitudinal friction coefficient or traction coefficient or adhesion coefficient right ok.

Similarly the lateral force available at the tyre road interface is given by fy equals Mu y once again it depends on lambda, alpha, gamma times Fz. Where this Mu y which is a function of the wheel slip ratio or the longitudinal slip the slip angle and the camber angle is essentially the ratio of Fy and Fz ok. So this is what is called as a lateral friction or traction or adhesion coefficient ok so this is Mu y ok. So these are some definitions. Now how do we take them forward?

So you can see that depending on whether I am if I look at a particular tyre road interface there is a component of the force along the longitudinal direction and a component of a force along the lateral direction ok. And there are limit's to how much the tyre can support at a particular interface with the road and why is this becoming important going to become important in our discussion let me take a simple example from our daily life.

Suppose let us that I am walking right on a surface right let us say on a road and let us say I am talking to somebody and I am walking, I am not looking at the road parse right. So I know that it is drive by and large so what does my brain command you know through my muscles and joints it commands the certain force at the interface between my feet and the road and then we walk right I am walking correct.

So we are stable in that sense because somehow we are figured out what is the capacity that can be supported at the particular interface between my feet and the ground and we are able to remain within that capacity is it not. So then everything is fine. Now let us say I am talking to you are walking on my side by in front of me in my path there is a puddle of water but I have not seen.

So if I place my feet on the puddle of water without being aware that there is one what would happen to me? I am placing my feet with the same effort right my brain is commanding the same effort or force through my joints and muscles right to the interface between the feet and the road. So that is like an actuator this is happening but the capacity now at the feet and the road is reduced right because due to the water which is present.

So what is going to happen I will slip correct same thing happens here also ok. So let say we are driving a car and we are braking our brake system is designed we are going to learn about that. It is going to designed for the best operating condition or wheel right because that is how that is what we encounter by and large or we will put it the other way it is going to be design by and large for the operating conditions that we would most commonly encounter which are going to be dry road right.

So now I have an emergency I press my brake pedal completely. So what is going to happen let us say I take a round number of 100 Newton’s. When I slam my brake pedal completely I am expecting my brake to deliver 100 Newton’s and it is been designed such that the force at the capacity at the tyre road interface is also 100 Newton’s right then everything is fine. However let us say it rains and I have a wet road and I am driving the same car same driver right same speed and same emergency I slammed the brake what happens now?

The brake system is still designed to deliver that 100 Newtons either through disc brake or the drum brake. But the capacity at the tyre road interface now has dropped or in other words the value of this Fx or this Mu x has now dropped then we have a problem because the tyre road interface cannot sustain what the brake system is asking or the driver is demanding through the brake pedal. Then we have issues then the wheel will tend towards locking because the wheel will start slipping more and it will lock.

See let us do a simple thought experiment let us say even we have a simple 2 wheeler a motorcycle we put it on a main stand so that the driven rear wheels is rear wheel is suspended in air. Now you give a bit of throttle the rear wheel is going to spin right it is going to rotate very fast. Now even if you touch the rear wheel brake little bit it immediately stops how come right because there is no load on the rear wheel right.

So of course, you suspended in air right so there is no normal load and no this Mu times Fz right. So the brake torque that you are applying is exceeding this limit but on the actual during the actual braking process when you are driving there is load on the particular tyre and that creates a traction at the tyre road interface and the braking system tries to remain within the tractive limit or matches the tractive limit under emergency conditions then everything will be stable. Otherwise you know like we are going to have issues.