MODULE 5

BRAKING SYSTEM

SYLLABUS:

Brakes: - mechanical and hydraulic brakes (review only) – properties of friction lining and pad materials, efficiency, stopping distance, theory of internal shoe brake, equations –effect of expanding mechanism of shoes on total braking torque, equations.

Braking vehicles: - brakes applied on rear, front and all four wheels, equations –calculation of mean lining pressure and heat generation during braking operation, equations. – braking of vehicle moving on curved path, simple problems.

Anti-Lock Braking system (ABS): - need and advantages of ABS – hydro-mechanical ABS - hydro-electric ABS - air-electric ABS.

Brake servos: - operating principle, vacuum servo - direct acting suspended vacuum assisted brake servo unit operation - hydraulic servo assisted brake systems.

Pneumatic operated disc brakes – air operated brake systems: - air over hydraulic brake system - Three-line brake system-– electronic-pneumatic brakes.

INTRODUCTION:

- The braking system is an important system in a vehicle, which helps in reducing speed of the vehicle or stopping the motion of the vehicle in the desired location by means of friction.
- It also helps to control the vehicle on inclined and curved roads.
- The device used for this purpose is known as brake.

TYPES:

- Based upon brake application:
    - Service or primary brakes
    - Parking or secondary brakes
- Based upon actuation:
    - Mechanical brakes
    - Hydraulic brakes
    - Air brakes
    - Servo brakes
    - Electrical brakes
- Based on construction:
    - Drum brake
    - Disc brake

MECHANICAL BRAKES:

- Mechanical braking system is also called as manual stretch braking, because the braking force is given by means of pedal which is transmitted by means of wire and ropes or mechanical linkages.

- A cam is attached along with the brake shoes so that it can be actuated by mechanical linkage. By revolution it brings contact between the shoes and the drum, thereby reducing the speed or to bring the vehicle to rest.

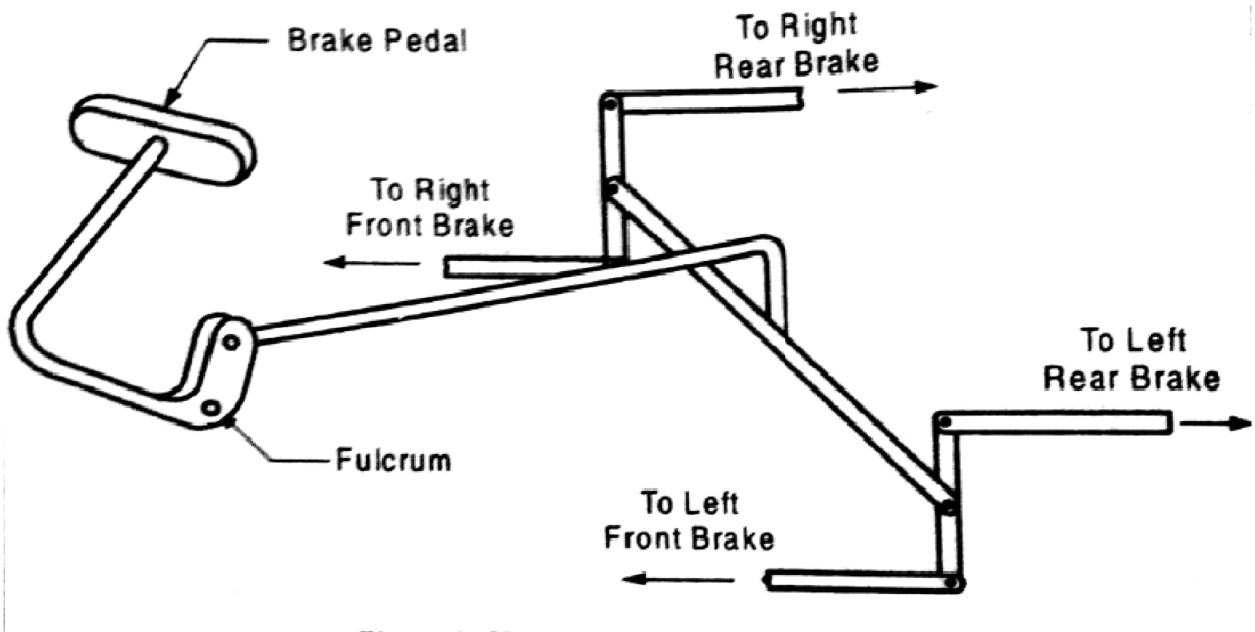


Fig. 5.9. Mechanical Brake Linkage

- This braking system is obsolete now as service brakes, but still used in some vehicles as secondary brakes.
- The main disadvantage of mechanical linkage is that braking effects on all wheels are not equal which bring instability of moving vehicle. Therefore, a compensation is employed to reduce the uneven braking effect.

HYDRAULIC BRAKES:

- Most of the cars today use hydraulically operated foot brakes on all the four wheels with an additional hand brake mechanically operated on the rear wheels.
- An outline of the hydraulic braking system is shown in Fig.

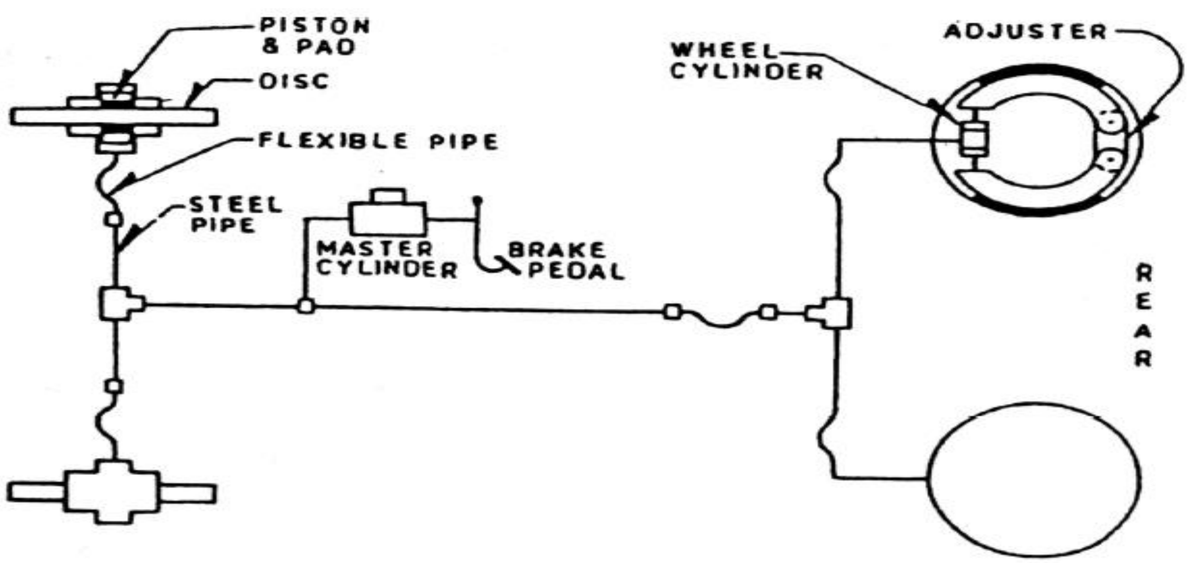


Fig. 10.26. Hydraulic brake system.

- The main component in this is the master cylinder, which contains reservoir for the brake fluid.
- Mater cylinder is operated by the brake pedal and is further connected to the wheel cylinders in each wheel through steel pipe lines, unions and flexible hoses.
- The system is so designed that even when the brakes are in the released position, a small pressure of about 50 kPa is maintained in the pipe lines to ensure that the cups of the wheel cylinder are kept expanded.
- This prevents the air from entering the wheel cylinders when the brakes are released. Besides, this pressure also serves the following purposes:
    - It keeps the free travel of the pedal minimum by opposing the brake shoe retraction springs.
    - During bleeding, it does not allow the fluid pumped into the line to return, thus quickly purging air from the system.

THEORY OF INTERNAL SHOE BRAKE: (calculation of braking torque)

8.3. Theoretical analysis

Let

W_L and W_T = Actuating force for leading and trailing shoe respectively

R = Radius of brake drum

R_f = Effective radius of the friction force P_T or P_L

θ = Angle between the line of action of the friction force and the line joining the centre of the brake drum to the anchor

μ_B = Coefficient of friction between the brake lining and the drum.

P_L and P_T = Normal forces between shoe (lining) and the drum.

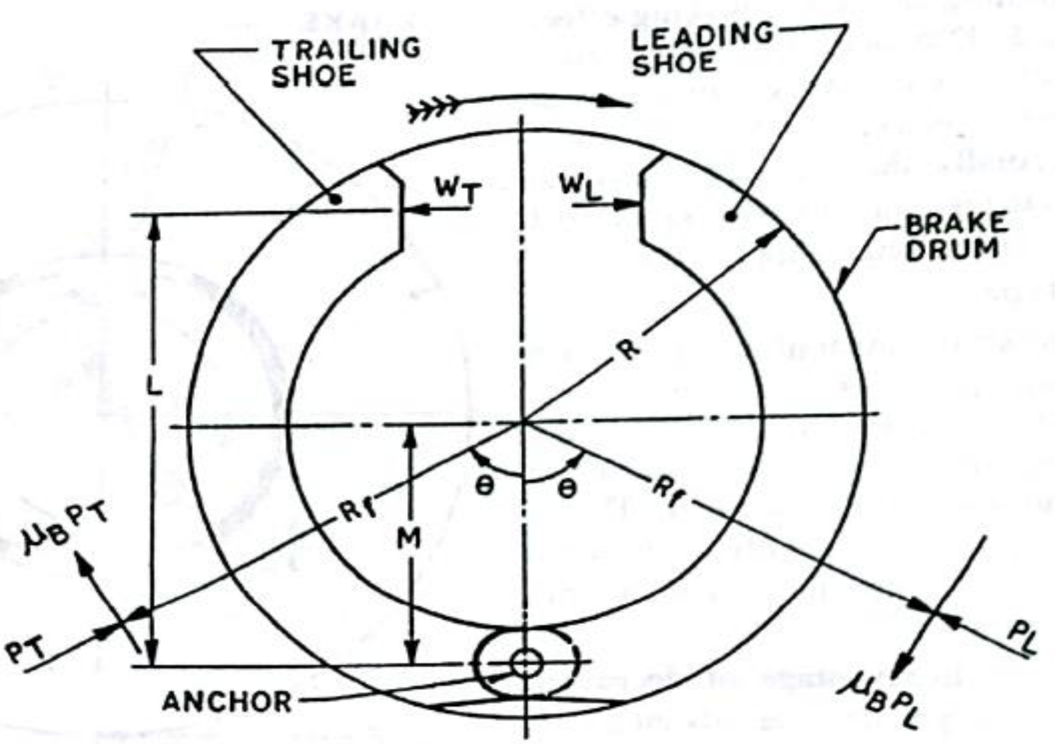


Fig. 10.7. Forces in internally expanding shoe brake.

The magnitudes of P_L and P_T may be calculated by taking moments about the fulcrum (anchor). Considering separately the equilibrium of the leading and the trailing shoes :

For leading shoe,

$$W_L \times L - P_L \cdot M \sin\theta + \mu_B P_L (R_f - M\cos\theta) = 0$$

$$\therefore \quad P_L = \frac{W_L \cdot L}{M\sin\theta - \mu_B (R_f - M\cos\theta)} \quad \text{...(10.18)}$$

$\therefore$ Braking toque,

$$T_L = \mu_B P_L \times R_f$$

$$= \frac{W_L \cdot L \cdot \mu_B \cdot R_f}{M\sin\theta - \mu_B (R_f - M\cos\theta)} \quad \text{...(10.19)}$$

For trailing shoe,

$$W_T \times L - P_T \cdot M\sin\theta - \mu_B P_T (R_f - M\cos\theta)$$

$$\therefore \quad P_T = \frac{W_T \cdot L}{M\sin\theta + \mu_B \cdot (R_f - M\cos\theta)} \quad \text{...(10.20)}$$

Braking torque,

$$T_T = \mu_B P_T \times R_f$$

$$= \frac{W_T \cdot L \cdot M_B R_f}{M\sin\theta + \mu_B (R_f - M\cos\theta)} \quad \text{...(10.21)}$$

If the forces on two shoes are equal,

$$W_L = W_T = W$$

Further if $\theta = 90°$, the equations (10.19) can be simplified as,

$$T_L = \frac{W \cdot L \mu_B \cdot R_f}{M - \mu_B \cdot R_f} \quad \text{...(10.22)}$$

$$T_T = \frac{W \cdot L \mu_B \cdot R_f}{M + \mu_B R_f} \quad \text{...(10.23)}$$

Since denominator in Eq. (10.23) will always be greater than the denominator in Eq. (10.22), T_L will always be greater than T_T.

Example 10.2. The brake drums of an automobile are of 380 mm diameter. The shoes are anchored together 150 mm away from the brake drum centre. The free ends of the two shoes are pushed apart with a force of 320 N which may be considered acting at a distance of 320 mm from the anchor. Assume that the normal pressure on the brake shoes acts at right angles to the line joining the anchor with the brake drum centre and the resultant frictional force acts at a distance of 200 mm from the brake drum centre. Take coefficient of friction between the shoes and the drum as 0.5.

Calculate the braking torque provided by each shoe.

Solution. Referring Fig. 10.7

$$R = 190 \text{ mm}$$
$$M = 150 \text{ mm}$$
$$W_L = W_T = W = 320 \text{ N}$$
$$L = 320 \text{ mm}$$
$$\theta = 90°$$
$$R_f = 200 \text{ mm}$$
$$\mu_B = 0.5$$

From Eq. (10.22) and (10.23),

$$T_L = \frac{W L \mu_B R_f}{M - \mu_B R_f}$$
$$= \frac{320 \times 320 \times 0.5 \times 200}{150 - 0.5 \times 200}$$
$$= 204800 \text{ Nmm}$$
$$= \mathbf{204.8\ Nm}$$
$$T_T = \frac{W L \mu_B R_f}{M + \mu_B R_f}$$
$$= \frac{320 \times 320 \times 0.5 \times 200}{150 + 0.5 \times 200}$$
$$= 40960 \text{ Nmm} = \mathbf{40.96\ Nm}$$

PROPERTIES OF FRICTION LINING AND PAD MATERIALS:

- **Friction level:**
  - In modern friction materials, the average coefficient of friction lies in between 0.3 and 0.5.
  - The coefficient of friction should adequately high so that it can limit brake pedal effort and reduce the expander leverage on commercial vehicle.
  - But, coefficient of friction has some limit. It should not be so high, so that rotation of the drum becomes impossible.
- **Resistance to heat fade:**
  - It is the ability of a material to retain its coefficient of friction even in a very high rubbing temperature.
  - A good quality material should retain its friction level throughout the working temperature range of the drum and shoes or disc and pads.
- **Recovery from fade:**
  - It is a measure of the ability of a friction material to return to its original friction level upon cooling after brake lining or pad temperature fade has taken place.
  - For a good quality material, even after being subjected to repeatedly severe heating, the frictional characteristics will return on cooling.
- **Resistance to wear:**
  - The wear in a lining material is greatly influenced by the working temperature. At higher range of temperature, the lining or pad material structure becomes weak.
  - Therefore, there is an increase in the shear and tear action at the friction interface resulting in a higher wear rate.
- **Resistance to rubbing speed:**
  - The intensity of speed tends to slightly reduce the friction level, specially at the higher operating temperature range.
  - Thus, suitable materials should be selected to get rid of reduction of friction properties due to high speed.
- **Resistance to the intensity of pressure:**
  - By the laws of friction, the coefficient of friction should not be influenced by the pressure holding the rubbing surfaces together.

  - but with some developed friction materials, which are generally compounds held together resin binders, pressure between the rubbing surfaces decreases friction properties
- **Resistance to water contamination:**
  - All friction materials are affected by water contamination to a certain extent. Thus, a safe margin of friction level should be available for wet conditions.
- **Resistance to moisture sensitivity:**
  - Moisture sensitive materials should not be used as friction material on brakes. Because they have high self-energizing characteristics.

BRAKING EFFICIENCY:

- It is defined as the braking force produced as a percentage of the total weight of the vehicle.
- $\text{braking efficiency} = \frac{\text{braking force}}{\text{weight of vehicle}} \times 100$
- The coefficient of friction is defined as the ratio of the frictional force to the normal load between the rubbing surface and it is similar to the brake efficiency.
- $\text{coefficient of friction } (\mu) = \frac{\text{friction force}}{\text{normal load}}$

ANTI-LOCK BRAKING SYSTEM:

- With conventional brake systems one of the road wheels will always tend to lock sooner than the other, due to the continuously varying road grip conditions for all the road wheels.
- An antilock brake system senses individual wheel slippage and automatically controls the brake line pressure rise and fall which counteracts any wheel skid tendency.
- Modern antilock brake systems not only cause the vehicle to stop without deviating from its straight-line path, these also provide directional stability since there is no skidding of the wheels.
- Skidding is avoided by releasing the braking pressure just before the wheels lock up, and then reapplying the same. This releasing and reapplying the brakes in succession is what an antilock system does and this process is called pressure modulation. These systems can modulate the pressure to the brakes about 15 times per second.
- ABS calculate the required slip rate of the wheels accurately based on the vehicle speed and the speed of the wheels and then controls the brake fluid pressure to achieve the target slip rate. Although ABS prevent complete locking of the wheels, in practice it allows some wheel slip in order to attain the best possible braking.
- A modern ABS consists of an electronic control unit (ECU), one sensor on each wheel, an electrically driven hydraulic pump and a pressure accumulator.

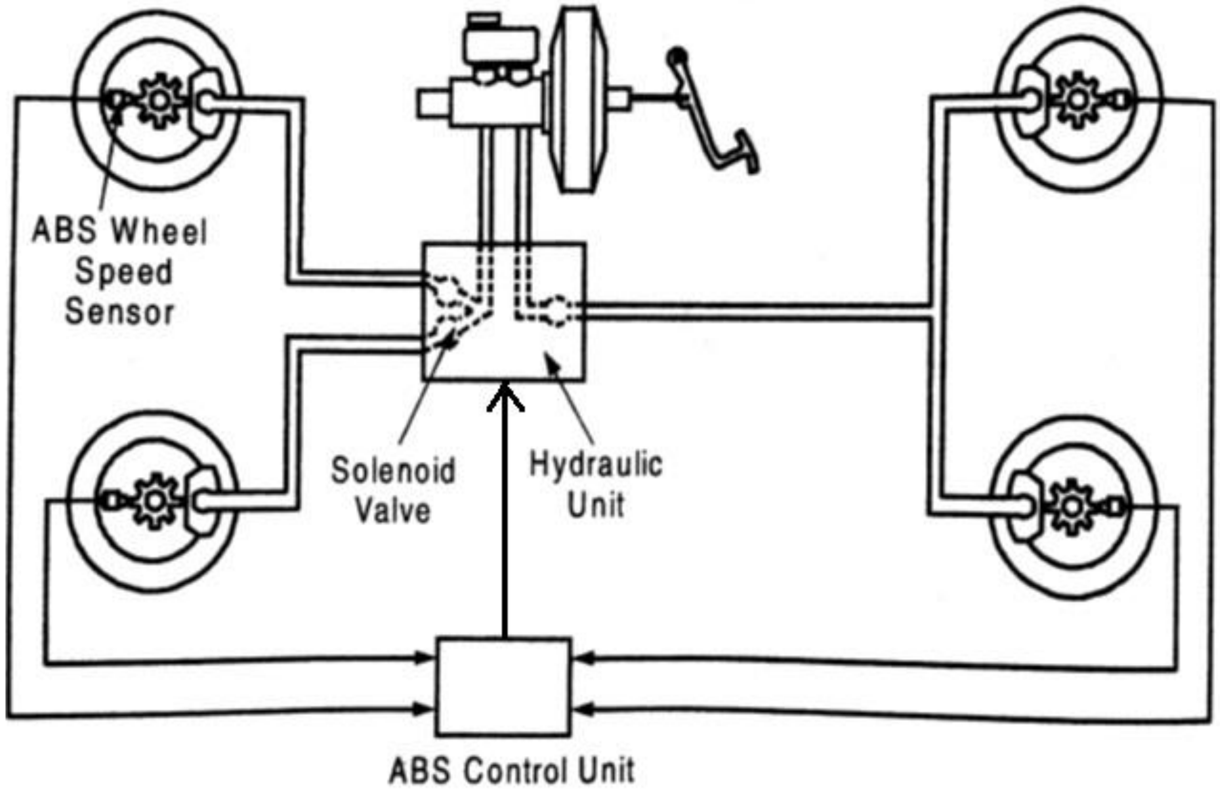


Fig. 5.19. Antilock Braking System

1. **HYDRO-MECHANICAL ANTILOCK BRAKE SYSTEM:**

- This hydro-mechanical antilock braking system has two modular units, each consisting of an integrated flywheel decelerating sensor, cam operated piston type pump and the brake pressure modulator itself.

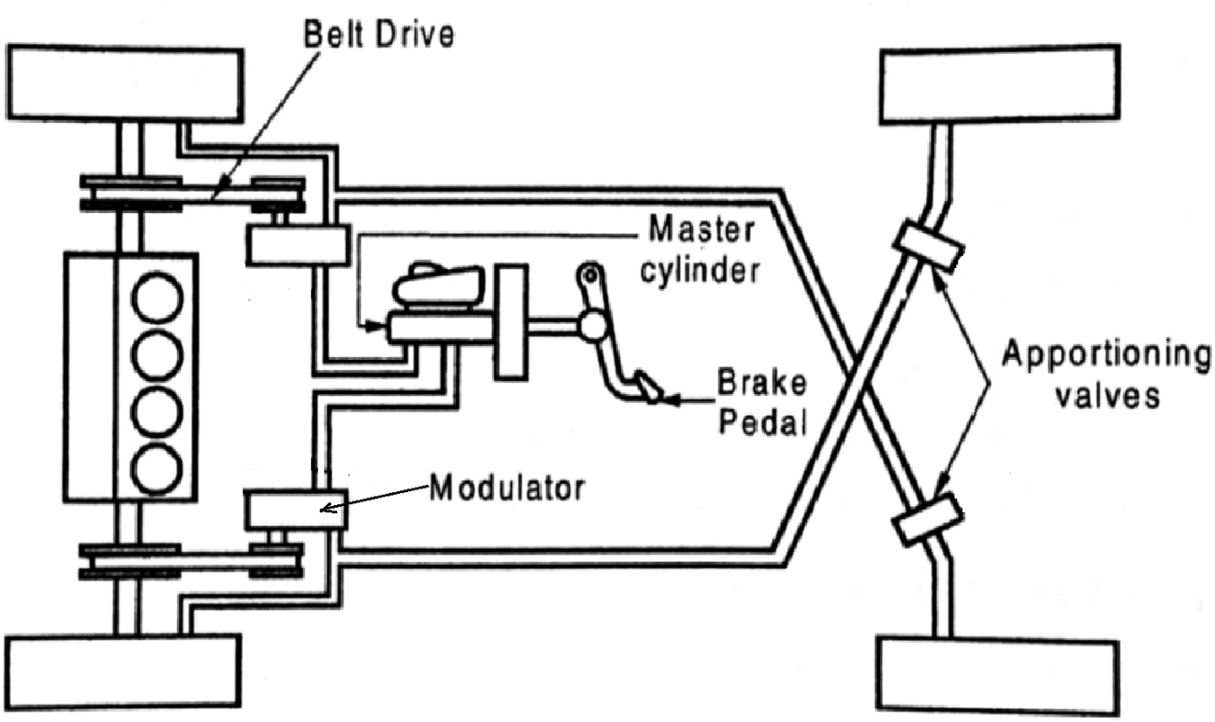


Fig. 5.22 Hydro Mechanical ABS Layout

- Each modulator controls the adjacent wheel brake and the diagonally opposite rear wheel via an apportioning valve.
- The modular flywheel sensor is driven by a toothed belt at 2.8 times the wheel speed. The flywheel sensor determines when the front wheel is approaching a predetermined deceleration.
- In response to this, the modulator reduces the pressure in the respective brake circuits.
- When the wheel speeds up again, the pump raises that pressure in order to bring the braking force back to a maximum level.
- This sequence of pressure reduction and build-up can be up to five times a second to avoid the wheel locking and also to provide the necessary deceleration of the car.

2. <u>HYDRAULIC-ELECTRIC ANTILOCK BRAKE SYSTEM:</u>

- It consists of following parts:
    - ➢ Speed sensor and excitor.
    - ➢ Electronic control unit
    - ➢ Hydro/electric modulator

A. Speed sensor and excitor:

- The speed sensor measures the road wheel speed. It gives the wheel deceleration and wheel acceleration signals for electronic control unit.

B. Electronic control unit:

- The electronic control unit is used to receive, process, compute and energize individual solenoid control valves.
- It is also used to calculate the minimum wheel deceleration and maximum wheel acceleration for optimum braking.

C. Hydro/electric modulator:

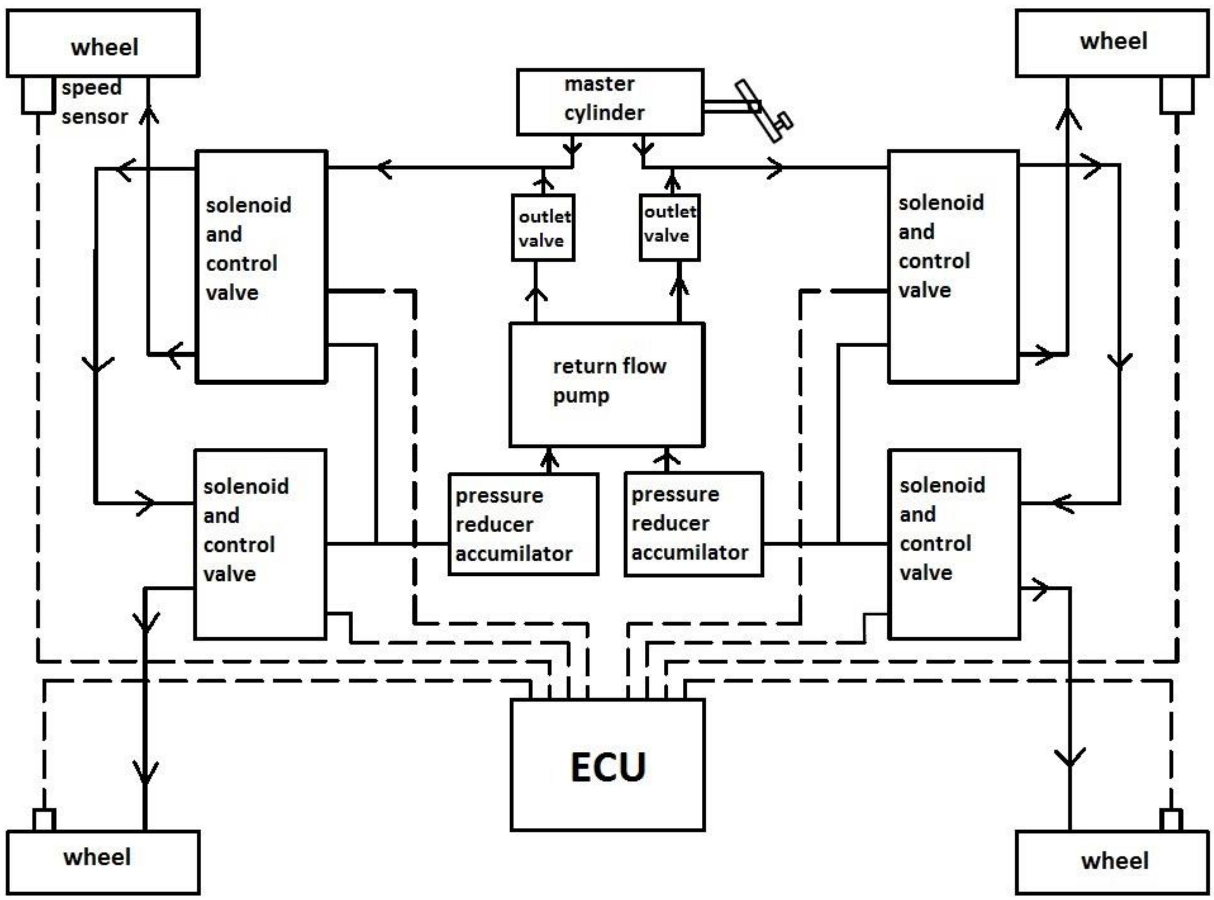
- This unit combines the solenoid control valves; one for each wheel, an accumulator for each of the dual-brake circuits and a return flow pump driven from an electric motor.
- The solenoid valve switches half or fully on and off through the control unit's solid-state circuits, causing the master cylinder to wheel cylinder fluid supply to be interrupted many times per second.
- The reduced pressure accumulator rapidly depressurizes the wheel cylinder pipe line fluid when the solenoid valve opens the return passage, due to the diaphragm chamber space instantly enlarging to absorb the outflow of fluid.
- The return flow pump, transfers fluid under pressure from the reducer accumulator to the master cylinder output leading to the brake cylinders. By these means, the wheel cylinder fluid pressure is matched to the optimum braking severity relative to the condition of the road surface.

Pressure reducing position:

- The wheel sensor signals an abnormally rapid speed reduction likely to cause the wheel to lock, the control unit increases the supply of current to the solenoid coil, causing the valve to lift to a position where it uncovers the return flow passage.

- The line pressure collapses instantly because the highly pressurized fluid is able to escape into the pressure reducer accumulator.

- At the same time as the accumulator is being charged, surplus fluid is drawn from the accumulator into the return flow pump where it is discharged back into the appropriate pressurized master cylinder output pipe line.
- Consequently, the reduction in pressure permits the wheel to accelerate once again and re-establish its grip with the road surface.



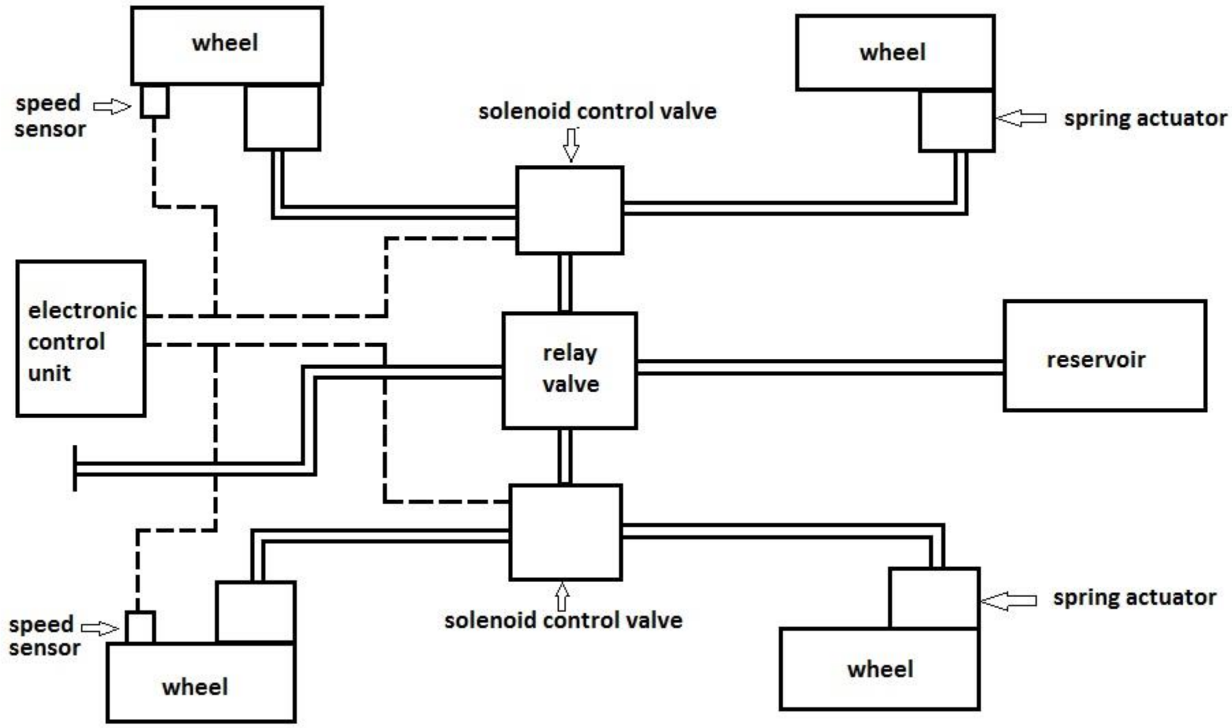
Pressure increasing position:

- Once the wheel rotational movement has changed from a deceleration back to acceleration, the sensor signals to the control unit to switch off the solenoid valve current supply.
- The return spring instantly snaps the solenoid valve into its lowest position and once again the fluid passage between the master cylinder output line and the wheel cylinder line is re-established, causing the brake to be re-applied.
- The sensitivity and response time of the solenoid valve is such that the pulsating regulation takes place four to ten times per second.

3. **<u>AIR - ELECTRIC ABS:</u>**

- The antilock brake system (ABS) consists of wheel sensors and excitors which detect the deceleration and an acceleration of individual wheels.
- Sensors on each wheel continually measure the wheel speed during braking and this information is transmitted to an electronic control unit which senses when any wheel is about to lock.

- Signals are rapidly relayed to solenoid control valve units which quickly adjust the brake airline pressure so that the wheels are braked in the optimum slip range.
- Each wheel is controlled according to the grip available between its tyre and the road. By these means, the vehicle is brought to a halt in the shortest time without losing vehicle stability and steerability.



BRAKE SERVOS:

- If the fore applied by the driver is not sufficient to stop the vehicle then some form of assistance is needed.
- The boosting force applied to improve the driver's effort is called as "Servo assistance".
- In general, the servo assistance is given by either pneumatic (or) hydraulic means.
- Types:

  Vacuum assistance - Medium cars.

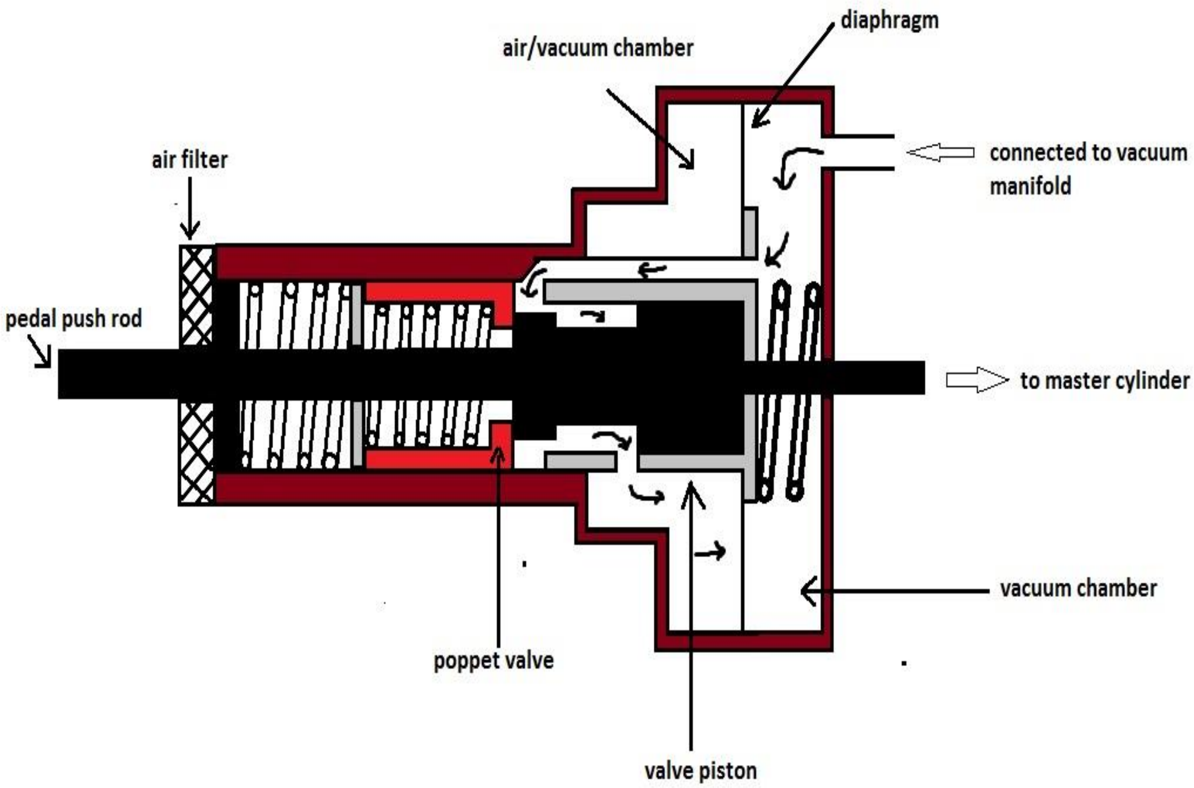
  Hydraulic assistance - Heavy cars.

  Compressed-air assistance - Some light trucks and minibuses.

VACUUM ASSISTED SERVO:

- The vacuum assisted servo system is the most popular system.
- In spark-ignition engine, the induction manifold depression is used as source of servo energy.
- But in case of diesel engine vacuum energy is not available at the manifold. Hence, an engine-driven 'vacuum' pump provides the required assistance.
- The servo assistance should be proportional to pedal effort for light pedal pressure.
- Vacuum servos used in common are called as "suspended vacuum system."
- The two main types of suspended-vacuum servos are the indirect and direct type.

1. **DIRECT ACTING SUSPENDED VACUUM ASSISTED SERVO:**



- When the foot pedal is pushed down the pedal pushrod moves the diaphragm valve piston, pushing the poppet valve.
- At this time, poppet valve closes the opening that connects the air/vacuum chamber with the vacuum chamber.
- The air/vacuum chamber is stopped from the vacuum supply.
- Then atmospheric air is free to pass to air/vacuum chamber through air filter located on pedal push rod side.
- The variation in pressure in between vacuum chamber and the high-pressure air/vacuum chamber makes the power piston and power push rod to move forward against the master cylinder piston.
- Therefore, the fluid pressure is produced in both brake circuits to operate the front and rear brakes.

Vacuum servo operating characteristics:

- The advantages of vacuum servo assistance are shown in the characteristic’s graphs in the Fig.
- Using servo assistance, master cylinder output pressure is increased.
- From this graph, the master cylinder line pressure increases in proportion to pedal push rod effort for manual operation.
- The point where the servo assistance varies from the manual output is noted. This point is called as crack point.

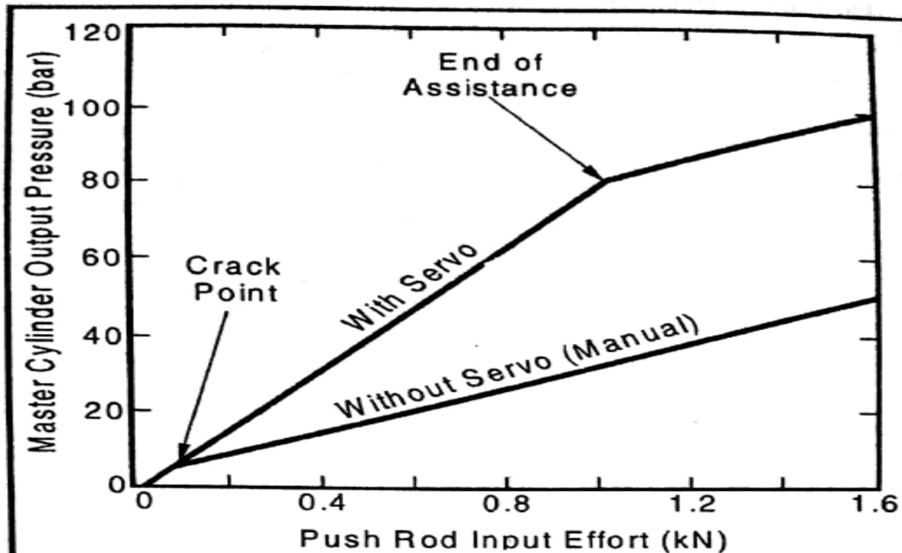


Fig. 5.30 Vacuum Servo Input to Output Characteristics

HYDRAULIC SERVO ASSISTED BRAKE SYSTEMS:

- In this braking, a hydraulic servo is used which operates on a pressure range of 5395 to 8842kPa.
- This system is used to provide a greater source of energy which is necessary to stop a heavy motor or light truck.
- There are two types:
  - Continuous flow system without accumulator.
  - Continuous flow system with accumulator.

Continuous flow system with accumulator:

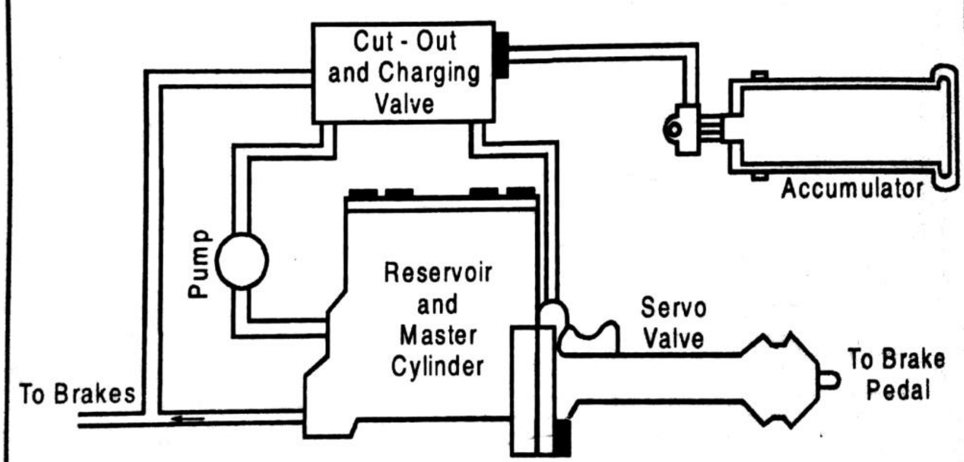


Fig. 5.31 (b) Continuos Flow System with Accumulator

- The accumulator is used to overcome the problem in the first type (i.e. without accumulator).
- Problem: Since the assistance provided by the continuous flow system depends on the pump speed, a hard pedal is felt whenever the pump is stationary or rotating slowly.
- The accumulator has spring-loaded piston which is acted upon by the fluid.

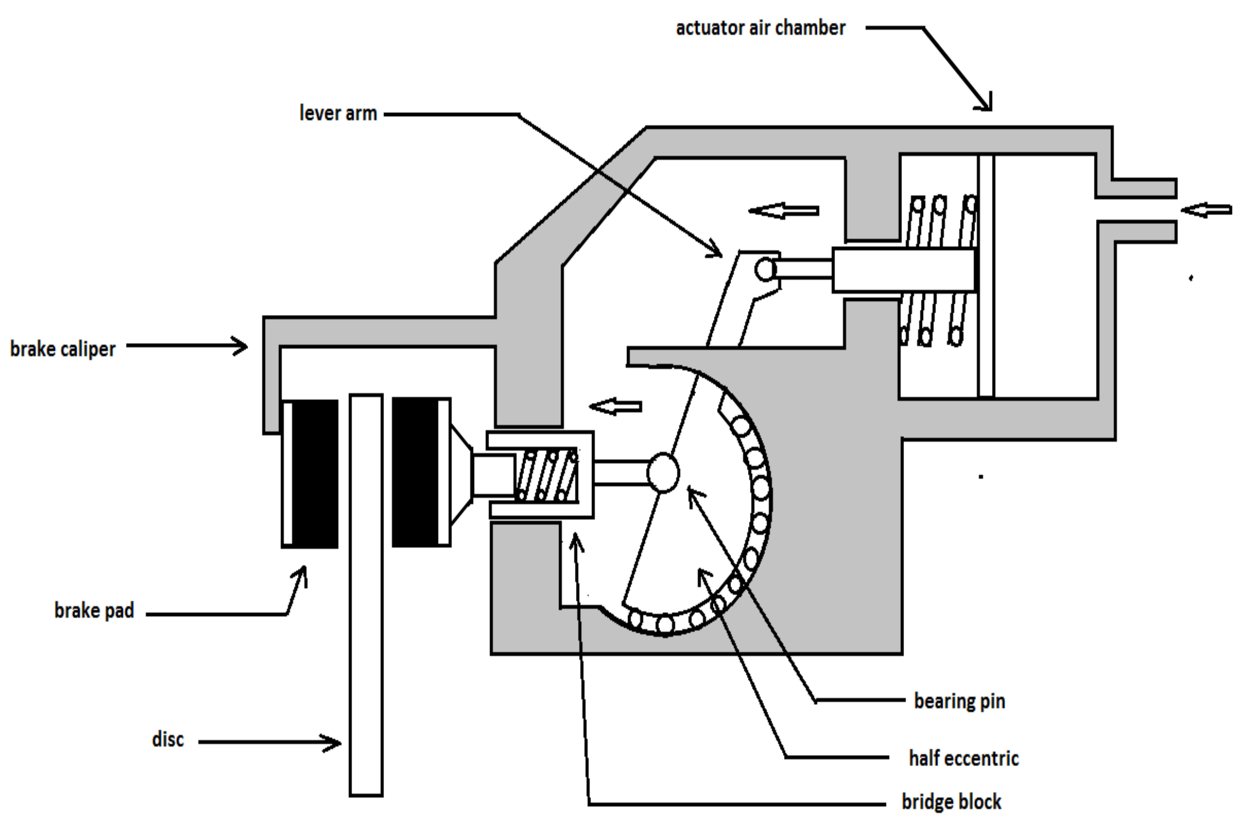
- If the fluid pressure is higher, the spring will be compressed more.
- A cut-out valve is installed to maintain the accumulator pressure in the range of 5395 to 8842 kPa.
- Charging valve supplies fluid from accumulator to act on the servo valve, when the pump fails to supply the required fluid.
- It is necessary to discharge and drain the accumulator before any pan is disconnected from this system.

PNEUMATIC OPERATED DISC BRAKES:

- In heavy duty disc brake arrangement, a floating caliper design is used.
- it does not resort to hydraulic actuation but instead relies on compressed air to provide the power source through a diaphragm operated air chamber actuator.
- Three types of pneumatic operated disc brakes are:
  - ➢ Floating caliper with integral half eccentric lever arm.
  - ➢ Eccentric shaft and lever with gear driven adjustment mechanism.
  - ➢ Half eccentric shaft and lever with gear driven adjustment mechanism.

Floating caliper with integral half eccentric lever arm:

- The actuator chamber diaphragm is pushed by the air pressure to the left-hand side, when the brakes are pressed.
- It also tilts the half eccentric about the roller bearing pin.
- Therefore, the right-hand friction pad is pushed by the eccentric bearing pin towards the disc's right-hand side through the bridge block.



- At the same time, as the right-hand side friction pad bears against the disc's, a reaction force imposes on the caliper.

- Then, this force is transmitted to the opposite friction pad so that both pads firmly press the disc with equal force.

AIR OPERATED BRAKE SYSTEMS:

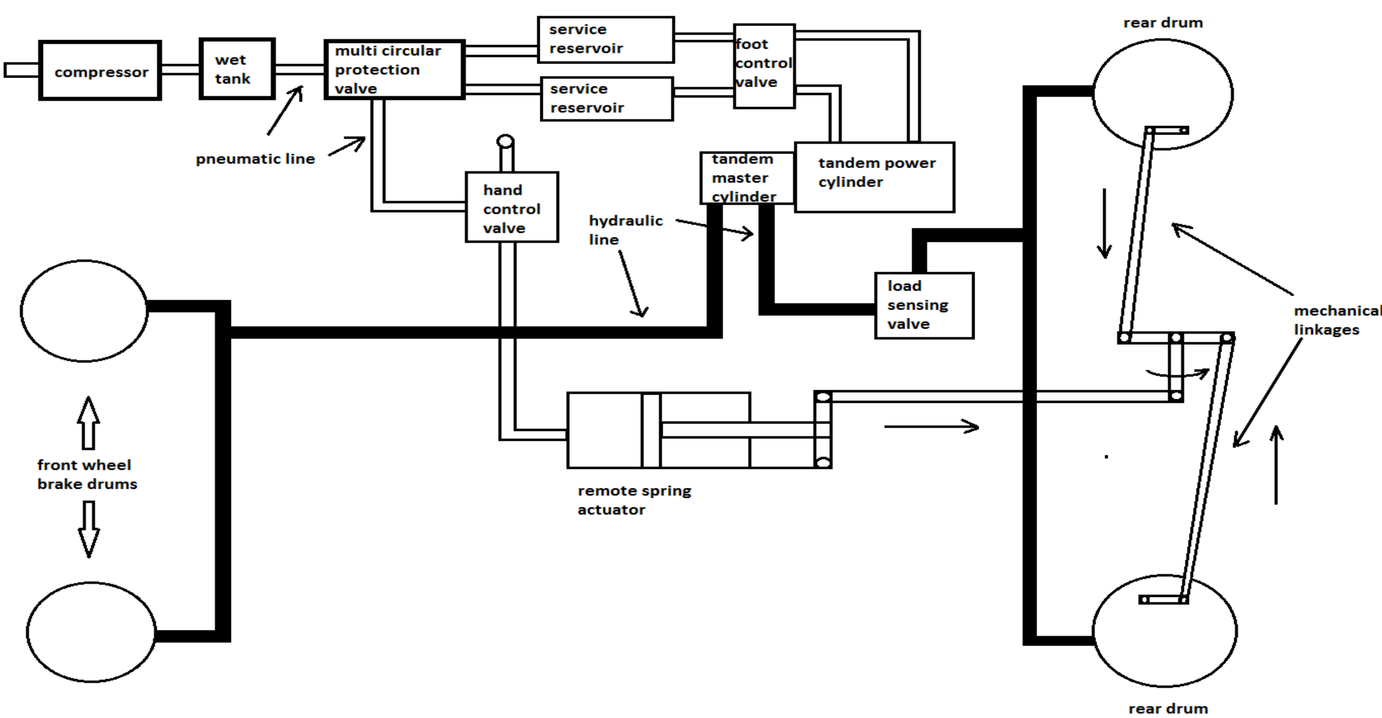
- The manual brakes are not sufficient in case of heavy vehicles due to large size and weight.
- In this situation, power operated brakes are important in heavy vehicles.
- Most of the commercial vehicles (Heavy) are operated using diesel engines.
- They do not have natural vacuum source. Therefore, the vacuum energy is supplied by an engine driven vacuum pump.
- Engine driven reciprocating compressors can function efficiently without any trouble at pressure range of 690 to 785 KPa, but the vacuum assisted brakes can only work at the most up to 88 kPa vacuum.
- Therefore, compressed air transmits a force because it has power factor advantage of between 7 and 8 times over an equivalent vacuum energy source.

TYPES:

- Air over hydraulic brake system (for truck)
- Three-line brake system (for tractor)
- Electronic pneumatic brakes (for train)

1. AIR OVER HYDRAULIC BRAKE SYSTEM: (FOR TRUCK)

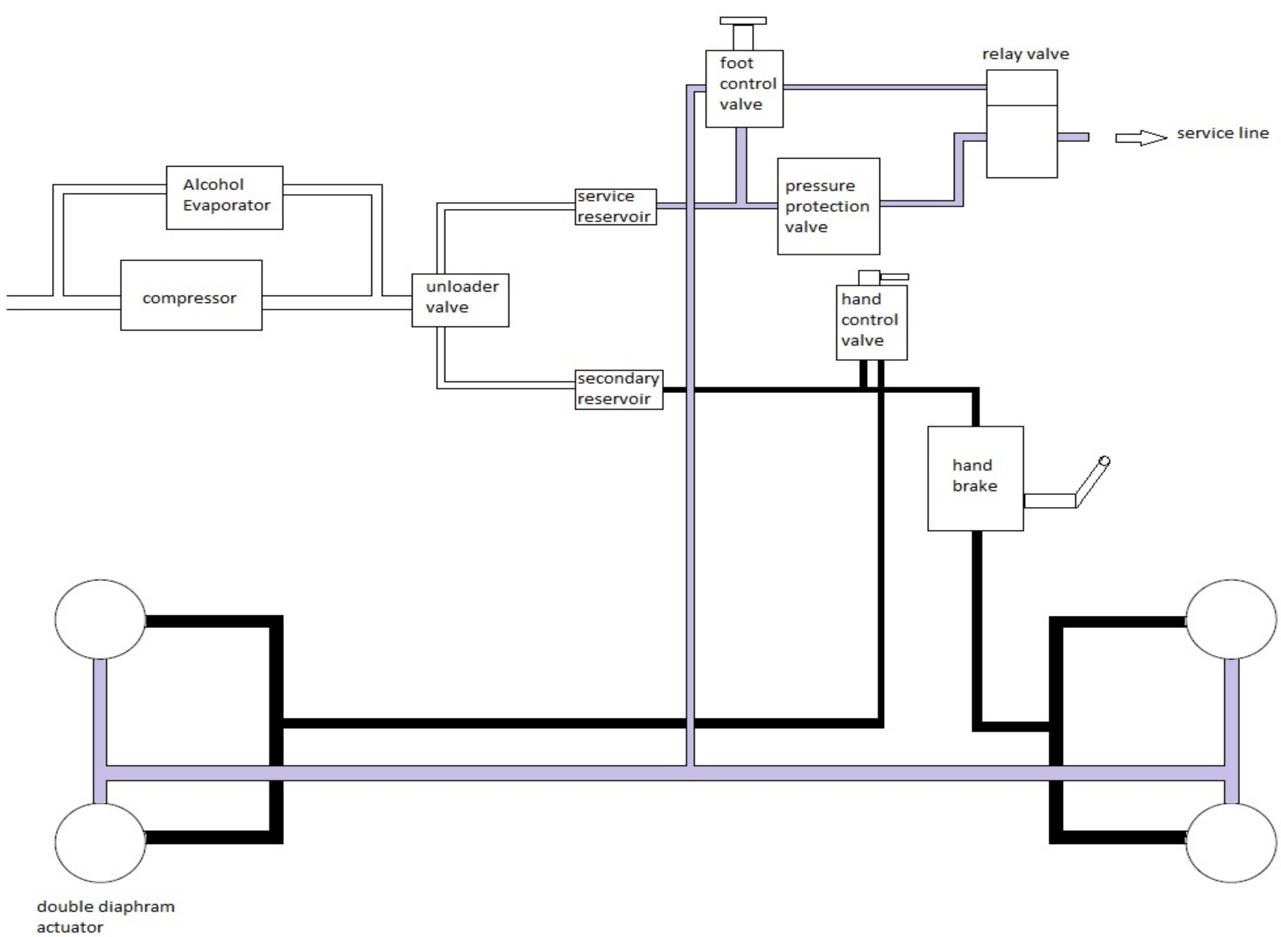
- The air over hydraulic brake system is shown in Fig.
- In semi-dried condition, compressed air (from the compressor) is stored in a wet tank.
- Then it circulates to the multi-circuit protection valve. This also divides the feed to the two service reservoirs.
- The same time, pressurized air (from the reservoirs) joins through the multi circuit protection valve to operate the remote spring brake actuator through the hand control valve.



- Two service lines are linked to a tandem power cylinder. It is controlled by a dual foot valve.
- This arrangement makes to maintain the air supply to the other circuit, [in case of a fault develops in one service line].
- The tandem master cylinder hydraulic piston is pushed forward by the power piston push rod.
- Hence, the air pressure is converted to the hydraulic pressure.
- The hydraulic fluid supply has two circuits to serve the front and rear brake cylinders.
- A hydraulic load sensing valve is fixed in the output circuit of rear axle of the tandem master cylinder.
- This valve appropriately proportions the brake effort provided by the rear axle based on the load carried.
- To park the vehicle, the hand control valve is used.

2. THREE-LINE BRAKE SYSTEM: (FOR TRACTOR)

- In this system, a separate unloader valve is used to control the compressor.
- An alcoholic evaporator is fixed in the air intake. It allows the introduction of alcohol into the air stream during cold weather to lower the freezing point of water.
- Compressed air is carried to both service and secondary reservoirs.
- The air from the service reservoir flows directly to the tractor's front and rear service line chambers. They are located in each of the double diaphragm actuators, mounted on the tractor axles (when the foot pedal is pressed condition).
- At the same time, relay valve piston receives a pressure signal. Therefore, the valve is opened.
- This will make the air to pass from service reservoir to service line.



- The tractor's air supply is protected by both the pressure protection valve in the service storage line and relay valve in the service line (if a loss of pressure occurs).
- The hand control valve is used to deliver a controlled air pressure, from secondary reservoir to front wheel chambers. These chambers form part of the double diaphragm actuators.
- The hand brake valve is opened, when the hand brake lever is operated.
- The pressurized air flows to the rear axle parking line chambers with in the double diaphragm actuators to apply brakes.

3. ELECTRONIC PNEUMATIC BRAKES: (FOR TRAIN)

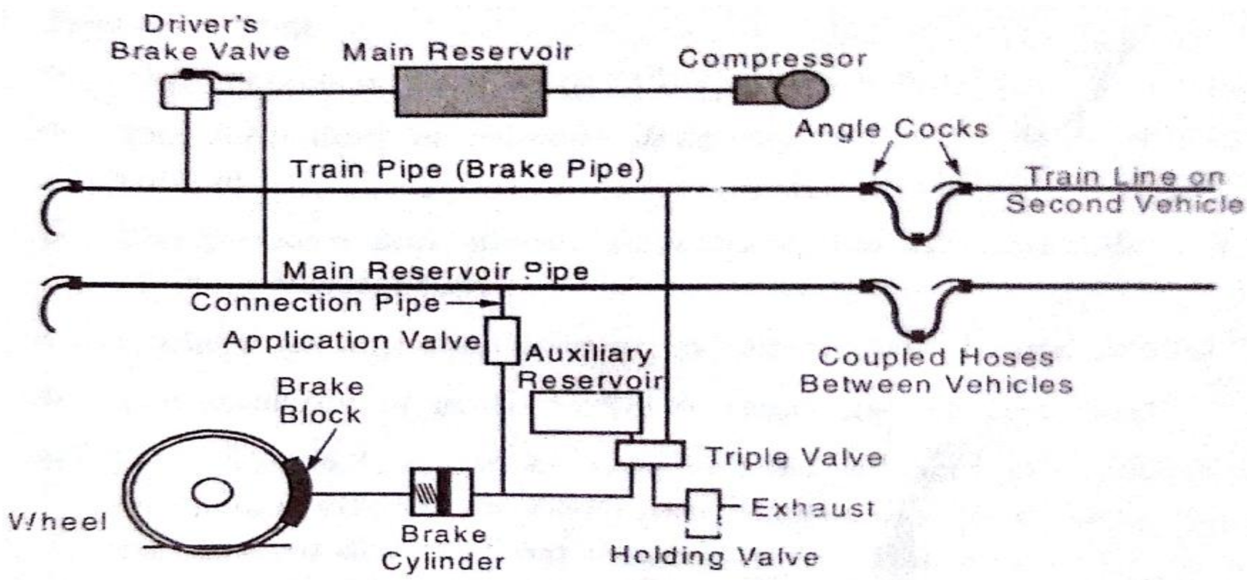


Fig. 5.36 Electronic Pneumatic Brakes (T. ain)

- The electronic pneumatic brake is advanced one. It can be used for quicker operations in railways.
- This brake system can be used on main line passenger railways.
- The advantage of this brake system is its control speed and quick on-vehicle reaction times giving instantaneous control of whole train to the driver.
- The electronic pneumatic brake is used to operate as service brake, while the air brake is kept for emergency use.
- The air brake normally remains in the "release" position while the electronic pneumatic brake is in "application".
- The number of train wires are used in this brake system to control the electrically operated brake valves on each car.
- The train wires used in this system are linked to the brake valve in driver's cab.
- From Figure, a main reservoir pipe is provided along the length of the train. (So that a constant supply of air is available in all cars.)
- A connection pipe is connected between the train reservoir and the brake cylinders on each car.
- An "application valve" in this connection pipe will open when required to allow main reservoir air into the brake cylinders.
- Because the brake pipe is fully charged (during an electronic - pneumatic brake application), the triple valve is kept in release position so that brake cylinder is connected to the exhaust.
- For electronic - pneumatic (e-p) operation, a "holding valve" is connected between triple valve and exhaust.