Parala Maharaja Engineering College

A CONSTITUENT COLLEGE OF B.P.U.T GOVT. OF ODISHA

LABORATARY MANUAL

(PC)Vehicle Dynamics Lab (VD)

Laboratory Location: 1st floor of workshop 2, Room no-

Department of

Automobile Engineering

Parala Maharaja Engineering College, Berhampur

A Government Engineering College affiliated to

Biju Patnaik University of Technology, Odisha, Rourkela, India

ପାରଳା ମହାରାଜା ଯାନ୍ତ୍ରିକ ମହାବିଦ୍ୟାଳୟ, ବ୍ରହ୍ମପୁର

(ସରକାରୀ ଯାନ୍ତ୍ରିକ ମହାବିଦ୍ୟାଳୟ)

SAFETY IN THE LAB

- You are only allowed in the laboratory when there is a 'responsible person' present such as a demonstrator or the laboratory staff.
- Do not touch any equipment or machines kept in the lab unless you are asked to do so.
- A tidy laboratory is generally safer than an untidy one, so make sure that you do not have a confused tangle of electrical cables. Electrical equipment is legally required to be regularly checked, which means it should be safe and reasonably reliable: do not tamper or attempt to repair any electrical equipment (in particular, do not rewire a mains plug or change a fuse - ask one of the laboratory staff to do it). Never switch off the mains using the master switches mounted on the walls. Please make yourself aware of the fire exits when you first come into the lab. When the alarm sounds please leave whatever you are doing and make your way quickly, calmly and quietly out of the lab. You must always follow instructions from your demonstrators and the laboratory staff.
- You must keep walkways clear at all times and in particular coats and bags must be stowed away safely and must not pose a trip hazard.
- It is important that you make a point of reading the "Risk Assessment" sheet included in the manuscript of each experiment before you start work on the experiment.
- Please take notice of any safety information given in your scripts. If an experiment or project requires you to wear PPE (personal protective equipment) such as gloves and safety glasses, then wear them.
- Always enter the lab wearing your shoes. It is strictly prohibited to enter the lab without shoes.
- There must be NO smoking, eating, drinking, use of mobile phones or using personal headphones in the laboratory. This last point is not because we dislike your choice of music but because you must remain aware of all activity around you and be able to hear people trying to warn you of problems.
- Keep the lab neat and clean.

Parala Maharaja Engineering College

A CONSTITUENT COLLEGE OF B.P.U.T GOVT. OF ODISHA

List of experiments

Serial no.	Name of the experiment	Page no.
01	Overhauling of independent suspension system	
02	Overhauling of recirculating ball type steering.	
03	Overhauling of rack and pinion steering gear box.	
04	Overhauling of hydraulic brake.	
05	Numerical Simulation of steering geometry optimization.	
06	Numerical Simulation of suspension’s dimension optimization.	
07	To study the Torsional vibration of single rotor system.	
08	To study the free vibration of two rotor system and determine its natural frequency.	

Experiment-1

Overhauling of independent suspension system

Objective:

- To study the construction and working of an independent suspension system.
- To dismantle, inspect, and reassemble the independent suspension system.

Tools and Equipment:

- Socket wrench set
- Spanners and screwdrivers
- Torque wrench
- Pliers and circlip pliers
- Ball joint separator
- Spring compressor
- Jack and jack stands
- Hammer and mallet
- Measuring tape and Vernier calliper

Types of Independent Suspension Systems:

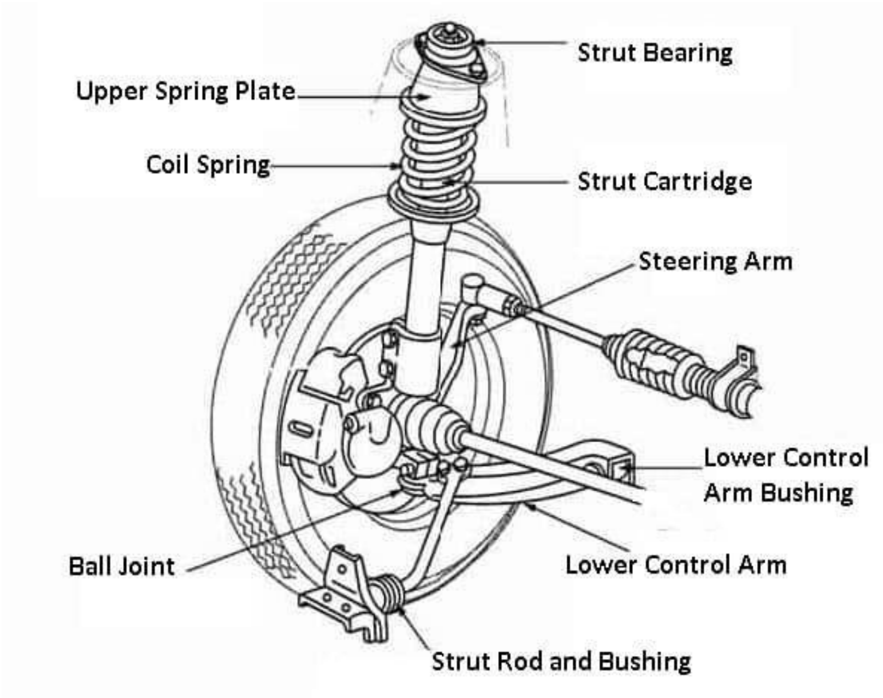
- MacPherson Strut
- Double Wishbone

Components of an Independent Suspension System:

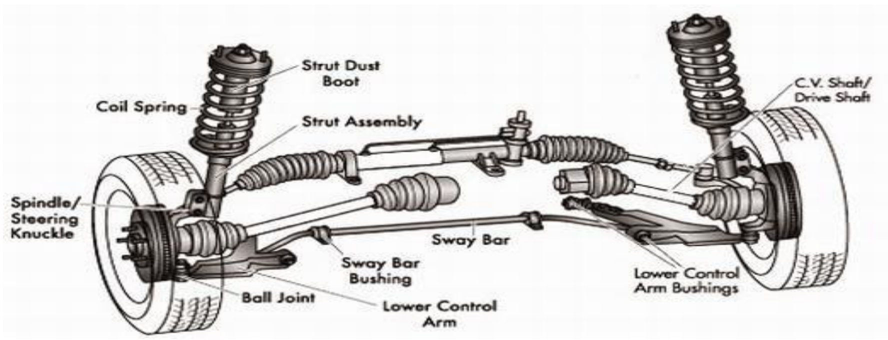
- Control Arms (Upper and Lower)
- Ball Joints
- Coil Springs / Leaf Springs
- Shock Absorbers / Dampers
- Stabilizer Bar (Anti-Roll Bar)
- Knuckles / Steering Arms
- Bushings and Mounts
- Tie Rod Ends (for Steering)
- Wheel Hub Assembly

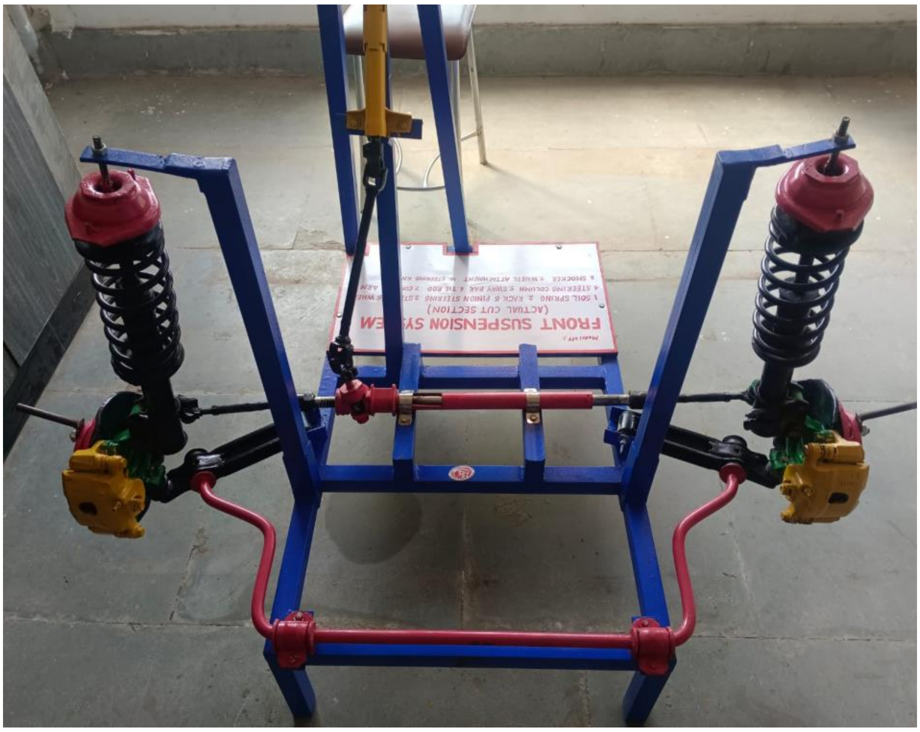
Dismantling Procedure:

1. Preparation:
    - Park the vehicle on a flat surface and engage the parking brake.
    - Lift the vehicle using a jack and secure it with jack stands.



2. Step 1: Remove the Wheel Assembly
    - Loosen and remove the wheel nuts and take off the wheel.
3. Step 2: Disconnect Suspension Components
    - Remove the stabilizer bar links and tie rod ends.
    - Detach the brake calliper and secure it to prevent strain on the brake lines.
4. Step 3: Detach the Shock Absorber and Coil Spring
    - Use a spring compressor to compress the coil spring and remove it safely.
    - Unbolt the shock absorber from the control arms.
5. Step 4: Remove Control Arms and Ball Joints
    - Use a ball joint separator to disconnect ball joints from the knuckle.
    - Remove the control arms from the frame mounts by loosening the bolts.
6. Step 5: Inspect Components
    - Check bushings, control arms, ball joints, and shock absorbers for wear, cracks, or corrosion.





(Front suspension model is located inside vehicle dynamics lab)

Assembly Procedure:

1. Reinstall Control Arms and Ball Joints:
    - Install control arms with new bushings if necessary.
    - Reattach ball joints securely and tighten bolts.
2. Install Shock Absorber and Coil Spring:
    - Use a spring compressor to mount the coil spring.
    - Bolt the shock absorber into place.
3. Reconnect Suspension Components:
    - Attach tie rod ends, stabilizer bar links, and brake caliper.
4. Install the Wheel Assembly:
    - Mount the wheel and tighten lug nuts in a crisscross pattern.
5. Check Alignment and Clearances:
    - Ensure proper alignment of suspension components.
6. Lower the Vehicle:
    - Carefully lower the vehicle and perform a visual inspection.

Precautions:

- Use proper safety gear such as gloves and safety glasses.
- Secure the vehicle with jack stands before working.
- Handle the compressed coil spring carefully to avoid accidents.
- Use proper torque settings during reassembly.
- Ensure all components are free of rust and properly lubricated.

Conclusion:

Experiment-2

Overhauling of recirculating ball type steering

Objective:

- To study the construction and working of the recirculating ball steering system.

Tools and Equipment:

- Spanners and wrenches
- Screwdrivers
- Torque wrench
- Pliers and circlip pliers
- Bearing puller
- Mallet and hammer
- Vernier caliper and micrometer
- Grease and cleaning agents

Overview of the Recirculating Ball Steering System:

Definition:

The recirculating ball steering system is a mechanical steering mechanism commonly used in trucks, SUVs, and heavy vehicles. It uses a worm gear and ball bearings to reduce friction and transfer steering input to the wheels smoothly.

Working Principle:

- When the steering wheel is turned, the worm gear rotates.
- Ball bearings circulate between the worm gear and the nut, reducing friction.
- The nut moves along the worm gear, causing the pitman arm to rotate, which turns the wheels.

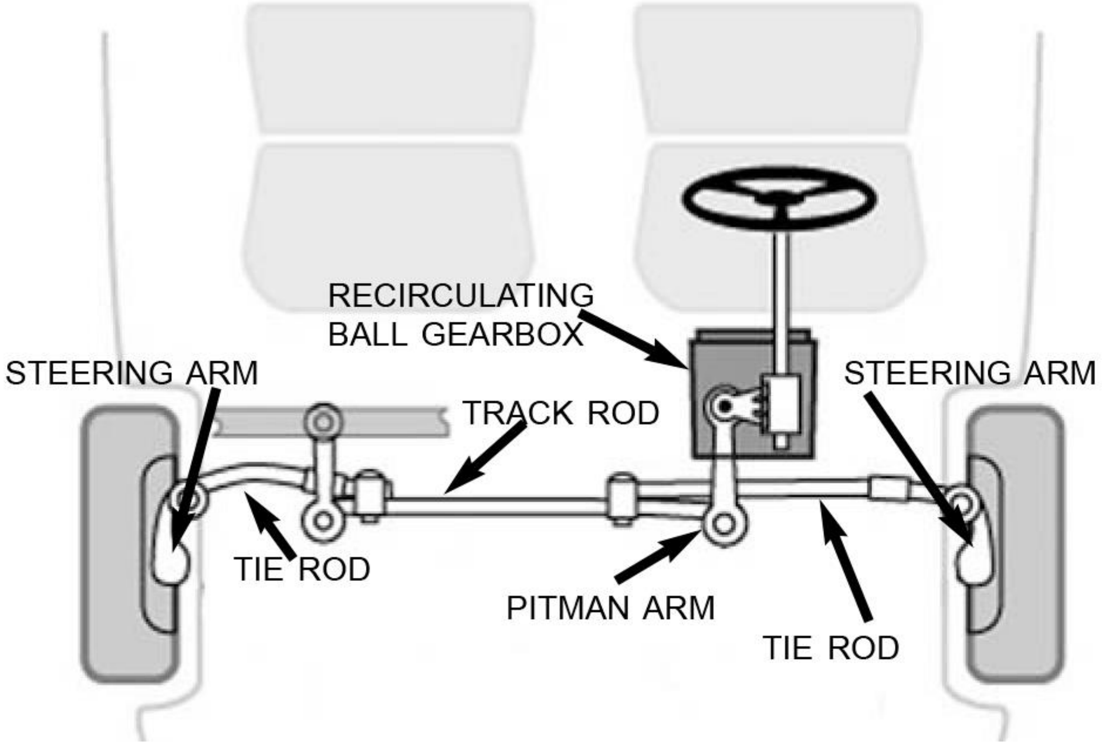
Components of the Recirculating Ball Steering System:

1. Steering Wheel
2. Steering Shaft
3. Worm Gear (Input Shaft)
4. Ball Nut Assembly
5. Recirculating Balls
6. Pitman Arm Shaft (Sector Shaft)
7. Sector Gear
8. Bearings and Bushings
9. Seals and Gaskets
10. Housing (Steering Box Casing)

(A model of recirculating ball type steering system located in vehicle dynamics lab)

Dismantling Procedure:

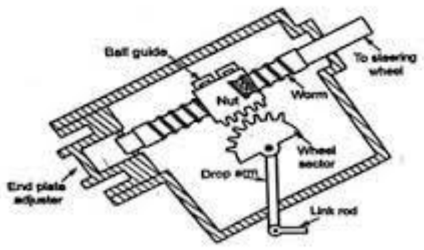
1. Preparation:
    - Mount the steering gearbox securely on a workbench.
    - Clean the outer surface of the steering box.
2. Step 1: Remove the Steering Shaft and Nut
    - Loosen and remove the steering shaft from the steering gearbox.
    - Remove the retaining nut on the shaft.
3. Step 2: Open the Steering Box Cover
    - Remove the bolts on the steering box cover.
    - Carefully lift the cover to expose internal components.
4. Step 3: Extract the Worm Gear and Ball Nut Assembly
    - Turn the input shaft to move the worm gear and ball nut outward.
    - Extract the recirculating balls carefully.
5. Step 4: Remove the Sector Shaft and Pitman Arm
    - Use a puller to remove the pitman arm from the sector shaft.
    - Pull out the sector shaft after loosening retaining bolts.
6. Step 5: Inspect Components
    - Check the worm gear and ball nut for wear or damage.
    - Inspect bearings, seals, and bushings.
    - Check the recirculating balls for smooth operation and any deformation.



Assembly Procedure:

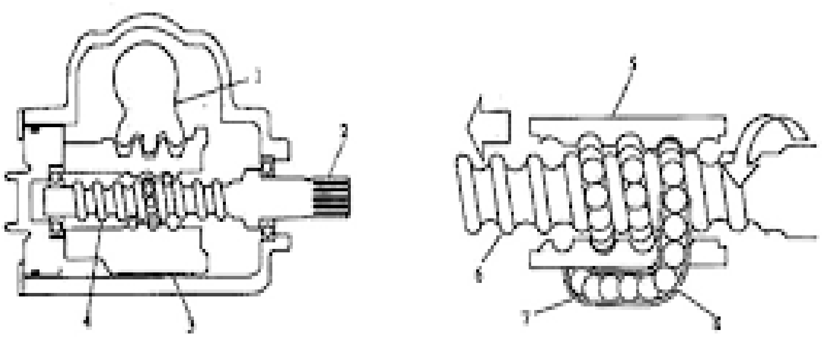
1. Reinstall the Worm Gear and Ball Nut:
   - Place new or cleaned recirculating balls in the ball nut.
   - Insert the worm gear and secure it properly.
2. Install the Sector Shaft and Pitman Arm:
   - Align the sector shaft with the worm gear correctly.
   - Attach the pitman arm and tighten with a torque wrench.
3. Reattach the Steering Box Cover:
   - Install new gaskets and seals if needed.
   - Reattach the steering box cover and tighten bolts.
4. Install the Steering Shaft:
   - Reconnect the steering shaft and input shaft.
   - Ensure proper alignment and smooth rotation.
5. Final Checks:
   - Apply grease to all moving parts.
   - Manually rotate the shaft to ensure smooth and free movement.

Recirculating Ball Type Steering Gear Box



Observation table

Component	Condition (Good/Replace)	Observation
Steering Shaft		
Worm Gear		
Ball Nut Assembly		
Recirculating Balls		
Pitman Arm and Sector Shaft		
Bearings and Bushings		
Seals and Gaskets		



Recirculating ball - rack and pinion fan steering rack

1—Tooth fan shaft 2— Steering Shaft 3、5— Steering nut (recirculating ball nut)
4、6—Steering screw 7— Steel Ball Conduit 8— Steel balls

Conclusion:

Experiment-3

Overhauling of rack and pinion steering gear box

Objective:

- To study the construction and working of a rack and pinion steering gearbox.
- To dismantle, inspect, and reassemble the steering gearbox.

Tools and Equipment:

- Spanners and wrenches
- Socket set and ratchet
- Screwdrivers (flat and Phillips)
- Torque wrench
- Pliers and circlip pliers
- Hammer and mallet
- Bearing puller
- Vernier caliper and micrometer
- Grease, cleaning agents, and new seals (if needed)

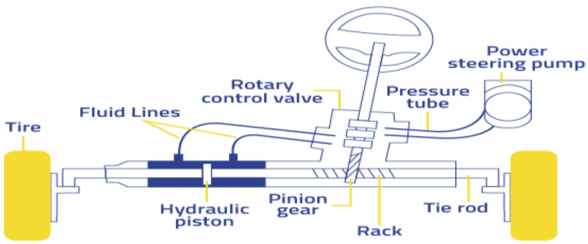
Overview of the Rack and Pinion Steering Gearbox:

Definition:

The rack and pinion steering system is a common mechanical steering mechanism used in most cars. It converts the rotational movement of the steering wheel into linear motion to turn the vehicle's wheels.

Working Principle:

- When the steering wheel is turned, the pinion gear rotates.
- The rotating pinion moves the rack gear left or right, steering the wheels.
- The system may include power-assisted hydraulic or electric components.



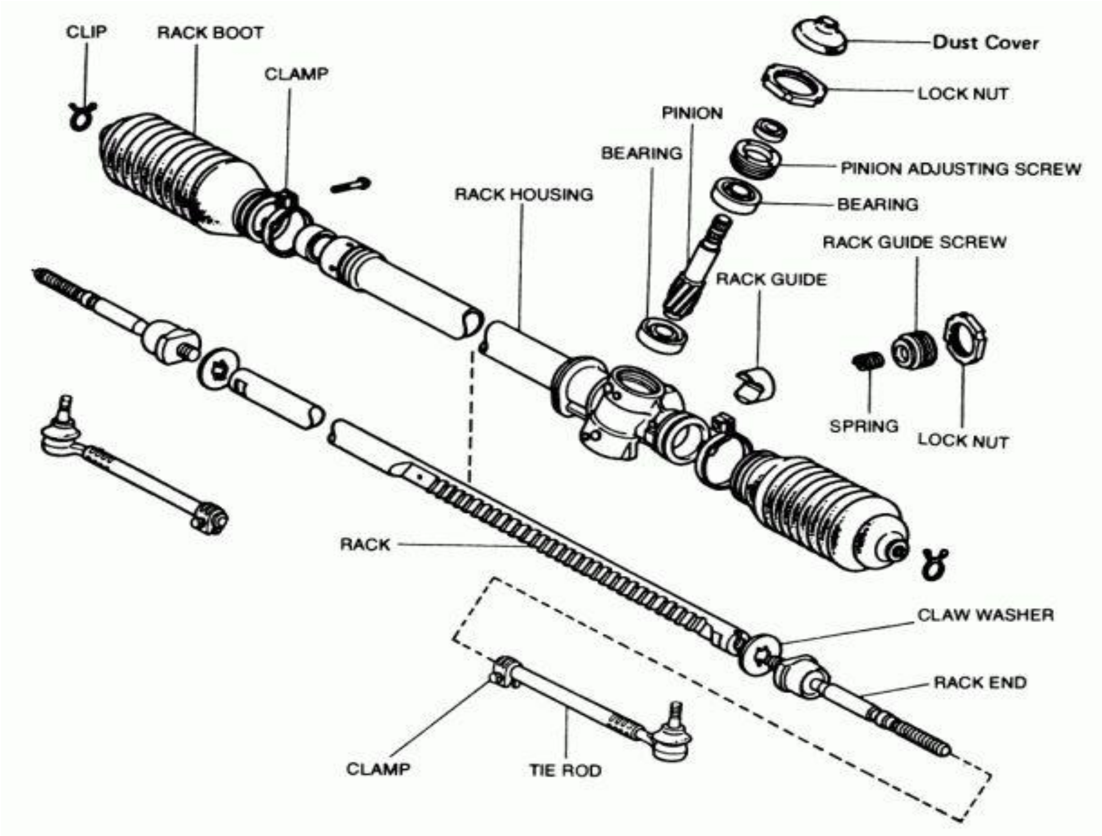
Components of the Rack and Pinion Steering Gearbox:

1. Steering Shaft (Input Shaft)
2. Pinion Gear
3. Rack Gear
4. Tie Rod Ends (Inner and Outer)
5. Rack Housing (Gearbox Casing)
6. Seals and Bushings
7. Steering Gear Boots (Dust Covers)
8. Bearings and Support Rings

(A model of rack and pinion steering system located in vehicle dynamics lab)

Working function:

The recirculating-ball steering gear contains a worm gear. You can image the gear in two parts. The first part is a block of metal with a threaded hole in it. This block has gear teeth cut into the outside of it, which engage a gear that moves the pitman arm. The steering wheel connects to a threaded rod, similar to a bolt, that sticks into the hole in the block. When the steering wheel turns, it turns the bolt. Instead of twisting further into the block the way a regular bolt would, this bolt is held fixed so that when it spins, it moves the block, which moves the gear that turns the wheels.



Dismantling Procedure:

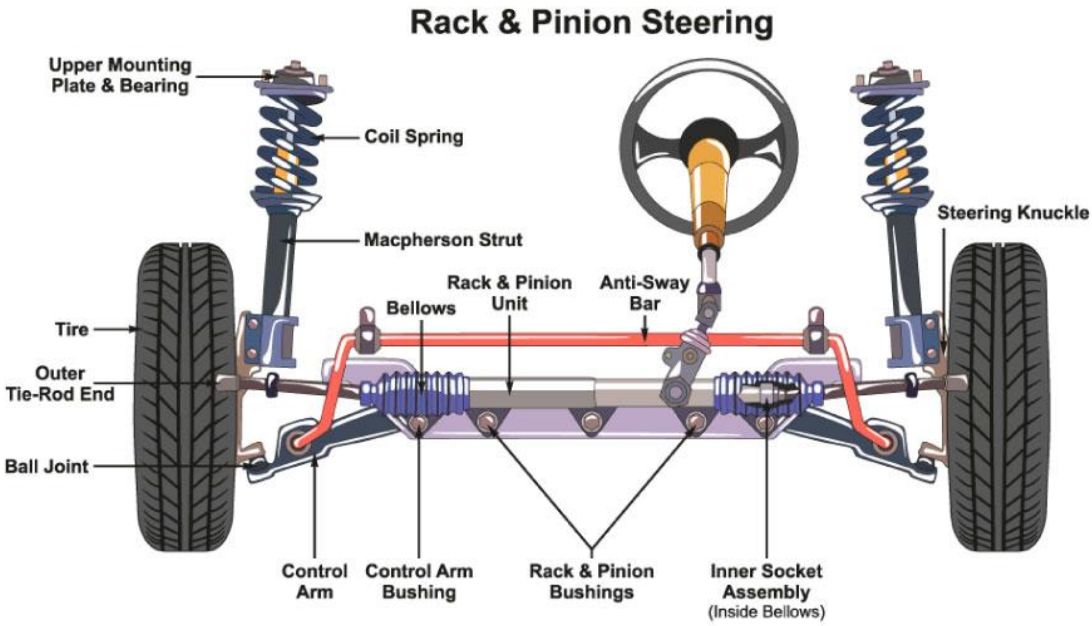
1. Preparation:
   - Secure the rack and pinion assembly on a workbench.
   - Clean the outer surface of the gearbox using a cleaning agent.
2. Step 1: Remove the Tie Rod Ends
   - Loosen and remove the inner and outer tie rods using a wrench.
3. Step 2: Open the Steering Gear Boots (Dust Covers)
   - Remove the clamps and slide off the dust covers to expose the inner components.
4. Step 3: Extract the Pinion Gear
   - Remove the locknut or retaining bolt from the input shaft.
   - Pull out the pinion gear using a bearing puller if necessary.
5. Step 4: Remove the Rack Gear
   - Slide the rack gear out of the housing carefully.
6. Step 5: Inspect Components
   - Check for wear, damage, or corrosion on the pinion gear and rack teeth.
   - Inspect seals, bushings, and bearings for cracks or wear.

Assembly Procedure:

1. Reassemble the Rack Gear:
    - Grease the rack gear teeth thoroughly.
    - Slide the rack gear back into the housing.
2. Install the Pinion Gear:
    - Apply grease to the pinion gear and insert it into the gearbox.
    - Secure the pinion gear with the locknut or retaining bolt.
3. Install New Seals, Bushings, and Bearings:
    - Replace worn-out seals and bushings with new ones.
4. Reattach the Steering Gear Boots:
    - Slide the dust covers back into place and secure them with clamps.
5. Reinstall Tie Rod Ends:
    - Connect the inner and outer tie rods and tighten them securely.
6. Final Checks:
    - Ensure smooth movement of the rack and pinion assembly.
    - Adjust tie rod length for proper alignment if required.

Precautions:

- Use appropriate tools for each step.
- Keep the working area clean and organized.
- Avoid damaging the rack gear teeth and pinion gear during removal.
- Use recommended lubricants and greases.
- Replace all damaged components, seals, and gaskets as needed.



Observation table:

Component	Condition (Good/Replace)	Observation
Rack Gear		
Pinion Gear		
Bearings and Bushings		
Seals and Gaskets		
Tie Rod Ends		
Steering Gear Boots		

Conclusion:

Experiment-4

Overhauling of hydraulic brake

Aim of the experiment: To study the working function of hydraulic brake with its advantages and limitation.

Apparatus required: A model of hydraulic braking system.

Theory:

Function of brake-

There are two distinct functions of the brake:

1. To stop or slow down the vehicle in the shortest possible distances in emergencies.

2. To control the vehicle to be retained when descending a hill.

Classification of brake-

From construction point of view

(a) Drum brakes

(b) Disc brakes

By method of actuation

(a) Mechanical brakes

(b) Hydraulic brakes

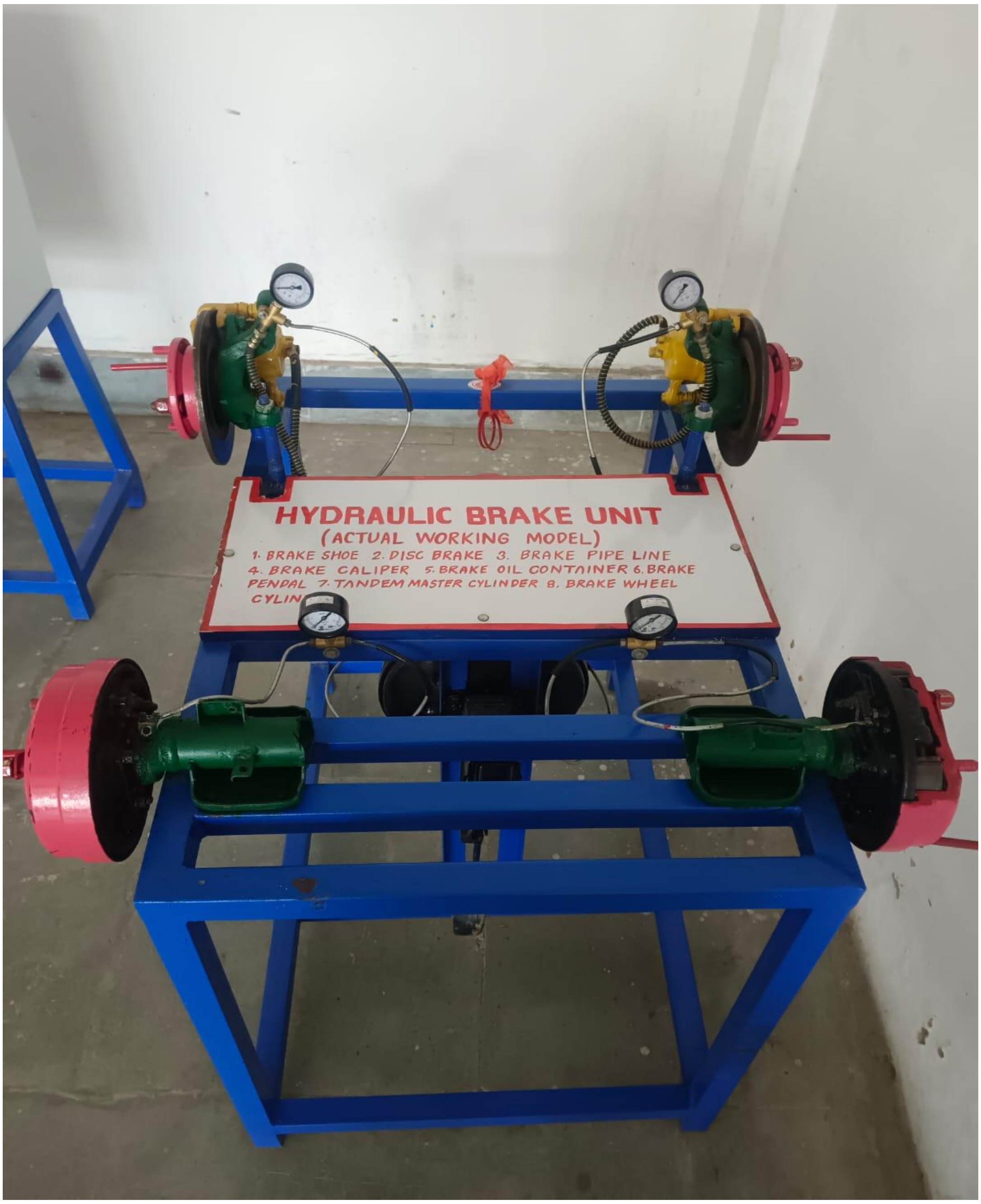
(c) Electric brakes

(d) Vacuum brakes

(e) Air brakes

Working function of hydraulic braking system-

These types of brakes consist of master cylinder, which contains hydraulic brake fluid. Master cylinder is operated by the brake pedal and is further connected to the wheel cylinder in each wheel through pipelines, unions and flexible lines. The system is so designed that even when the brakes are in the released position, a small pressure of about 50kpa is maintained in the pipelines to ensure that the cups of the wheel cylinder are kept expanded. This prevents the air entering the wheel cylinders when the brakes are released. Besides this pressure also serves the following purposes:



(A working model of hydraulic braking system located in dynamics lab)

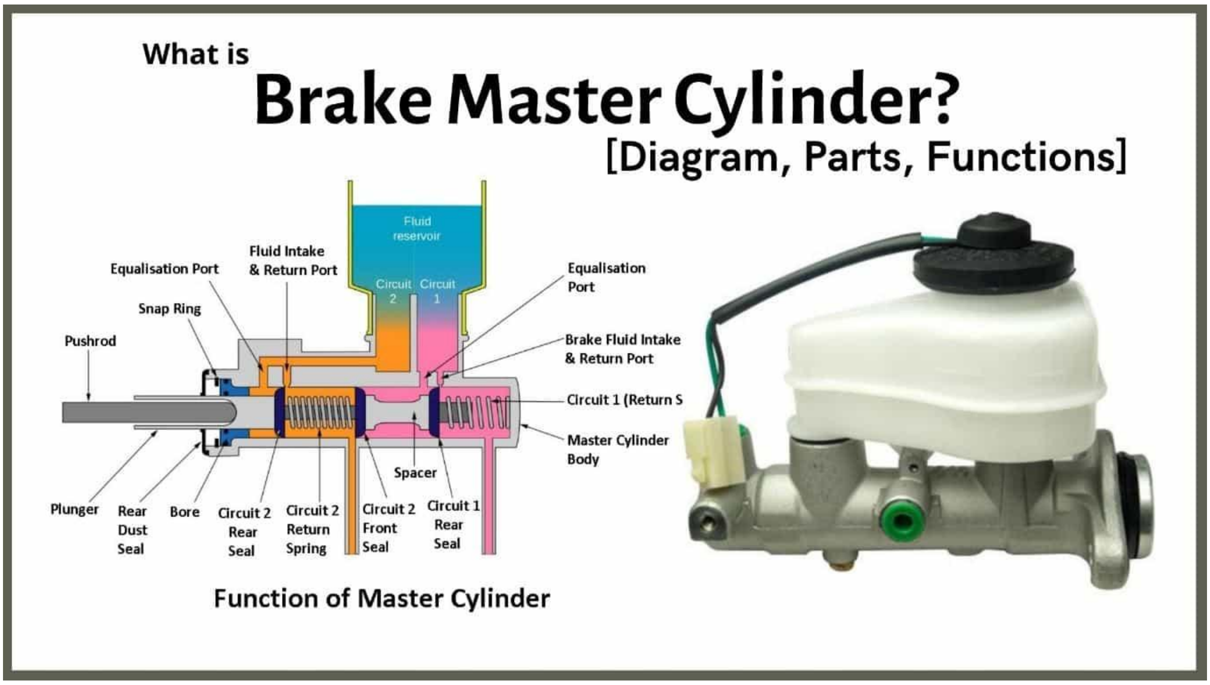
1. It keeps the free travel of the pedal minimum by opposing the brake shoe retraction springs.

2. During bleeding, it does not allow the fluid pumped into the line to return, thus quickly purging air from the system.

Master cylinder-

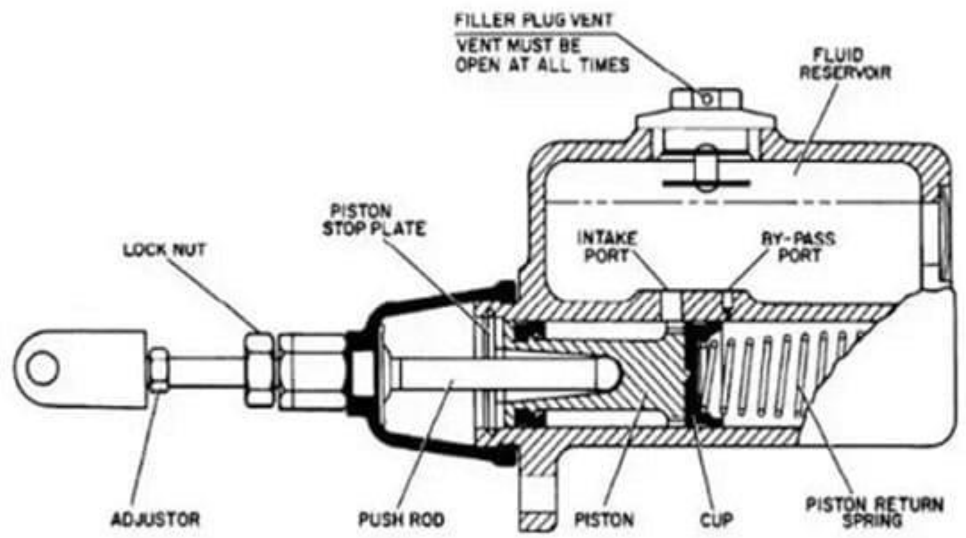
It consists of fluid reservoir and compression chamber in which piston operates. The fluid in the reservoir compensates for any change in the fluid volume in the pipelines due to temperature variations and to some extent due to leakage. To prevent leakage there are rubber seals on both sides of the piston in the compression chamber. The fluid always surrounds the reduced diameter region of the piston. A rubber boot covers the push rod and of the master cylinder to prevent the dirt entering inside. Towards the brake lines side of the compression chamber, there is fluid check valve with a rubber cup inside. It serves to retain the residual pressure in the brake lines even when the brakes released.

There are a number of holes in the piston head on the primary (high pressure) seal side. Two holes connect at the reservoir to the compression chamber. The smaller one out of these is about 0.7 mm diameter and is called the bypass or compression port. The second hole is called the intake or recuperation port. Besides, there is a vent in the cap, to keep the brake fluid always at atmospheric pressure.



The push rod is operated with the foot brake pedal through the linkage. As the pedal is pressed, push rod moves against the force of the spring, till it covers the bypass port. Further movement of the push rod causes building up of pressure in the compression chamber. Finally, when sufficient pressure has built up, the inner rubber cup of the fluid check valve is deflected, forcing the fluid under pressure in the lines. This fluid enters the wheel cylinder or the calliper and moves the pistons thereby applying the brakes. When the brakes are released, the spring pressure in the master cylinder moves the piston to the right extreme position. This same force of the spring keeps the fluid check valve pressed on its seat for some time and thereby delays the return of fluid from the lines into the compression chamber again.

Some delay is also caused by the inertia of the fluid in the lines. This produces a vacuum in the compression chamber and unless this is destroyed immediately, there are all chances of air leakage into the system. Even a very small amount of air will render the brakes unless, the air being compressible. Having intake port as shown in figure solves this problem. As soon as some vacuum is formed, the atmospheric pressure in the fluid reservoir forces the fluid through intake port and holes in the piston, which deflects the rubber, cup and enters the compression chamber, destroying the vacuum.



Dismantling Procedure:

1. Preparation:
   - Secure the vehicle on a lift or jack stands.
   - Remove the wheels using a lug wrench.
2. Step 1: Drain the Brake Fluid
   - Open the brake fluid reservoir cap.
   - Use a brake bleeder kit to drain fluid from the system.
3. Step 2: Remove Brake Calipers (Disc Brakes)
   - Remove the caliper mounting bolts using a socket wrench.
   - Slide the caliper off the rotor and suspend it with a wire to prevent strain on the brake hose.
4. Step 3: Remove Brake Pads and Rotors
   - Remove the brake pads from the caliper bracket.
   - Remove the brake rotor from the wheel hub (use a mallet if stuck).
5. Step 4: Dismantle Drum Brake Assembly (if applicable)
   - Remove the drum by sliding it off the hub.
   - Disconnect the brake shoes, springs, and wheel cylinder.
6. Step 5: Dismantle the Master Cylinder
   - Disconnect brake lines from the master cylinder.

- Remove the master cylinder from the brake booster.

7. Step 6: Inspect Components
    - Inspect brake pads, shoes, rotors, and drums for wear.
    - Check calipers, wheel cylinders, and master cylinder for leaks or damage.
    - Inspect hoses and brake lines for cracks and corrosion.

Assembly Procedure:

1. Reinstall the Master Cylinder:
    - Mount the master cylinder to the brake booster.
    - Reconnect brake lines securely.
2. Assemble Drum Brake Components:
    - Attach brake shoes, springs, and adjusters.
    - Install the wheel cylinder and secure it.
    - Slide the brake drum back into place.
3. Reinstall Brake Calipers and Pads (Disc Brakes):
    - Apply brake grease to the back of the pads and mounting points.
    - Insert brake pads into the caliper bracket.
    - Reattach the brake caliper and tighten mounting bolts.
4. Install Rotors and Wheels:
    - Reinstall brake rotors on the wheel hub.
    - Reattach the wheels and tighten lug nuts in a crisscross pattern.
5. Refill and Bleed the Brake System:
    - Refill the brake fluid reservoir with fresh brake fluid.
    - Bleed the brake system using a brake bleeder kit to remove air bubbles.
6. Final Checks:
    - Ensure there are no fluid leaks.
    - Press the brake pedal to check for firmness and responsiveness.
    - Test drive the vehicle carefully.

Conclusion:

Experiment-5

Numerical Simulation of steering geometry optimization

Objective:

- To study and simulate the steering geometry parameters using numerical methods.
- To optimize steering geometry for improved vehicle handling and stability.

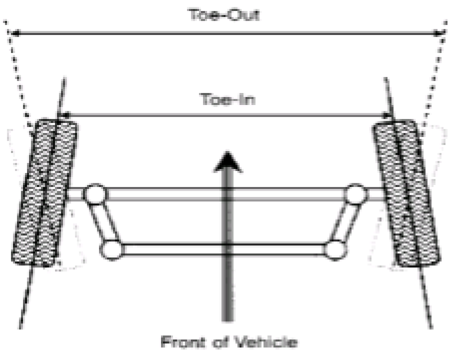
Tools and Software Required:

- Solidwork/ANSYS

Definition:

Steering geometry refers to the alignment and arrangement of the suspension and steering components that affect vehicle handling, stability, and tire wear. Numerical simulation helps optimize these parameters for better performance.

Steering geometry is known as the value of the lengths and angles inside a steering system, as well as their geometric arrangement. It describes the angle that exists between the front wheels, any components that are mounted to them, and the vehicle's structure. A steering geometry that is properly adjusted provides predictable and secure vehicle handling, maximizes fuel efficiency, and minimizes tire wear.



Toe-in & Toe-out

Key Steering Geometry Parameters:

1. Toe Angle:
   - Toe-In: Front of the tires points inward.
   - Toe-Out: Front of the tires points outward.
2. Camber Angle:
   - Negative Camber: Top of the tires leans inward.
   - Positive Camber: Top of the tires leans outward.

3. Caster Angle:
   - The angle of the steering axis viewed from the side.
   - Positive caster improves straight-line stability.
4. Kingpin Inclination:
   - The angle between the vertical axis and the steering axis.
5. Ackermann Steering Angle:
   - Determines the inner and outer wheel steering angles for cornering.

(A model of steering geometry is located in vehicle dynamics lab)

Procedure:

Simulation Procedure:

Step 1: Vehicle Parameter Definition

- Define vehicle specifications such as wheelbase, track width, tire size, and steering arm length.

Step 2: Mathematical Model Setup

- Use the following equations for steering geometry calculations:

1. Ackermann Steering Angle Formula:

   $\tan(\theta_{inner})=L/R-W/2$

   $\tan(\Theta_{outer}) = L/R+W/2$

   Where:

   - L: Wheelbase
   - W: Track width
   - R: Turning radius

2. Toe Angle Calculation:

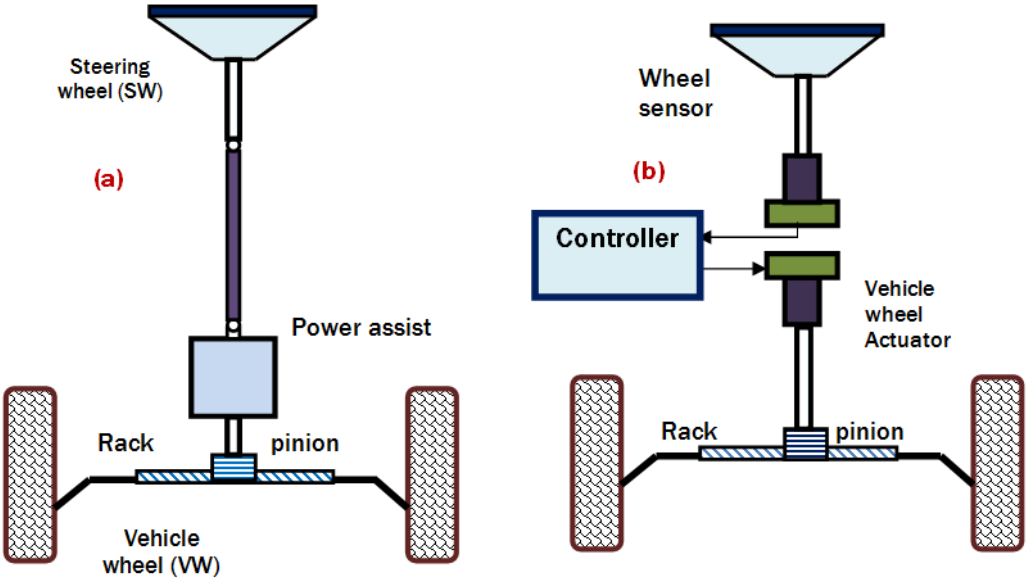
   $\text{Toe Angle}=\theta_{left}-\theta_{right}$

3. Camber Angle:

   $\theta_{camber}= \tan^{-1} \Delta h/L$

Step 3: Simulation Model Creation

- Use simulation software (MATLAB/Simulink, ADAMS/Car) to create a kinematic model of the suspension and steering system.
- Apply input parameters such as steering wheel angle and vehicle speed.



Step 4: Optimization Process

- Use optimization tools in the software to improve the steering geometry.
- Apply constraints such as minimum turning radius, reduced tire wear, and better stability.

Step 5: Run Simulations and Collect Data

- Simulate various steering angles and turning radii.
- Record output data such as:
  - Ackermann angle error
  - Maximum turning angle
  - Lateral forces on tires

Step 6: Analyze Simulation Results

- Generate plots for steering angles, camber angles, and toe-in/out adjustments.
- Evaluate performance indicators and identify areas of improvement.

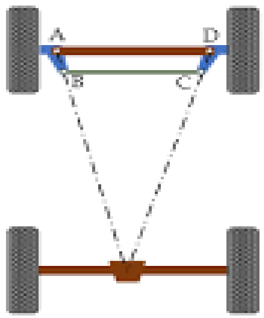


Figure 1: Ackermann steering with links AD and BC of unequal length and AB and CD of equal length

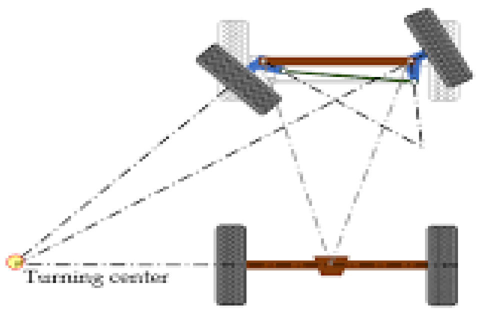


Figure 2: Ackermann steering mechanism with two correct steered positions

Optimization Criteria:

1. Minimize tire scrub during cornering.
2. Ensure proper Ackermann angle to reduce tire wear.
3. Improve vehicle stability and handling performance.
4. Ensure turning radius meets design requirements.

CONCLUSION:

EXPERIMENT-6

Numerical Simulation of suspension's dimension optimization

Objective:

- To study the suspension system geometry and its parameters.
- To perform numerical simulations for suspension dimension optimization.

Tools and Software Required:

SolidWorks/ANSYS for CAD modeling

Definition:

The suspension system connects a vehicle's chassis to its wheels and supports vehicle stability, comfort, and control. Optimizing suspension dimensions enhances performance by minimizing forces transmitted to the vehicle body.

Types of Suspension Systems:

1. Double Wishbone Suspension
2. MacPherson Strut
3. Multi-Link Suspension
4. Trailing Arm Suspension

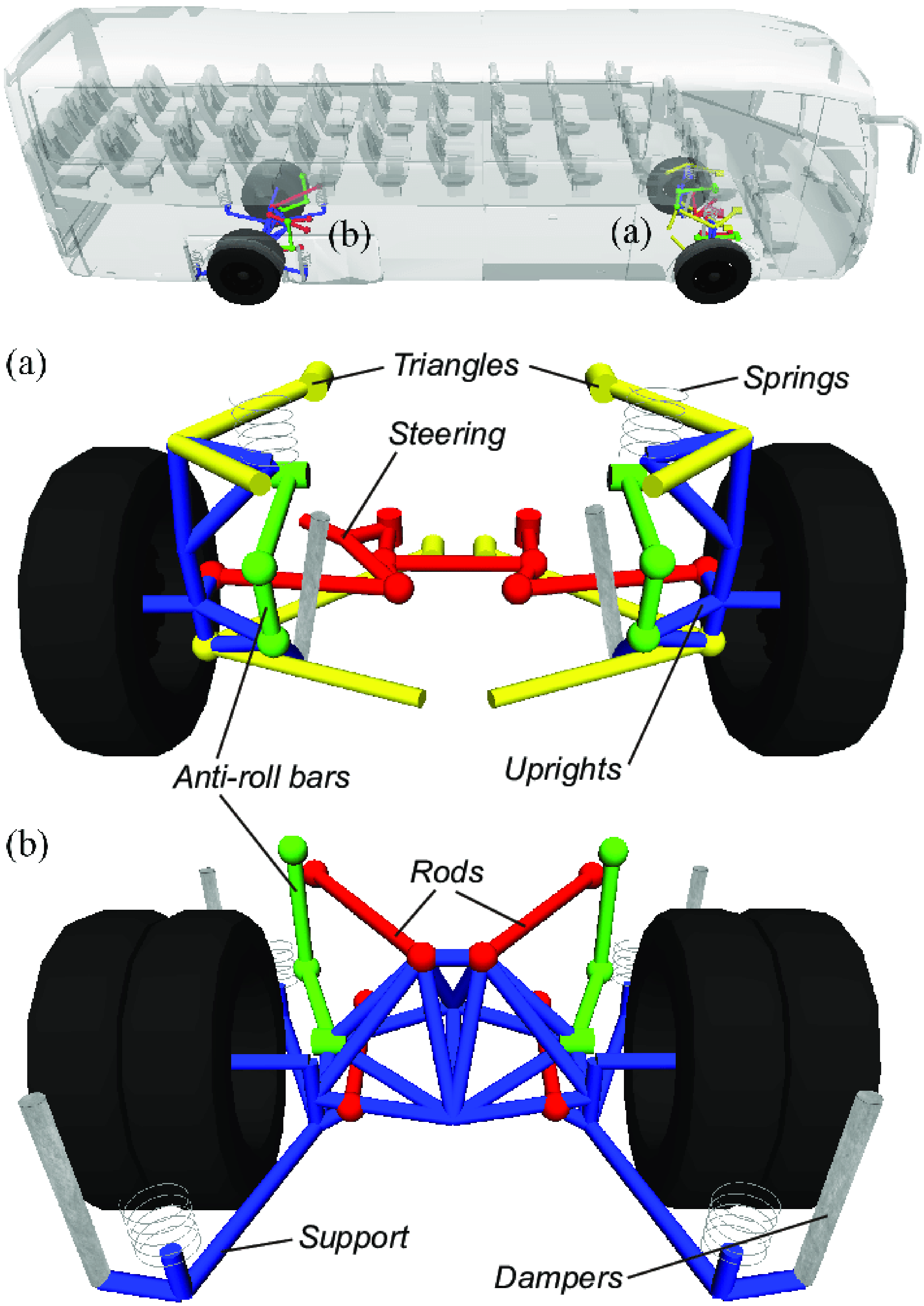
Suspension Geometry Parameters:

1. Ride Height: Vertical distance from the ground to the chassis.
2. Camber Angle: Tilt of the tires inward or outward.
3. Caster Angle: Forward or backward tilt of the steering axis.
4. Toe Angle: Alignment of tires pointing inward or outward.
5. Kingpin Inclination (KPI): Steering axis inclination.
6. Scrub Radius: Distance between the wheel center and ground contact point.

Procedure:

A. Study Section:

1. Study the working principles of various suspension systems.
2. Understand the effect of each suspension parameter on handling, stability, and comfort.
3. Define the optimization goals such as reducing body roll, maximizing traction, and improving ride comfort.


(b)
(a)
(a)
Triangles
Springs
Steering
Anti-roll bars
Uprights
(b)
Rods
Support
Dampers

B. Simulation Procedure:

Step 1: Define Vehicle Specifications

- Wheelbase (L)**:** Distance between the front and rear axles.
- Track Width (W): Distance between the left and right wheels.
- Suspension Arm Lengths: Lengths of upper and lower control arms.
- Spring and Damper Rates**:** Define spring stiffness and damping coefficient.

Step 2: Create a Mathematical Model

Use standard suspension geometry equations:

1. Camber Angle Calculation:

   $\theta_{camber} = \tan^{-1} \Delta h / L$

2. Roll Center Height (RCH):

   $RCH = W * H / 2 \cdot (L + W)$

3. Suspension Travel:

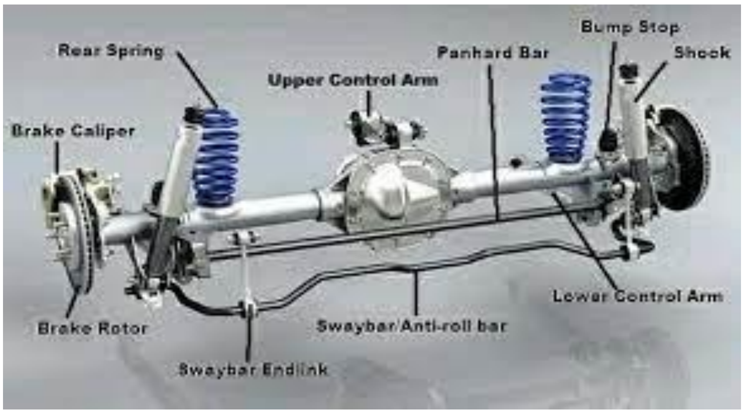
   Suspension Travel=Initial Length−Compressed Length

4. Spring Stiffness (k):

   $k = F / \Delta x$

Step 3: Develop Simulation Model

- Use MATLAB/Simulink or ADAMS/Car to simulate vehicle suspension kinematics.
- Create a multi-body dynamics model with defined suspension points.
- Apply load cases such as cornering, braking, and bumps.



Step 4: Perform Optimization

- Define an optimization problem with constraints:
    - Minimize roll angle
    - Maximize stability and ride comfort
    - Limit maximum suspension travel
- Use optimization tools (fmincon in MATLAB or optimization modules in ADAMS/Car).

Step 5: Run Simulations and Collect Data

- Conduct simulations under various conditions (bumps, turns).
- Collect output parameters such as camber gain, roll center movement, and suspension travel.

C. Optimization Criteria:

1. Minimum body roll during cornering.
2. Maximum ride comfort over bumps.
3. Controlled camber gain for better traction.
4. Improved handling and reduced tire wear.

Conclusion:

Experiment-7

To study the Torsional vibration of single rotor system

Objective of Experiment: To determine the natural frequency of undamped torsional vibration of a single rotor shaft system.

Apparatus required :

Stop watch, vernier calliper and steel rule.

Theory:

When the particles of the shaft or disc move in a circle about the axis of the shaft, then the vibrations are known as torsional vibrations. The shaft is twisted and untwisted alternatively and the torsional shear stresses are induced in the shaft. Since there is no damping in the system these are undamped vibrations. Also there is no external force is acting on the body after giving an initial angular displacement then the body is said to be under free or natural vibrations. Hence the given system is an undamped free torsional vibratory system.

Specification:

Shaft diameter = mm

Diameter of disc = mm

Weight of disc = kg

Modulus of rigidity for shaft = $7.84*10^{10}$ N/m^2

Acceleration due to gravity g = 9.81 m/s^2

Procedure:

1. Fix the brackets at convenient position along the lower beam.

2. Grip one end of the shaft at the bracket by chuck.

3. Fix the rotor on the other end of the shaft.

4. Twist the rotor through some angle and release.

5. Note down the time required for 10 to 20 oscillations.

6. Repeat the procedure for different length of the shaft.

Observation table:

Sl. No.	Length of shaft L in (mm)	No. Of oscillation n	Time for 'n'oscillation In 't'	Time period T=t/n sec.	Frequency F=1/T (Throry)	Frequency F=1/T (Exper.)

(Experiment set up installed in VD Lab)

Model of calculation:

Polar moment of inertia of shaft = $(\Pi / 32)*D^4$

Moment of inertia of disc, I = (W/g)*(D2 /8)

1. Torsional stiffness , Kt =(G*Ip)/L
2. Where G = modulus of rigidity of shaft = $7.848 * 10^{10}$ N/m2

2. Periodic time, T (theoretically) = $2\pi\sqrt{I/K_t}$

3. Periodic time, T (expt) , T = t / n

4. Frequency, f (exp.) = 1 / T

5. Frequency, f (theo.) = $1/2\pi\sqrt{I/K_t}$

Conclusion:

1. The natural frequency of undamped free torsional vibration (theo)

2. The natural frequency of undamped free torsional vibration (expt)

Experiment-8

To study the free vibration of two rotor system and determine its natural frequency

Objective of Experiment: To determine natural frequency of torsional vibration two rotor system experimentally and compare with experimental values.

Apparatus required :

Stop watch, vernier calliper ,steel rule, cross arm and spaner

Theory:

The shaft mounted on two bearing on either side. The above system is atwo degree of freedom. For our convinence we wil break the system down into two degree of freedom system for analysis. In order to do this we have to first identify the nodal point in the system.

If we twist the two rotors in opposite direction and the rotor, the two rotors will move in opposite direction but there will not vibrate. This is nodal point. Hence each of the two rotors can be considered as single degree of freedom system both vibrating at same frequency.

Specification:

Shaft diameter = mm

Diameter of disc A = mm

Diameter of disc B = mm

Weight of disc A = kg

Weight of disc B= kg

Weight with arm (with nut and bolt) = kg

Length of cross arm = gms

Length of shaft between rotor L = m

Modulus of rigidity for shaft = $7.84*10^{10}$ N/m^2

Acceleration due to gravity g = 9.81 m/s^2

(Free vibration of two rotor system placed in vehicle dynamics lab)

Procedure:

1) Fix two discs A and B to the shaft and fit the shaft in the bearings.

2) Deflect the discs A and B in opposite direction by hand and release.

3) Note down time required for particular number of oscillations.

4) Fit the cross arm to one of the discs say A and attaches different masses to the ends of cross arm and again note down time.

5) Repeat the procedure with different equal masses attached to the ends of cross arm and note down the time.

Observation table:

Sl. No.	Length of shaft L in (mm)	No. Of oscillation n	Time for 'n'oscillation In 't'	Time period T=t/n sec.	Frequency F=1/T (Throry)	Frequency F=1/T (Exper.)

Model of calculation:

Polar moment of inertia of shaft = (Π/ 32)*D^4

Moment of inertia of disc, I = (W/g)*(D2 /8)

1. Torsional stiffness , Kt =(G*Ip)/L
2. Where G = modulus of rigidity of shaft = 7.848 *10^{10} N/m2

3. Periodic time, T (theoretically) = $2\pi\sqrt{I_A I_B / K_t (I_A+I_B)}$ Sec.

   Where, MoI of disc A $I_A = m_A (D_A{}^2/ 8)$ kg/m^2
   MoI of disc B $I_B = m_B (D_B{}^2/ 8)$ kg/m^2

3. Periodic time, T (expt) , T = t / n

4. Frequency, f (exp.) = 1 / T

5. Frequency, f (theo.) = $1/2\pi\sqrt{I/K_t}$

Conclusion:

1. The natural frequency of undamped free torsional vibration (theo)

2. The natural frequency of undamped free torsional vibration (expt)