Design, Simulation and Analysis of Vacuum Assisted Power Brake

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Abstract – ***This paper focusses on Design and simulation of vacuum assisted power brake which is also called as vacuum brake booster used in vehicles to amplify the force applied on the brake pedal during braking.*** *Vacuum power brakes are generally tested via physical manufacturing and modelling. In this case, if the efficiency and performance of the brake booster after production is less, it is discarded which results in huge loss in production cost and time.* ***An alternative way to test the efficacy of brake booster is to simulate it on a software called MATLAB.*** *This software provides a wide range of blocks that can replace the live parts of practical brake booster and also provides the option to input necessary parameter values which can be varied to the performance of vacuum brake booster without actually manufacturing it.* ***This research paper showcases the mathematical and physical model which simulates vacuum power brakes****. Fore while it can be useful in production of vacuum brake booster which offers highest efficacy with varying sets of parameters. This model for testing can be used for vacuum power brakes manufactured in industries to be tested within few seconds and with 90% accuracy.*

Key Words: Brake booster, Simulation, Parameters, MATLAB, Efficiency, Physical model, Master cylinder, Transfer, Key parameters.

1. INTRODUCTION

Vacuum assisted power brakes are designed to create a greater braking force from a minimum pedal effort, using a difference in atmospheric pressure and the engine's manifold vacuum. It increases the pedal force 2 to 4 times depending on the size of the diaphragm. The brake booster is located between the brake pedal and the master cylinder. When pressure is applied to the brake pedal, pressure is exerted on the booster air valve. With pressure created by the booster the master cylinder is applied. Should the booster malfunction, the normal mechanical braking force of the master cylinder is maintained.

The brake booster consists of the body, booster piston, piston return spring, reaction mechanism, and control valve mechanism. The body is divided into a constant pressure chamber and a variable pressure chamber. The chambers are separated from each other by a diaphragm. The control valve mechanism regulates the pressure inside the variable pressure chamber. When the driver applies force on the pedal it gets amplified and the force passing on to the master cylinder gets doubled or even more depending upon the intensity and quality of parts being used in power brake.

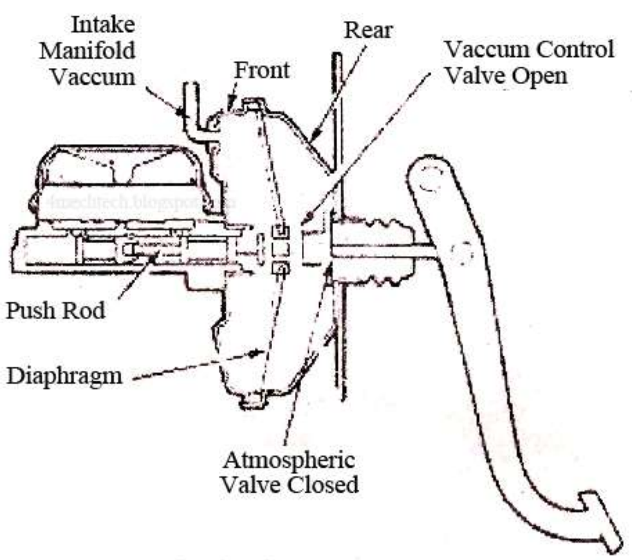


Fig-1: Brake Booster parts

1.1 BASIC DEFINATIONS

DIAPHRAGM: It is a flexible wall member which separates vacuum chamber with variable pressure chamber in order to create a pressure difference between them further amplifying the force on pedal.

MASTER CYLINDER: The master cylinder is located behind the driver's side dashboard mounted on the vacuum booster. The pressure inside of the master cylinder is created by a primary and secondary piston. These are pushed by the output rod of the vacuum booster to compress fluid within its primary and secondary chambers (hydraulic pressure). The hydraulic pressure is translated through the brake lines to the brake callipers. When the brake fluid is pushed through the brake lines, the master cylinder chambers are replenished by the reservoir (attached to the top of the master cylinder).

CONTROL VALVE: A control valve is a valve used to control fluid flow by varying the size of the flow passage as directed by a signal from a controller.[1] This enables the direct control of flow rate and the consequential control of process quantities such as pressure, temperature, and liquid level.

VACUUM CHAMBER AND VARIABLE PRESSURE CHAMBER : These are the 2 chambers separated by diaphragm in the later one atmospheric pressure is allowed to turn in through a control valve after which due to high pressure it applies force on the previous Vacuum Chamber where vacuum is maintained through a pump connected to engine. This pressure difference in both the chamber is the driving force for the vacuum booster.

POPPET VALVE: A poppet valve (also called mushroom valve [1]) is a valve typically used to control the timing and quantity of gas or vapor flow into an engine. It consists of a hole, usually round or oval, and a tapered plug, usually a disk shape on the end of a shaft also called a valve stem. The portion of the hole where the plug meets with it is called the "seat" or "valve seat". The shaft guides the plug portion by sliding through a valve guide. In exhaust applications a pressure differential helps to seal the valve and in intake valves a pressure differential helps open it.

1.2 WORKING

When the driver steps on the brake pedal, it moves the brake pedal pushrod forward, which transmits movement through the power unit to the master cylinder piston to apply the brakes. It also operates a control valve that controls the flow of vacuum and atmospheric pressure to each side of the diaphragm. How it works depends on the position of the control valve.

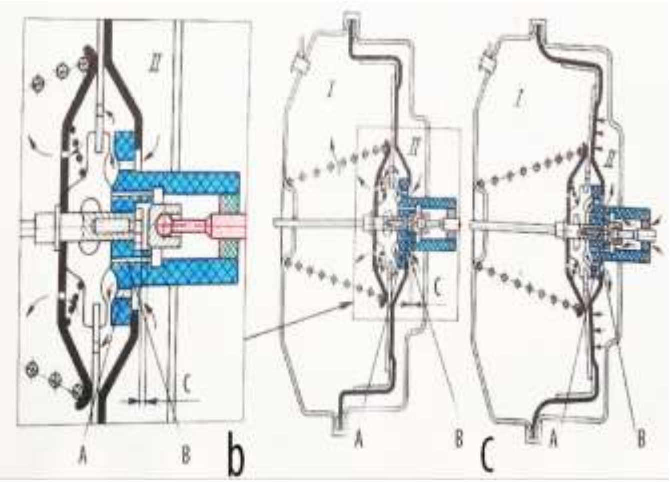
A hose connects the intake manifold to a vacuum check valve on the power brake unit. With the engine running, the check valve allows air to be evacuated from the booster, but not to return. Vacuum in the intake manifold is used to evacuate the power unit. The valve stays open until vacuum in the unit is as high as or higher than manifold vacuum. It then seals the booster off from the intake system. It also holds vacuum in the booster in the case of an engine failure where it will allow at least one full boosted brake application.

The booster chambers are separated by a flexible rubber diaphragm attached to the diaphragm plate. It is held in the off position by a large-diaphragm return spring. The master cylinder pushrod and the control valve assembly are centrally located on each side of the plate. The master cylinder pushrod normally incorporates a system to provide an adjustment for pushrod length. The adjustable length provides the proper clearance between the master cylinder pushrod and the master cylinder piston. The length normally does not need to be adjusted, but if adjustment is required, use the proper tools and follow the service information completely.

As the brakes are applied, the pedal pushrod and plunger move forward in the diaphragm plate, which brings the vacuum valve into contact with the vacuum port seat. This closes the vacuum port, sealing off the passage connecting the two chambers and holding the pressure and vacuum steady in each chamber. This is called the hold position.

Further movement of the pushrod and plunger moves the atmospheric valve away from the atmospheric port seat. Air at atmospheric pressure comes in through the air filter in the rear of the unit and enters the chamber behind the diaphragm. The difference in pressure now on both sides of the diaphragm moves the diaphragm plate forward, and it takes the master cylinder pushrod with it, applying greater force to the master cylinder. In this position, called the apply position, the vacuum valve is closed and the atmospheric valve is open.

Fig -2: Working of Brake Booster

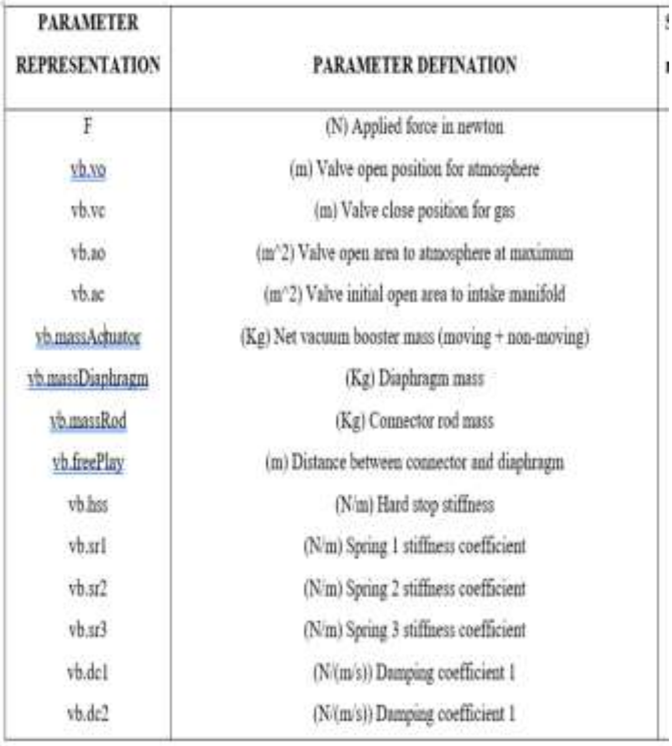


When the brake pedal is released, the atmospheric valve is closed and the vacuum valve opens. As a result, any atmospheric pressure is evacuated from the rear chamber, through the front chamber, out the booster, through the check valve, and into the intake manifold. This reduces the atmospheric pressure pushing on the diaphragm plate. The return spring then pushes the diaphragm plate back to its off position. With the driver's foot off of the brake pedal, the vacuum valve remains open, ensuring that there is equal vacuum on both sides of the diaphragm plate ready for the next application. When the engine is switched off or stops for any reason, no manifold vacuum is available to supply the booster. The vacuum remaining in the booster, held by the one-way check valve, will provide for at least one power-boosted brake application. After this, the brakes will still operate, but without power assistance, they require more brake pedal effort from the driver. The vacuum remaining in the booster, held by the one-way check valve, will provide for at least one power-boosted brake application. After this, the brakes will still operate, but without power assistance, they require more brake pedal effort from the driver.

2. INPUT PARAMETERS

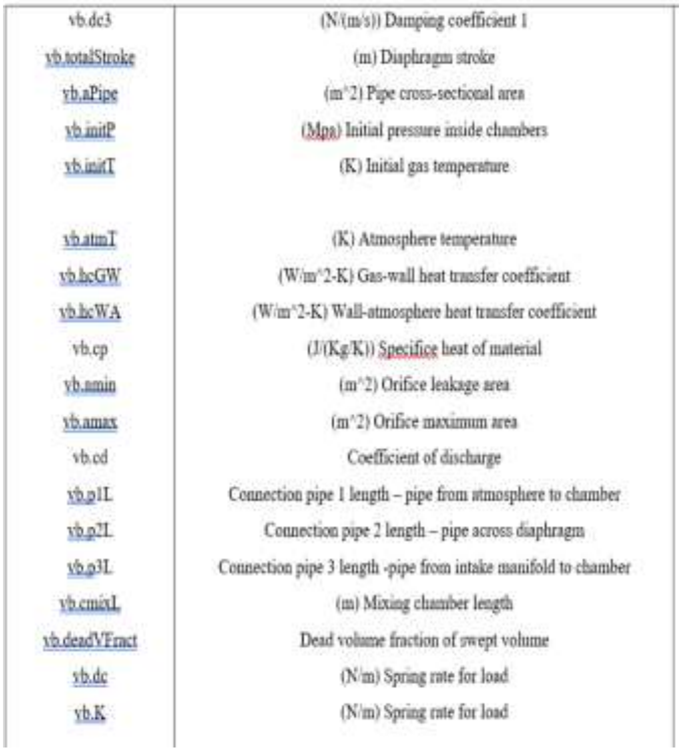
Parameters on which the performance of vacuum assisted power brake depends are mentioned in the table as follows:

Table -1: Parameters 1



PARAMETER REPRESENTATION	PARAMETER DEFINATION
F	(N) Applied force in newton
vb.vo	(m) Valve open position for atmosphere
vb.vc	(m) Valve close position for gas
vb.ao	(m^2) Valve open area to atmosphere at maximum
vb.ac	(m^2) Valve initial open area to intake manifold
vb.massActuator	(Kg) Net vacuum booster mass (moving + non-moving)
vb.massDiaphragm	(Kg) Diaphragm mass
vb.massRod	(Kg) Connector rod mass
vb.freePlay	(m) Distance between connector and diaphragm
vb.hss	(N/m) Hard stop stiffness
vb.sr1	(N/m) Spring 1 stiffness coefficient
vb.sr2	(N/m) Spring 2 stiffness coefficient
vb.sr3	(N/m) Spring 3 stiffness coefficient
vb.dc1	(N/(m/s)) Damping coefficient 1
vb.dc2	(N/(m/s)) Damping coefficient 1

Table-2: Parameters 2



vb.dc3	(N/(m/s)) Damping coefficient 1
vb.totalStroke	(m) Diaphragm stroke
vb.aPipe	(m^2) Pipe cross-sectional area
vb.initP	(Mpa) Initial pressure inside chambers
vb.initT	(K) Initial gas temperature
vb.atmT	(K) Atmosphere temperature
vb.hcGW	(W/m^2-K) Gas-wall heat transfer coefficient
vb.hcWA	(W/m^2-K) Wall-atmosphere heat transfer coefficient
vb.cp	(J/(Kg/K)) Specifice heat of material
vb.amin	(m^2) Orifice leakage area
vb.amax	(m^2) Orifice maximum area
vb.cd	Coefficient of discharge
vb.p1L	Connection pipe 1 length – pipe from atmosphere to chamber
vb.p2L	Connection pipe 2 length – pipe across diaphragm
vb.p3L	Connection pipe 3 length -pipe from intake manifold to chamber
vb.cmixL	(m) Mixing chamber length
vb.deadVFract	Dead volume fraction of swept volume
vb.dc	(N/m) Spring rate for load
vb.K	(N/m) Spring rate for load

Based on these parameters design of vacuum power brake is executed. The values of these parameters taken for the simulation are the values showing maximum efficiency and is observed to multiply the brake pedal force F twice or sometimes even thrice the value of F.

3. SIMULATION OF VACUUM BRAKE BOOSTER

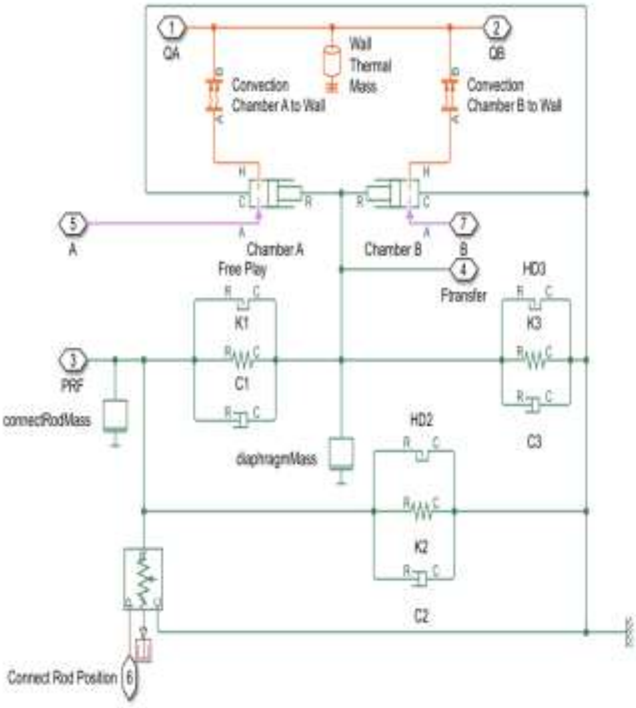
Simulation model suggests the clone of the practical vacuum booster which perform functions similar to that of real parts of vacuum booster based on the parameter values took for the showcased experiment.
Simulation model has three sub models under it namely:
Model-1: Diaphragm Chamber Subsystem
Model-2: Manifold Subsystem
Model-3: Vacuum Brake System

3.1 MODEL-1

First model indicates diaphragm chamber which consists of two partitions divided between **A (pedal side)** and **B(engine side).** 2 pistons placed at the angle of 180 degrees with each other on both sides A and B. 3 spring subsystem is aligned in a way to cover both the pistons. Wall thermal mass is a constant value of the boundary walls, Diaphragm mass is kept constant. Connecting rod takes input from push rod to pass this force towards piston A and piston B inscribed in the coils. Output **Ftransfer** the force value after the action of diaphragm to multiply the force.

Ftransfer is analyzed in the simulation and is considered as the final value of force after the action of brake booster.

Fig-3: Diaphragm Chamber Subsystem



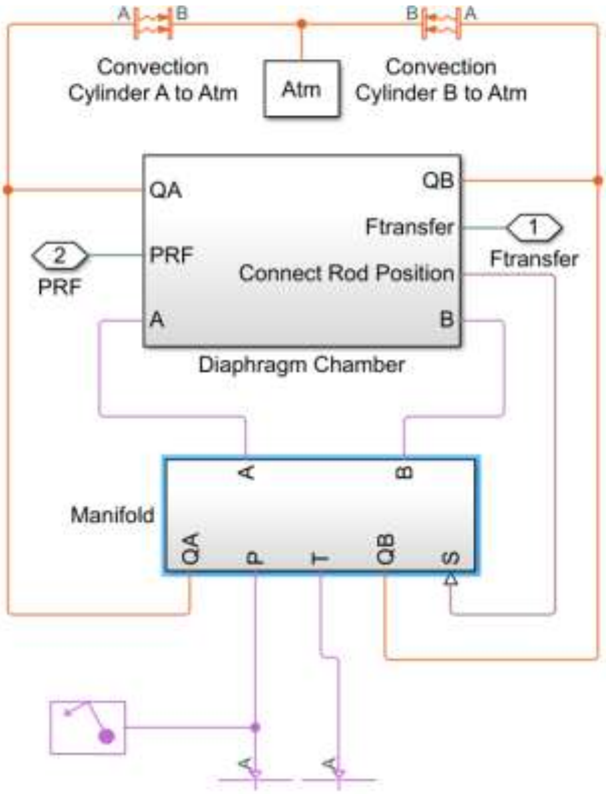
3.2 Model-2

Second model indicates the manifold subsystem which controls the flow of intake atmospheric air towards chamber

‘A’ based on the location of connection rod. It also governs the outward flow of air from chamber A through a miniscule gap on the diaphragm by varying its area. Losses from the area of pipe and heat convection through the walls are also considered. It is also said to be the Electronic Control Unit (ECU) of the brake booster.

Outputs from model 1 including piston A force, Piston B force, position of connecting rod and Ftransfer are given as a input to the manifold subsystem to take decisions for opening and closing of valves.

Fig-4: Manifold Subsystem



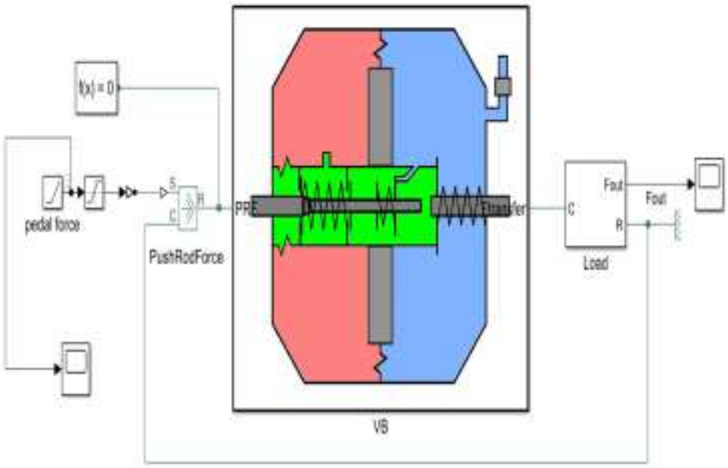
3.3 Model-3

Brake force is provided on the pedal which contributes to push rod force (PRF) after that it enters vacuum brake booster incorporating Model-1 and Model-2 performing their respective tasks. The output force of vacuum brake booster is load which in turn goes to the master cylinder with force multiplied by the factor of 2 or more.

This actual force Ftransfer is the final force which master cylinder applies to the disc brake for stopping of the wheel with full efficiency.

The efficiency of this model on MATLAB is proved by the the plot curve between pedal force and Ftransfer which will show the efficacy of brake booster model.

Fig-5: Simulation Model Of Vacuum Power Brake



4. RESULT FROM SIMULATION

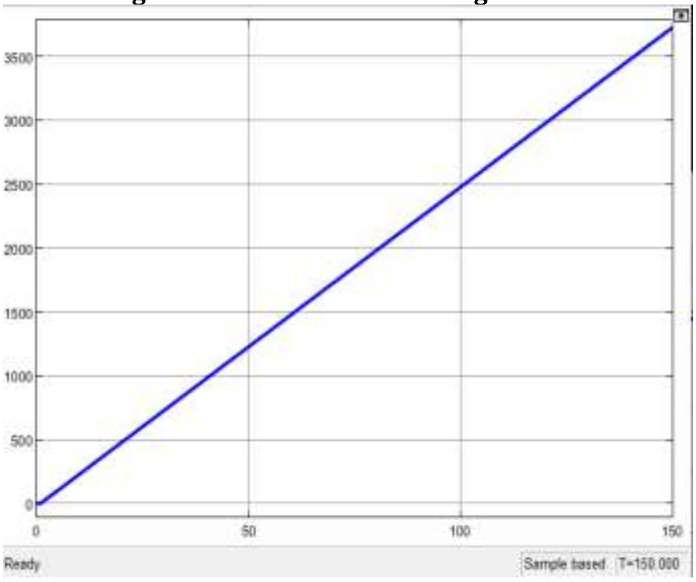
To verify the result of the simulation via MATLAB , a plot curve between the applied force and output force after application of vacuum booster is observed. Results are observed in 2 ways:

(i) Plot curve without Vacuum brake booster
(ii) Plot curve with Vacuum brake booster

4.1: PLOT CURVE WITHOUT VACUUM BRAKE BOOSTER

X axis: Force applied to pedal in newton per 10N
Y axis: Force applied to wheels in newton N

Fig-6: Plot curve shows a straight line

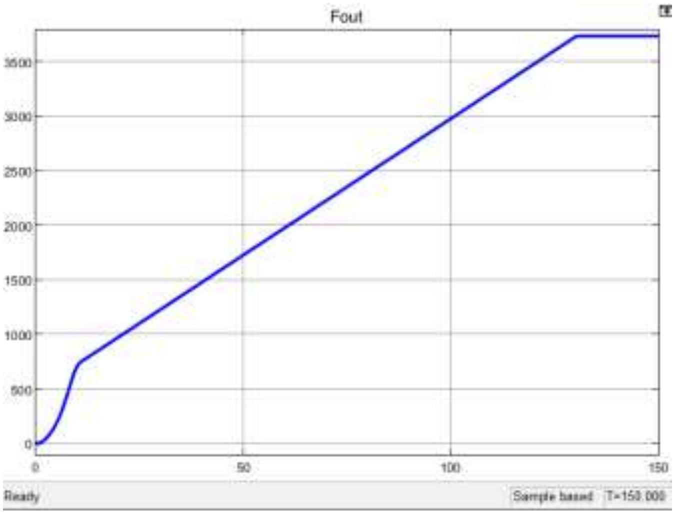


As evident from the graph at the 500N pedal force the applied force at the 1250N. Because the vacuum booster is not the only part responsible for force amplification but nowadays more advanced technologies like ABS are also installed to assist Vacuum booster.

This is the case when vacuum booster is absent.

4.2: PLOT CURVE WITH VACUUM BRAKE BOOSTER

X axis: Force applied to pedal in newton per 10N
Y axis: Force applied to wheels in newton N



The graph shows a sudden curve break from 100N to 200N which is due to the presence of vacuum brake booster. **And if compared for the desired value of 1250N on the wheels respective value of pedal force is 500N but on adding a brake booster, pedal force value is reduced to 300N. Which suggests that the pedal force is reduced by 200N and by applying less force the amplified wheel force is even more than the twice of pedal force.**

5. RESULT

From the observations of simulating a Vacuum assisted power brake suggests that the present simulated model designed for the testing of brake booster is valid and is a easy and less time consuming alternate for the conventional method of testing in laboratories.

The brake booster multiplies the effort put on a brake pedal by a factor of two and even more if the material quality is not compromised.

6. CONCLUSION

The current research paper aimed at design and simulation of vacuum assisted power brake which is certainly installed in every automotive vehicle nowadays for the multiplication of applied pedal force which is not sufficient for stopping of a wheel. This vital part of the braking system is often ignored and appropriate testing is not done. To overcome this problem an alternate testing method is provided in this research with the help of a physical simulation model on the software MATLAB. By analyzing the graphs plotted between applied pedal force on X axis and Force applied on wheel on Y axis. It is observed that the simulated brake booster model is showing expected results as the real brake booster practically used in vehicles.

Ftransfer force applied on wheels is increased by a factor of 500N and nearly doubles the pedal force F which suggests that the current simulation model can be a decent alternate in design and testing of a vacuum brake booster. And will save time, cost and efforts in designing a fully efficient brake booster.

7. REFERENCES

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8. BIOGRAPHIES

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