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# Experimental Investigation of Vacuum Brake System Performance in Light Commercial Vehicles

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## ABSTRACT:

*This paper presents experimental investigation of braking performance of vacuum brake system for light commercial vehicles. The vacuum brake system uses a compressor for creating vacuum and requires less driver effort compared to the conventional brake system. In this work various components of vacuum brake system are designed and fabricated and then installed in Maruti Omni vehicle for performance testing. The stopping distance, braking force and braking efficiency are analysed for vacuum brake system.*

## KEYWORDS:

*Vacuum brake system; Light commercial vehicle; Compressor; Stopping distance; Brake efficiency*

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## 1. Introduction

Most of the light vehicles are fitted with vacuum-assisted hydraulic brake system where vacuum is created from the engine which reduces the driver effort on foot pedal. Considering safety of the conventional brake system, completely vacuum assisted brakes can be used in place of the air or hydraulic brake system. This brake system uses a vacuum pump or compressor to create vacuum in the brake pipe and store in the vacuum reservoir. The main difference with air brake system is that vacuum is used instead of compressed air. Bharath et al [1] dealt with nonlinear lumped multi-capacity models with train pipe capacity and brake cylinder capacity lumped separately to predict pressure rise in the pneumatic brake cylinders for step type input pressure. The first model is a two-capacity system in which all the brake cylinder capacitance and the entire pipe line capacitance are separately. The second model is multi-capacity system in which the train pipe capacitance between the brake cylinders of adjacent wagons is lumped near the brake cylinder capacitance in each wagon separately. The third model is also of multi-capacity type and includes the effect of varying brake cylinder capacity in its formulation. Ding et al [2] developed an efficient and reliable means of friction and pressure estimation algorithm, based on wheel speed signals and control commands for hydraulic valve operation. The achieved results are estimated by comparing the sums of squared speed errors between the measured wheel speeds and those based on the brake pressure model and wheel dynamics. Algorithm performance is evaluated using Anti-lock Braking System (ABS) test data under various braking conditions.

Hulten [3] discussed the unstable modes from the mechanisms containing wave moving in different directions. In a drum brake four mechanisms and four waves travelling in different wave directions are superposed. If directions of waves are superposed, the result is forced towards a standing wave which is always stable. Every step towards a standing wave and noise would be eliminated at the source. Haidong and Mei [4] discussed the line design and operation management of urban rail transit and braking performances of train. They analyzed the braking performances of urban train rail line gradients, train weights, braking forces and train speeds during initial braking. Countermeasures to improve the braking effects are proposed accordingly. Koziol et al [5] described the evaluation methodology for the Intelligent Cruise Control (ICC) and Field Operation Test (FOT). The primary purpose of the evaluation is to assess the safety impact of the ICC system along with convenience and comfort benefits.

Liang and Chon [6] modified the sliding control with variable control parameters to reduce the large change of pressure feedback in the hydraulic brake control process of automated highway vehicles. An average decay function was used to smooth both the high and low frequency oscillations of the desired diaphragm force and output force in the vacuum booster to remedy the oscillations generated by using the pushrod force at the end-brake control. Simulation results indicated that the sliding control with variable parameters significantly reduced the speed and space tracking errors in the braking process. The errors experienced during these processes are dominated by the large brake pressure lag rather than the switching delay time between throttle and brake.

Radlinski et al [7] showed that a major portion of the water picked up by the brake fluid in a brake system is transmitted through the hoses. The effects of water pick-up on brake fluid performance, reduction in vapour lock temperature and increase in low temperature viscosity were discussed. Performance data for several “wet” brake fluids operating in actual brake systems at high and low temperatures were presented. Yeerla et al [8] discussed the safe operation of brake system in vehicles travelling on roadways. The commercial vehicles, such as buses and trucks are equipped with an air brake that uses compressed air as energy transmitting medium. The conventional air brake has a significant time lag that affects its performance. An electro-pneumatic brake system uses an electric signal to modulate the air pressure in the brake system and it has been shown to significantly reduce the time lag when compared to the conventional air brake system. Jung et al [9] estimated the braking performance of a vehicle and brake system consisting booster, master cylinder and calliper. The calculation of braking force through vehicle tests requires much time and money. Therefore, development of methods to estimate the braking performance of vehicle using qualitative methods is beneficial. The disc temperature increases during braking as well as the properties of various boosters can be calculated using the proposed program.

Karthikeyan et al [10] presented a model-based control scheme for an electro-pneumatic brake system for use in commercial vehicles. Hao et al [11] focused on quality of vacuum booster with brake master cylinder. They introduced a control system of multi-function durability testing device which is designed for experimental test of ABS performance. In this work a vacuum brake system with fail safe condition to ensure safety of vehicle and occupant is designed and fabricated. The fabricated vacuum brake system is fitted on to Maruti Omni vehicle and then performance tests are carried out to investigate stopping distance, braking force and braking efficiency. The test results are compared with conventional brake system performance.

## 2. Vacuum brake system assembly for test

The vacuum brake system components are fabricated by welding, binding, riveting, threaded fasteners and bending in the form of a crimped seam. Structural Steels and metal sheets are used. In this work the welding rod, flux and fasteners are used to join the cut pieces. The wheel cylinder and retractor spring of the drum brake are removed and then suitable compression spring is installed. The spring is placed in between the two cups, as shown in Fig. 1, so that it is seated properly. Pneumatic cylinders are mechanical devices which utilize the power of compressed gas to produce a force in a reciprocating linear motion as shown in Fig. 2. Like hydraulic cylinders, pneumatic cylinders are used to store the potential energy of a compressed air and convert it into kinetic energy as the air expands in an attempt to reach atmospheric pressure. The specifications and operating ranges of various constituent components of the fabricated vacuum brake system, as shown in Fig. 3, are given in Table 1.

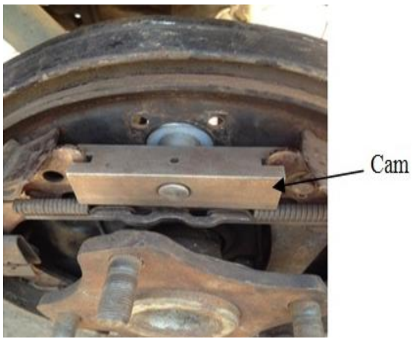

**Fig. 1: Modification to drum brake system**

**Fig. 2: Pneumatic cylinder**

**Table 1: Specifications of vacuum brake system components**

| Component | Parameter | Value |
|---|---|---|
| Pneumatic cylinder | Dimension | 100 x 50 mm |
| | Stroke | 100 mm |
| | Bore diameter | 50 mm |
| | Limiting pressure | 10 kgf/cm$^2$ |
| | Max. working pressure | 10 bar |
| | Max. / Min. working temp. | 70 °C / -10 °C |
| Compressor | Power | 0.75 kW |
| | Speed | 1400 rpm |
| | Volume | 50 cc |
| Reservoir | Length | 30.5 mm |
| | Diameter | 20.5 mm |
| | Volume | 10067 cc |

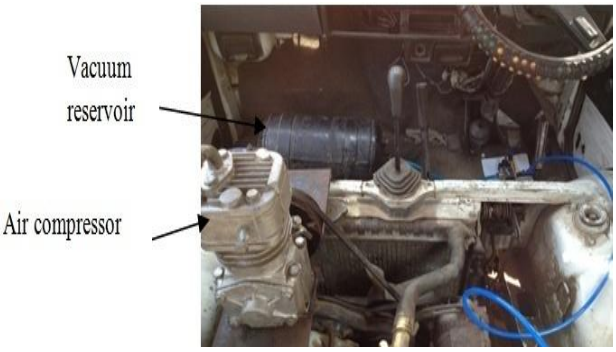

**Fig. 3: Fabricated vacuum brake system assembly**

## 3. Results and discussion

When brake is applied the vacuum in pneumatic cylinder is used for actuation of brakes. The compressor driven by the engine is used for creating vacuum in vacuum reservoir. One end of vacuum reservoir is connected to flow control valve. The input and output of flow control valve is connected to pneumatic cylinders. The pneumatic cylinders are connected to slack adjuster through ball joint. Cam is connected to slack adjuster. Cam is placed in between the brake shoes. The input of the compressor is connected to vacuum reservoir through polyurethane hose. When brake is applied, flow control valve allows the vacuum to flow in to the pneumatic cylinder. The pneumatic cylinder pulls the slack adjuster which is attached to the cam. Thus the actuation of cam expands the brake shoes leading to braking. Maruti Omni is the one of the best light commercial vehicle because the engine power is sufficient to run the compressor and it satisfies the needs of vacuum brake system. It is also spacious which made it possible to assemble the parts of vacuum brake system. The main specifications of Maruti Omni test vehicle are given in Table 2. The vacuum brake system fitted in Maruti Omni vehicle is tested to study the braking performance at various vehicle speeds.

**Table 2: Specifications of Maruti Omni test vehicle**

| Parameter | Value |
|---|---|
| Engine type | 3-cylinder,4 stroke, water cooled |
| Fuel used | Petrol |
| Transmission | 4- speed manual |
| Engine capacity | 796 cc |
| Fuel tank capacity | 36 *l* |
| Mileage (ARAI) | 14.7 kmpl |
| Max. power/rpm | 33 bhp/5000 rpm |
| Max. torque/rpm | 57 Nm/2500 rpm |
| Drive train | Rear wheel drive |
| Turning radius | 4.1 m |
| Seating capacity | 8 Occupants |
| Bootspace | 210 litres |
| Front/Rear brake | Disc/Drum |
| Front/Rear tyres | 145R/154R 12 LT 6PR |
| Front suspension | McPherson strut |
| Rear suspension | Leaf spring & shock absorbers |
| Dimension | 3370 x 1410 x 1640 mm |
| Wheel base | 1840 mm |
| Ground clearance | 165 mm |
| Vehicle kerb weight | 800 kg |

In accordance with Standard Highway Code the stopping distance ($S$) in the event of braking is given by,

$$S = Vt + V^2/(2\mu g) \tag{8}$$

Where $V$ is initial driving speed, $t$ is the perception-reaction time, typically 1.5s and $\mu$ is the coefficient of friction between tyres and road surface, typically 0.7. Fig. 4 shows the variation of braking distance of a vehicle fitted with conventional drum brake and vacuum brake for various vehicle speeds. The stopping distance of the vehicle fitted with vacuum brake is lesser than the one fitted with hydraulic brake for all vehicle speeds.

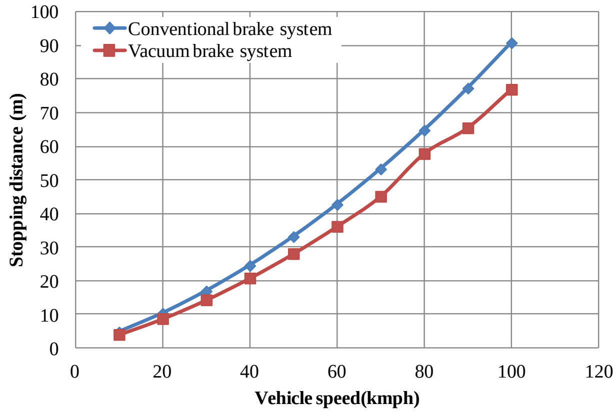

**Fig. 4: Stopping distance vs. Vehicle speed**

Fig. 5 shows the variation of brake force with brake efficiency of a vehicle fitted with hydraulic and vacuum brakes. It is evident from the graph that for the same braking force, the braking efficiency of the vacuum brake is marginally higher than that of the hydraulic brake due to effective braking force.

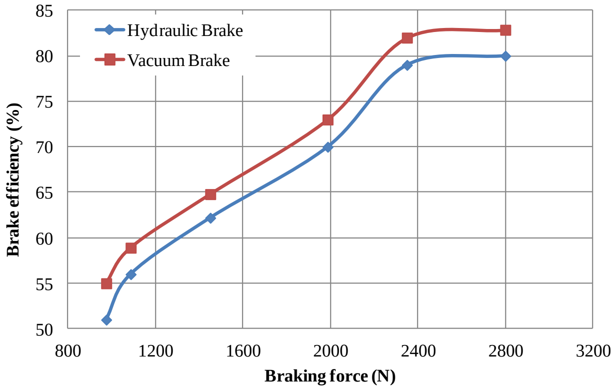

**Fig. 5: Braking force vs. Brake efficiency**

## 4. Conclusion

In this work, a vacuum brake system is designed and fabricated with its components such as pneumatic cylinder, compressor and reservoir for the purpose of enhancing the braking performance of light commercial vehicles. After conducting test of fitted vacuum brake system in Maruti Omni vehicle, it can be concluded that the stopping distance of vacuum brake system is lesser than that of conventional brake system.

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## EDITORIAL NOTES:

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