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Experimental Investigation of Hydraulic Performance of Automobile Disc Brakes

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ABSTRACT. This paper presents the experimental investigation of losses incurred during the hydraulic braking in automobiles using a brake test rig that has been recently developed at Automobile lab, Delhi Technological University, New Delhi. Various parameters are considered as per ergonomics of driver and extreme conditions while designing the braking test rig. Brake test rig is designed as hydraulic brake dynamometer and from that we obtained the real-time values of brake line pressure and obtained clamping force in the caliper with the load cell attached to the piston assembly in caliper. Further the values of calculated clamping force are compared with the observations of load cell and analysis of losses incurred during this experiment are calculated. Eventually we found that losses in lower brake pressure are quite notable but as the brake pressure increases, these losses cut to significant amount.

Keywords: Hydraulic Performance, Hydraulic brakes, Brakes, Brake force, Clamping force, Load cell

1 Introduction

After the engine, most of the power wasted in an automobile is in the process of braking. Making the process of braking energy efficient while not compromising with safety has been a hotspot of research. After application of brakes in hydraulic braking, the lack of retraction of the piston causes rubbing between the rotor and the brake pads. This phenomenon of rubbing offers resistance and has adverse effects on the overall fuel economy of vehicle and life of the brake pads.

Braking system of an automobile plays a crucial role when it comes to the safety of vehicle. It converts the kinetic energy of the vehicle to thermal energy by rubbing the brake pads against the walls of the disc attached to the wheels. Reliability factor of braking system should be kept high and to maintain it, they should be serviced timely.

During the braking of automobile, the operation of caliper is to support the brake pads against disc while transferring the hydraulic pressure in the brake line to piston attached with brake pads. One of the important aspects of the caliper is to be a light weight assembly and also high stiffness. In order to achieve optimal braking force, evenly distributed brake pressure on brake pads is necessary.

A literature survey has revealed that the problems of reduction in hysteresis losses in the brake system components have been actively investigated in many respects. The analysis performed shows that the hysteresis impacts in one way or another on the following [4] The operation of the brake calipers and valves.[8] The performance of the disc brakes, especially for heavy vehicles. [2] The response speed of anti-lock braking systems. [8] research is using a new electronic upgraded system where it uses an electric pressure sensor and an electrical closure valve and warning signs for the presence of leakage in the hydraulic circuit and is automatically closed electronically in a simple time in the defective circuit and this system is called the developed BSP (Brake system protection).

[13] Ibrahim Ahmed et al stated the pressure exerted on the brake pedal, supported by the system, acts as a tensioning force within the brake caliper that presses the brake pads onto the brake discs. As a result of the friction force created by this, the greater portion of the kinetic energy of the vehicle is converted to heat within a short time. [11] The mechanical and thermal stresses acting on the brake disc and brake pads are very high. In extreme cases, the braking power occurring during deceleration can be many times the maximum engine power

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[20] Vinay Kumar et al stated that even during the complete pull of brake pedal, brake pads tend to attach to the rotor disc and provides additional resistance to the rotor. These losses which incur during the braking period of automobile inhibits the free rotation of rotor or wheel and hence diminishing the efficiency of hydraulic braking system.
This report highlights the hydraulic efficiency of a brake caliper operated with DOT3. The brake force which should be generated beneath the piston of caliper (Calculated force) vs actual brake force obtained as shown in Fig.1. The scope of this report limits to the hydraulic efficiency of automobile disc brakes by limiting the factors involved in losses and gripping all the aspects while designing the testing rig.

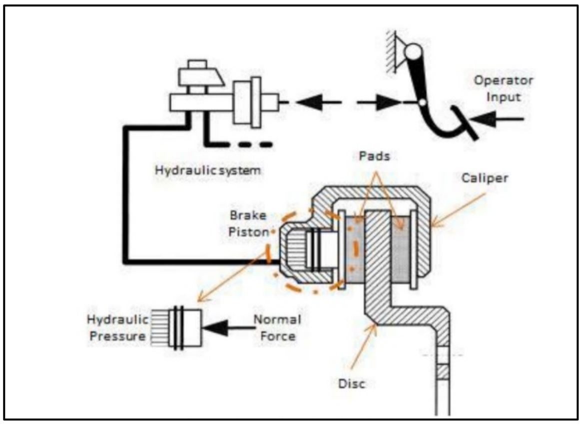

Fig. 1. Schematics of hydraulic braking system

2 Methodology

A significant problem of braking arises as a result of dynamic load transfer induced by the vehicle deacceleration. This is especially important in the design of the vehicles braking system herein a significant difference in center of gravity location exists between loaded and unloaded cases. The analysis and design of automobile brake systems draw mainly upon the physical laws of statics, dynamics and heat transfer. In most cases practical engineering equations are used to determine braking performance and thermal response in a variety of braking situations.
The basic aim of this experiment is to find out the hydraulic efficiency of automobile braking system in which we will find out the losses incurred during the braking procedure. As hydraulic systems have high reliability and minimal losses but in order to achieve the optimal performance and further to do calculations based on drag force offered by braking calipers. To perform this experiment, we have setup a braking system which consist:

Table 1. Parameters of braking system

ITEM	SPECIFICATIONS
Brake pedal	6:1
Master Cylinder	Tandem type with 19.05mm Bore
Brake hoses	Steel
Average working pressure of hose	35 Bar
Max. Hose burst pressure	810 Bar
Min. Hose bend radius	25 mm
Caliper	Floating type
Caliper Bore	34.05mm
Pressure gauge	0 to 106 kg/cm^2
Load cell	5000 N

This setup is based on test rig of hydraulic brake dynamometer (used further) in which firstly we had measured the constant brake pressure present in the brake line and simultaneously noting down the load cell indicator readings (brake force in N). on application of force on pedal the master cylinder piston compresses and generates a hydraulic pressure in the braking system, the hydraulic pressure reading is obtained from the hydraulic pressure gauge and then the piston attached in the caliper starts its actuation outwards. On this, the pancake type load cell attached to the piston therefore compresses and shows its output in newton-force in the indicator.

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3 DESIGN CONSIDERATIONS:

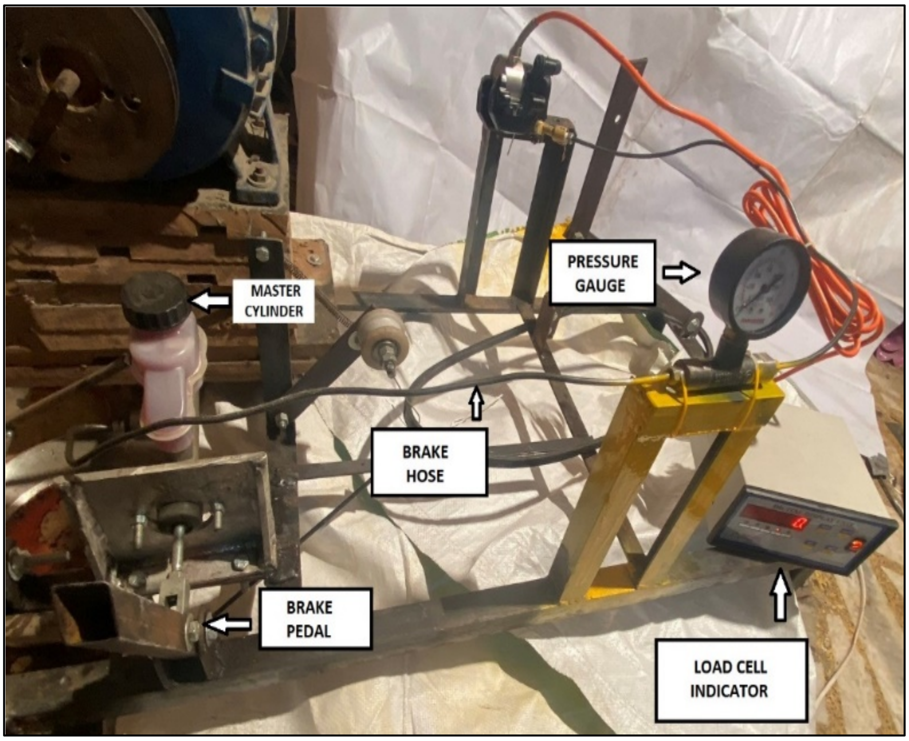

Fig. 2. Test rig of hydraulic brake dynamometer

3.1 MASTER CYLINDER

Tandem master cylinder is used in this experiment with no brake biasing as shown in Fig.2. Master cylinder hose range of pressure is 0 to 2.5Mpa were to selected and used in automobile braking. To obtain the complete travel of pedal, sufficient amount of displacement is to be provided. [3] Taking into consideration of above parameters OEM master cylinder manufactured by BOSCH is used having a bore diameter of 19.05 mm. Stoke length of master cylinder is 28.4mm which provides the displacement needed. This master cylinder is compatible with hygroscopic DOT3/DOT4 brake oil. Various master cylinders were chosen from BOSCH catalogue [6] but 206-10378 is the master cylinder best for this experiment.

3.2 Brake pedal

Lower hinged mild steel brake pedal has been designed to obtain maximum leverage and considering the human factors of the operator. [18] Leverage is of the ratio of 6:1 is provided so that sufficient amount of lever force is obtained at the master cylinder input with minimal pedal efforts as shown in Fig2. Positioning of the pedal is done as the ball of foot point of the operator is following the arc made by pedal.

3.3 Brake lines/Hoses

In this experiment the brake hoses which support the thermal and hygroscopic nature of DOT3/DOT4 are selected as shown in Fig.3. [21] Rating of these hoses are SAE 100 R17, are used as they provide optimal working conditions. Working range of pressure in these hoses is nearly 210 Bar and burst pressure of 810 Bar. Steel lines are used in ease of safety of this experiment.

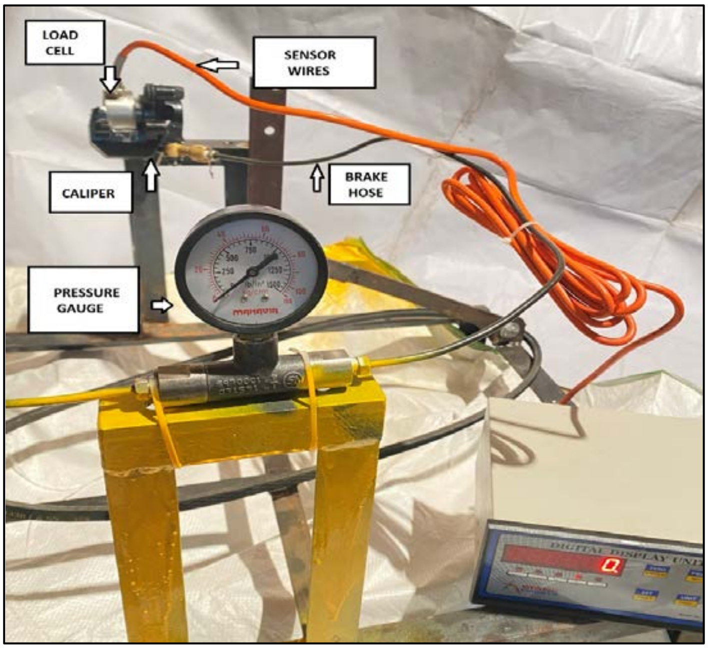

Fig. 3. Test rig of hydraulic brake dynamometer

3.4 Brake Caliper

while designing the caliper and rotor positioning, line geometry as taken into consideration in order to provide the maximum contact area between the rotor and brake pads. [4] Bore diameter of caliper is selected as 34.05mm (OEM Based) which provides the sufficient brake pressure and displacement required as shown in Fig4. Considering the packaging constraints of the caliper, floating type caliper is then used. Assembly of the caliper contains the slider pin as it's integrated part and positioning of the mounting points of caliper to reduce its weight OEM type brake pads are used which comes with the caliper. Oil seals and dust seals as selected as per criteria to the parker's handbook for oil seals. Aluminum 7050-T6 was selected as the caliper material.

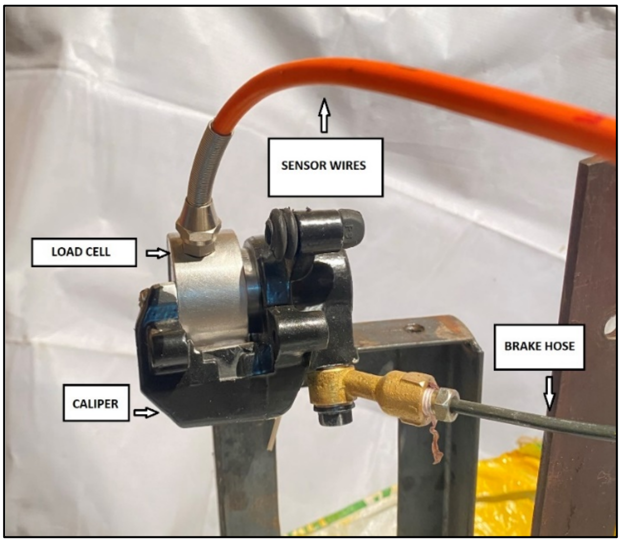

Fig. 4. Brake caliper and load cell assembly

3.5 Hydraulic pressure gauge

Hydraulic pressure gauge is used with the working range of 0 to 106 kg/cm2. [15] Selected gauge is having steel casing with dial of 4 inches and covered with glass as shown in Fig 3. This pressure gauge is attached directly to the brake line so in order to have experiment's working range in 0 to 40 kg/cm2 which will work finely and have a FOS of 2.5.

3.6 Load cell

[22] Pancake type load cell is used in this experiment in order to full fill the design constraints associated with the setup as shown in Fig.4. This load cell is attached directly to the piston assembly of the caliper and fitted between the two jaws which are made to hold the brake pads. Load capacity of load cell is 5000 N load capacity keeping the FOS = 2 of the setup and least count of 0.1 N. Calibration of this load cell is done as per IS4169:2014 with digital indicator setup.

4 CALCULATIONS:

Brake line pressure can also be taken from master cylinder calculations as the bore size and application of force on pedal is given but in order to minimalize the errors and take the real time pressure, we have used hydraulic pressure gauge (B_p) in the brake line.
Brake line pressure = B_p
Area of caliper piston = A_p
Calculated brake force on rotor (Clamping force) = F_1
Experimental brake force obtained = F_2
Caliper piston bore diameter = 34.05 mm
Area of caliper piston = A_p

$$B_p = F_1 / A_p \quad (1)$$

$$F_1 = B_p \text{ X } A_p \quad (2)$$

$$A_p = \pi\left(\frac{35.02}{2}\right)^2 \text{ mm}^2 = 907.46 \text{ mm}^2 \quad (3)$$

Brake pressure:

$$1 \text{ N/mm}^2 = 0.0980665 \text{ kg/cm}^2 \quad (4)$$

$$F_1 = B_p \text{ x } 9253.5167 \quad (5)$$

Loss in force:

$$= F_1 - F_2 \quad (6)$$

Loss percentage

$$= (F_1 - F_2)/ F_1 \text{ x}100 \quad (7)$$

5 RESULTS:

Table 2. Observation Table

Brake pressure (kg/cm^2)	Brake pressure N/mm2	CALCULATED FORCE (N)	EXPERIMENTAL FORCE (N)	LOSS (N)	% LOSS
10	0.980665	889.9142609	660	229.9142609	25.83555192
12	1.176798	1067.897113	856	211.8971131	19.8424652
14	1.372931	1245.879965	1103	142.8799653	11.46819672
16	1.569064	1423.862817	1258	165.8628174	11.64879196
18	1.765197	1601.84567	1419	182.8456696	11.41468701
20	1.96133	1779.828522	1624	155.8285218	8.755254784
22	2.157463	1957.811374	1748	209.811374	10.71662862
24	2.353596	2135.794226	1895	240.7942262	11.27422404
26	2.549729	2313.777078	2150	163.7770783	7.078343021
28	2.745862	2491.759931	2326	165.7599305	6.652323464
30	2.941995	2669.742783	2496	173.7427827	6.507847266
32	3.138128	2847.725635	2678	169.7256349	5.960041684
34	3.334261	3025.708487	2856	169.7084871	5.608884259
36	3.530394	3203.691339	3145	58.69133924	1.83199107
38	3.726527	3381.674191	3301	80.67419142	2.38562874
40	3.92266	3559.657044	3501	58.6570436	1.647828509

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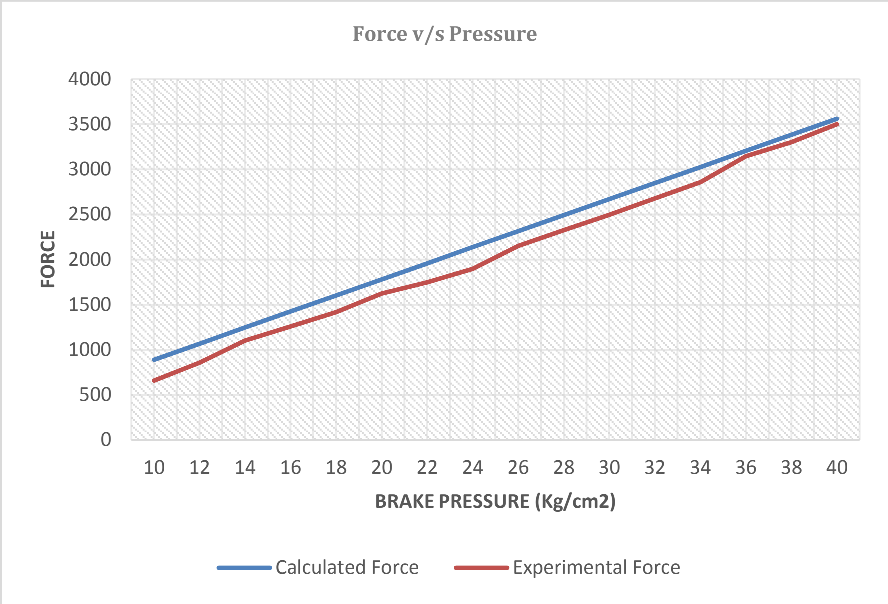

Fig. 5. Graph of Experimental force Vs Calculated force for different brake pressure

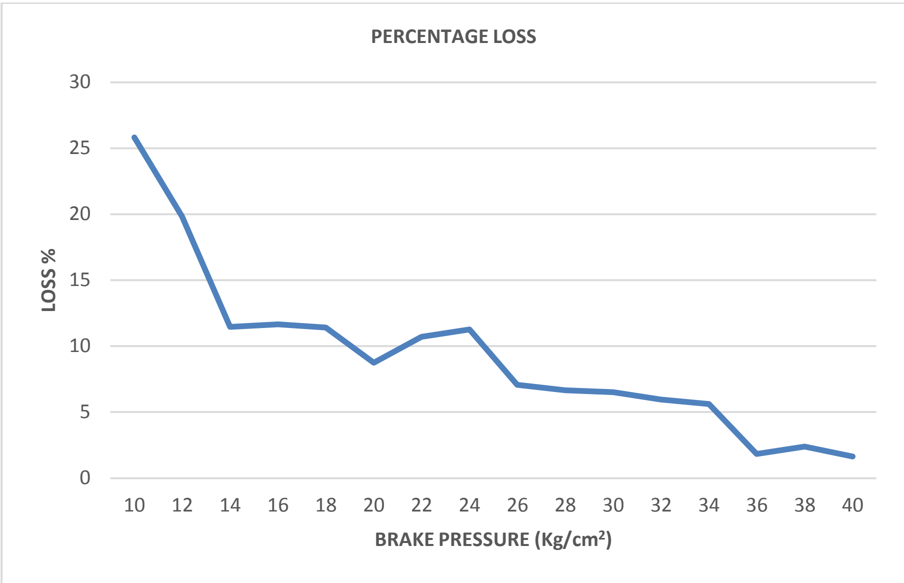

Fig. 6. Loss percentage incurred during braking at different pressures

6 CONCLUSION:

The aim of this experiment is to find out the reliability of hydraulic braking system used in automobiles. A trend as observed in this experiment that losses tend to minimize hen the brake pressure increases as shown in Fig 6. From a maximum loss percentage of 25.8% at 10 kg/cm^2 to minimum loss percentage of 1.67% at 40 kg/cm^2.To achieve that we, detailed study, design the setup and obtained the results. Various parameters of this experimental setup were studied and latterly optimized in order to get best results with minimal losses thus, improvising the efficiency of the setup. The components which are used in this experiment were designed and manufactured not only based on their performance but also to provide the ease of their assembly. All the additional mountings and fasteners attached to caliper are removed in order to achieve minimum losses and light weight assembly. A test rig was setup to find out the losses incurred during braking. Driver ergonomics ere also considered while designing the setup and hence we obtain that on higher braking forces these losses get minimalized.

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