Development of Hydraulic Brake System Performance for Increasing the Car Safety

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Abstract – *The automotive industry has become one of the important industries in the world, and its investments may exceed the budget of major countries. Car manufacturers are always racing to introduce the latest technology to develop the brake system successively and to always increase safety for passengers.*

At present, the rapid progress of the engines and speeds has been offset by increased safety of brake system technology. This paper aims to develop the hydraulic brake system in case of leakage of brake oil in one of the hydraulic brake lines in the dual brake circuit where the pressure junction valve is used (Warning key, one of the two circles has broken down). Only this mechanical circuit reduces the response in critical situations. This 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).

Key Words: Brake, warning, electric signs, BSP (Brake system protection), ABS, EBD, Electro-hydraulic brake.

1. INTRODUCTION

Brakes are one of the most important systems in the car. It is a key component in securing the safety of passengers. Braking performance becomes increasingly important as vehicle speed increases. The hydraulic brake system comprises numerous components, including a booster, master cylinder, valve, and caliper. The effect of each hydraulic component on the entire system has to be carefully considered in designing a reliable hydraulic brake system [1]. The main difference between the electromechanical and electro-hydraulic brakes is the presence of some hydraulic parts such as hydraulic pump instead of electric power supply with the electromechanical brake, as shown in Figure 1. The electro-hydraulic brake has also hydraulic actuators instead of electric motors. The hydraulic actuators are connected with the hydraulic pump through valves which are electrically controlled. The electro-hydraulic brake has usually a backup in the hydraulic system [2]. Power requirements for EMB (Electro-Mechanical Brake) are high and overload the capabilities of conventional 12-volt systems installed in today's vehicles. Therefore, the electro-mechanical brake is usually designed for a working voltage of 42 volts. The power flow of an electromechanical brake is shown in Figure 1 also, [3]. ABS is recognized as an important contribution to road safety as it is designed to keep a vehicle steerable and stable during heavy braking moments by preventing wheel lock. It is well known that wheels will slip and lockup during severe braking or when braking on a slippery (wet, icy, etc.) road surface [4]. The simple idea behind an EBD system is that it need not be necessary to apply the same amount of braking force on each wheel so as to reduce the speed of the car or bring it to a complete stop. An EBD system makes use of three components which make it tick. The speed sensors, brake force modulators and electronic control unit (ECU) [5]. ESP (Electronic Stability Program) has recently been introduced onto the market in an effort to reduce the number and severity of loss-of-control automobile accidents. This reduction is expected to be particularly evident for accidents on roads with low friction (e.g., wet or icy conditions). This study aimed to evaluate the statistical effectiveness of ESP using data from accidents that occurred in Sweden during 2000 to 2002. To control for exposure, induced exposure methods were used, where ESP-sensitive to ESP-insensitive accidents and road conditions were matched in relation to cars equipped with and without ESP. Cars of similar, or in some cases identical, make and model were used to isolate the role of ESP. As predicted, the study showed a positive effect of ESP in circumstances where road surfaces have low friction. The overall effectiveness was 22.1 (±21) percent, while for accidents on wet roads, the effectiveness increased to 31.5 (±23.4) percent. On roads covered with ice and snow, the corresponding effectiveness was 38.2 (±26.1) percent. In addition, ESP was found to be effective for three different types of cars: small front-wheel drive; large front-wheel drive; and large rear-wheel drive [6]. In leakage case in figure 1 the driver feels an increase in the distance of the switch (the excess piston movement until the extension of the secondary piston touches the secondary piston at the end of the main cylinder. The driver also needs more pressure on the switch to reach the same braking force (one circle running during braking), as well as the warning bulb will light up to show that there is a malfunction in one of the brake circuits [7].

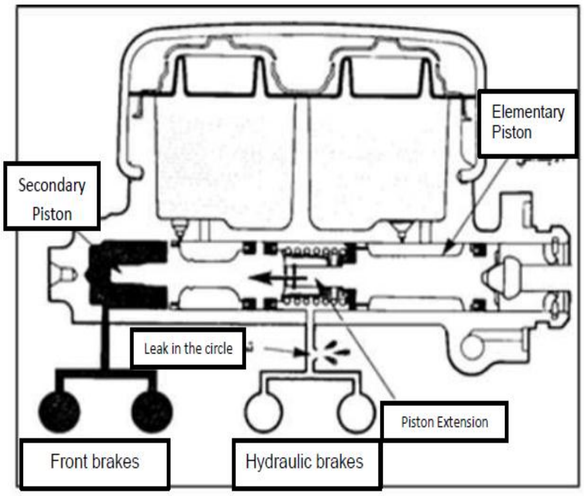

Fig – 1: Rear-wheel leak case

2. EXPERIMENTAL SYSTEM

The test rig that was used in the experimental work of this research and its constructive drawing are shown in Figures 2-a and 2-b. The hydraulic brake system was coupled to a brake system protection unit (BSP) which allows maintaining a constant pressure and simulation of the system with several faults during the tests. The used hydraulic brake system of Hyundai Excel which was used in the experimental work. The brake system protection unit (BSP) is a controller to close a faulty line in the brake system. Three valves distributed at specific locations away from the pressure sensor were used to perform experimental procedures with different opening ratios (25-50-75-100%). The protection unit of the brake system switched on by proximity sensor which give pulse when brake pedal was pressed. A panel meter which a device that used to display pressure measurement, and was set to the critical pressure (zero bar) as clear in the flow chart shown in figure 3. At critical pressure, the panel meter send order to solenoid valve to close the faulty line.

A stop watch is used to measure the required time to close the faulty line however; a test tube is used to measure the leakage fluid volume.

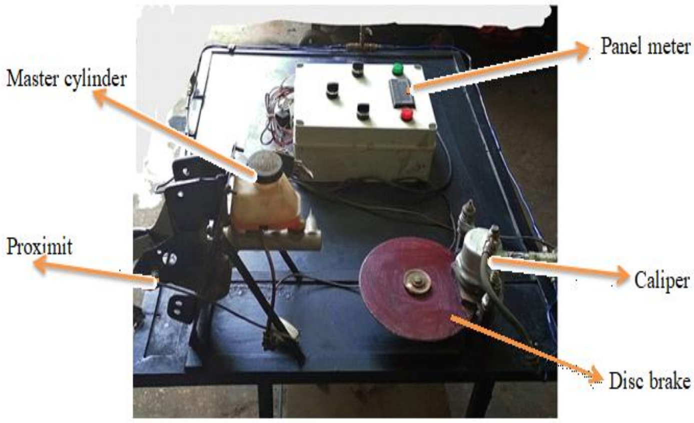

Fig – 2a : The main components of the test rig.

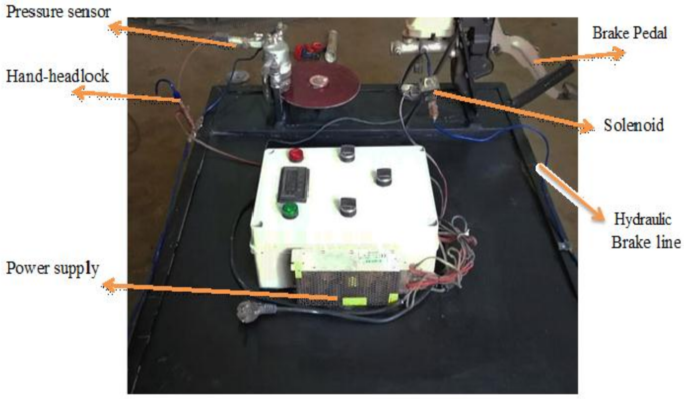

Fig – 2b : The main components of the test rig.

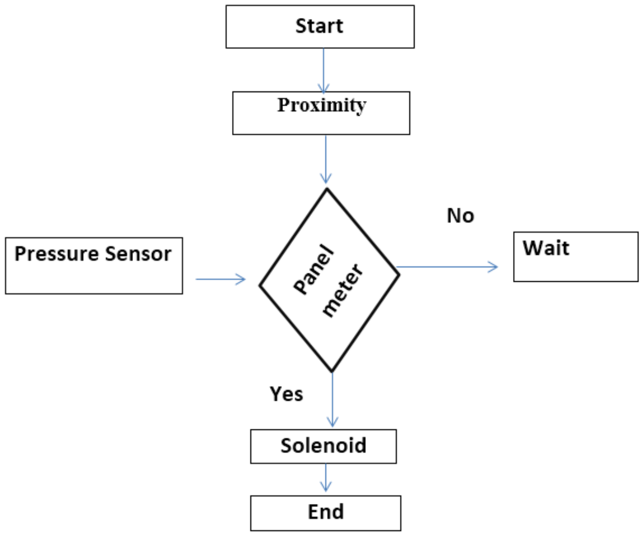

Fig – 3 : Flow chart of brake system protection unit.

3. MEASUREMENT PROCEDURES:

The measurement procedures are as follows;

1. Ensure the safety of the system in the standard condition before operation.
2. Leak valve is opened by 25% at positions1, 2, and 3 at pressure 5, 10, 15 and 20 bars.

3. Leak valve is opened by 50% at also positions1, 2, and 3 at pressure 5, 10, 15 and 20 bars.
4. Leak valve is opened by 75% at positions1, 2, and 3 at pressure 5, 10, 15 and 20 bars too.
5. Leak valve is opened at full at positions of 1, 2, and 3 at also pressure of 5, 10, 15 and 20 bars respectively.

4. RESULTS AND DISCUSSIONS

Implementation of this measurement requires certain operating conditions such as the pressure of the brake oil, the leakage position and the amount of the leak valve opening. The results of practical experiments on the developed brake system in order to measure the effectiveness of the brake safety system are presented here as follows;

4.1 Experiments with 25% leakage at three positions of 1, 2 and 3.

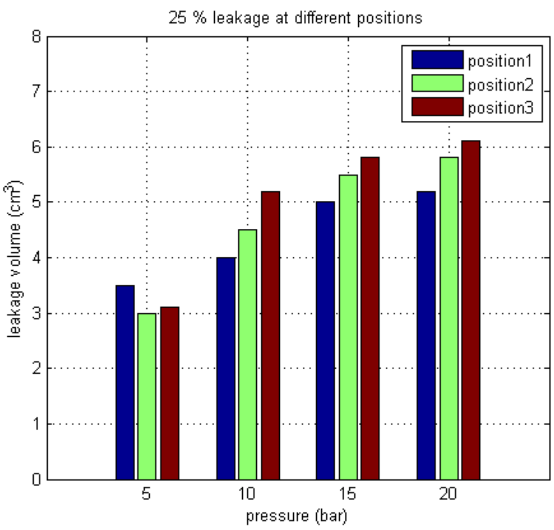

Fig – 4 : The volume of oil leaked when the leak valve is opened by 25%.

Figure 4 shows the relation between the leakage volume and the brake line pressure at 25% of the leak valve leakage. This leakage is at three different positions from the brake master cylinder taking into consideration that the length of the brake line is 3.30 m. Position 1 is at a distance of 1 m from the brake master cylinder and position 2 is at a distance of 1.75 m from the brake master cylinder. However; position 3 is at a distance of 2.75 m from the brake master cylinder. If the brake system leaks when the leak valve is opened by 25% at any position from the 3 different positions, the brake oil pressure in the system decreases to a certain limit in a period of time. This pressure limit allows the safety system to operate to take precautionary action. It is realized from this figure that at low pressure of 5 bar, the leakage volume at position 1 is bigger than position 2 and 3. However; at high pressures of 10, 15 and 20 bar, the leakage volume at position 3 is bigger than at positions 1 and 2. This is due to brake line losses.

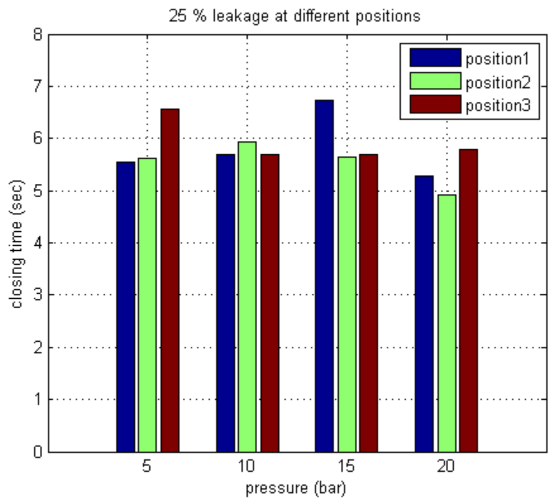

Fig – 5 : The closing time when the leak valve is opened by 25%.

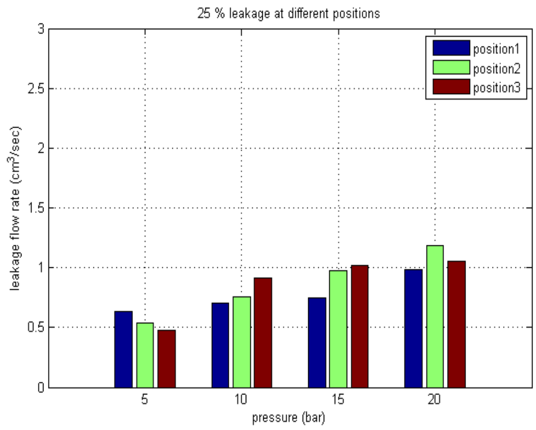

Fig – 6 : The leakage flow rate when the leak valve is opened by 25%.

Figure 5 shows the relation between the closing time (the safety system response time) of the circuit against the brake line pressure. It is realized that the maximum closing time is 6.6 sec that occurs at brake line pressure of 5 bar at position 3. However; the maximum closing time of 6.8 sec that occurs at position 1 when the brake pressure is 15 bar. **Figure 6** shows the leakage flow rate at the different brake line pressures and at the different three positions 1, 2 and 3. Generally, it is noticed that the time required to close the faulty line (the closing time (the safety system response time) when the leakage valve was opened 25% was about 5: 6.8 seconds.

4.2 Experiments with 50% leakage at three positions of 1, 2 and 3.

Figure 7 shows the relation between the leakage volume and the brake line pressure at 50% of the leak valve leakage at the different three positions 1, 2 and 3 as previously explained. If the brake system leaks when the leak valve is opened by 50% at any position from the 3 different positions, the brake oil pressure in the system decreases to a certain limit in a period of time. This pressure limit allows the safety system to operate to take precautionary action as mentioned previously. It is realized from this figure that the effect of increased leakage valve opening on leakage volume at different brake oil pressures. The leakage volume increases with the leakage valve opening more.

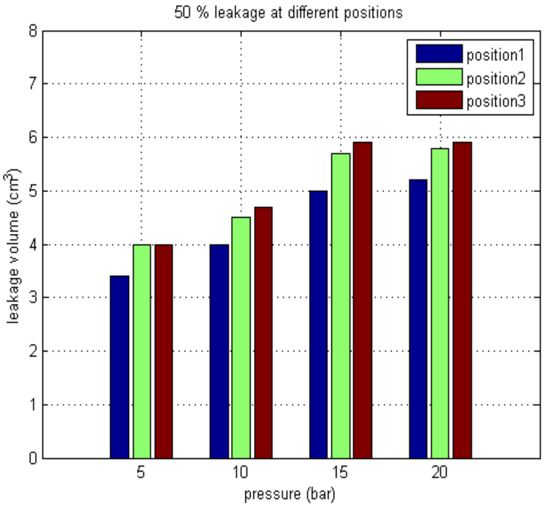

Fig – 7 : The volume of oil leaked when the leak valve is opened by 50%.

As for Figure 8, it shows the time required for the safety system to respond when the leakage valve opens 50% to close the affected line. It is realized from **Figure 8** that the maximum closing time is 5 sec that occurs at brake line pressure of 5 bar at position 1. However; the minimum closing time of 4 sec that occurs at position 2 when the brake pressure is 10 bar.

As in the case of the leakage flow rate exceeding the initial case in **Figure 9**. The leakage rate increases due to the decrease in the closing time of the affected line and it is noticed the higher value is at position 2 at all different braking line pressures.

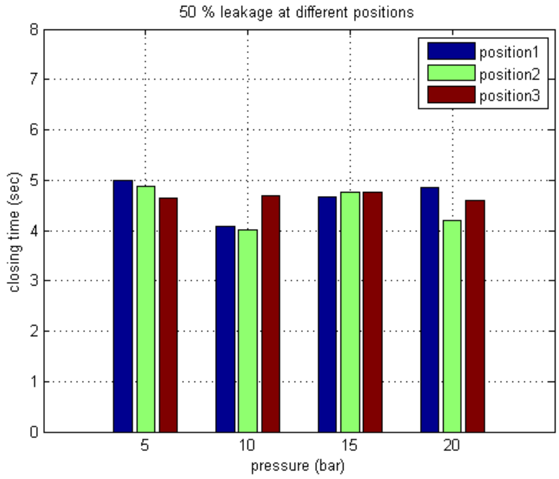

Fig – 8 : The closing time when the leak valve is opened by 50%.

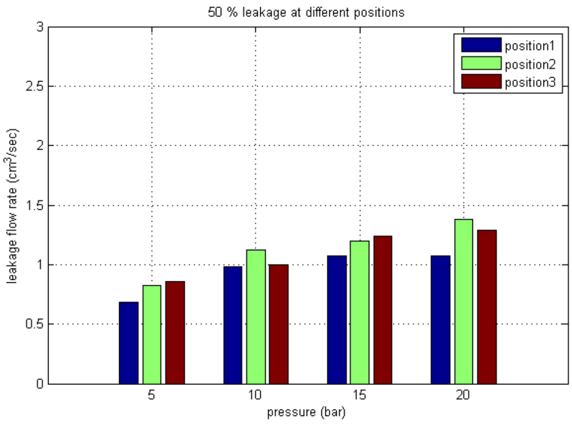

Fig – 9 : The leakage flow rate when the leak valve is opened by 50%.

4.3 Experiments with 75% leakage at three positions of 1, 2 and 3.

Figure 10 shows the relation between the leakage volume and the brake line pressure at 75% of the leak valve leakage at the different three positions 1, 2 and 3 as previously explained. If the brake system leaks when the leak valve is opened by 75% at any position from the 3 different positions, the brake oil pressure in the system decreases to a certain limit in a period of time. This pressure limit allows the safety system to operate to take precautionary action as mentioned previously. It is realized from this figure the minimum leakage volume is 3 cm^3 that occurs at brake pressure of 5 bar at position 2. However; the maximum leakage volume of 6 cm^3 that occurs at braking pressure of 20 bar at positions 1 and 2. Generally, it is realized that the leakage volume increases with the leakage valve opening more.

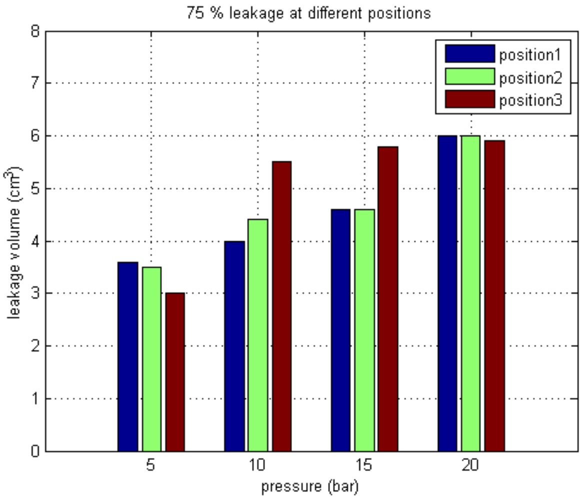

Fig – 10 : The volume of oil leaked when the leak valve is opened by 75%.

The safety system response time decreased from the previous state when the leakage valve was opened by 75% of the full opening. This period recorded about 3:4 seconds as shown in **Figure 11**.

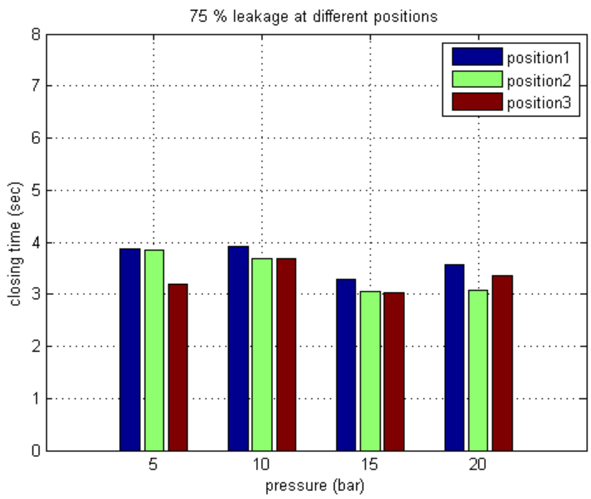

Fig – 11 : The closing time when the leak valve is opened by 75%.

Figure 12 shows the relation between the leakage flow rate and the braking line pressures of 5, 10, 15 and 20 bar at leak valve is opened by 75%. It is realized from this figure the minimum leakage volume flow rate is 0.9 cm^3/sec that occurs at brake pressure of 5 bar at positions 1 and 3. However; the maximum leakage volume of 6 cm^3/sec that occurs at braking pressure of 20 bar at position 2. As for the leakage rate, there is a clear increase due to the decrease in the closing time of the affected line.

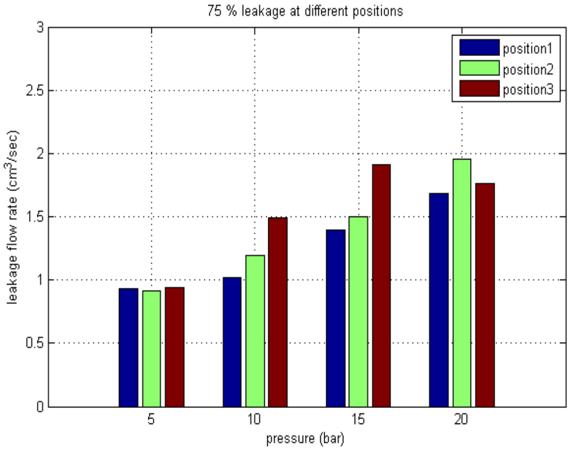

Fig – 12 : The leakage flow rate when the leak valve is opened by 75%.

4.4 Experiments with 100% leakage at three positions of 1, 2 and 3.

Figure 13 shows the relation between the leakage volume and the brake line pressure at 100% of the leak valve leakage at the different three positions 1, 2 and 3 as previously explained. If the brake system leaks when the leak valve is opened by 100% at any position from the 3 different positions, the brake oil pressure in the system decreases to a certain limit in a period of time. This pressure limit allows the safety system to operate to take precautionary action as mentioned previously. It is realized from this figure the minimum leakage volume is 3.1 cm^3 that occurs at brake pressure of 5 bar at position 3. However; the maximum leakage volume of 6 cm^3 that occurs at braking pressure of 20 bar at position 2.

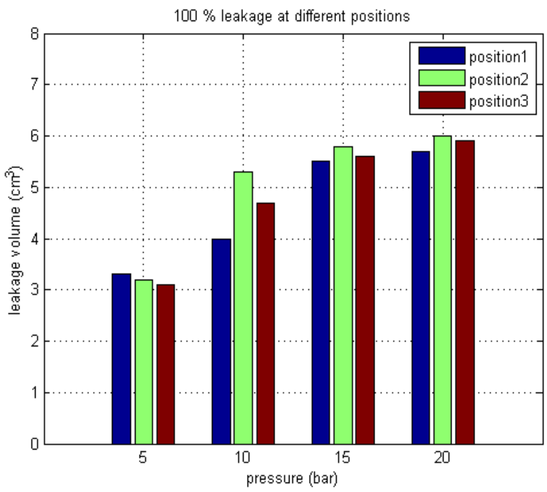

Fig – 13: The volume of oil leaked when the leak valve is opened by 100%.

As for the safety system response time to close the affected line, its lowest value was recorded at approximately 2:3 seconds, as shown in **Figure 14**.

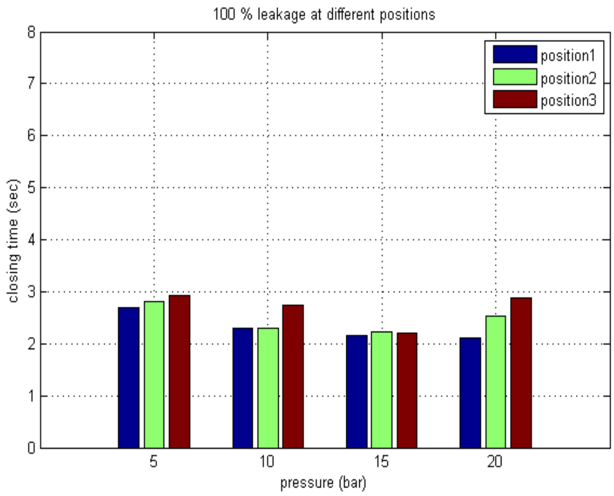

Fig – 14 : The closing time when the leak valve is opened by 100%.

Figure 15 shows the relation between the leakage flow rate and the braking line pressures of 5, 10, 15 and 20 bar at leak valve is opened by 100%. It is realized from this figure the minimum leakage volume flow rate is 1.1 cm^3/sec that occurs at brake pressure of 5 bar at position 3. However; the maximum leakage volume of 2.7 cm^3/sec that occurs at braking pressure of 20 bar at position 1. This highest value occurs due to the closing time was decreased to its lowest value.

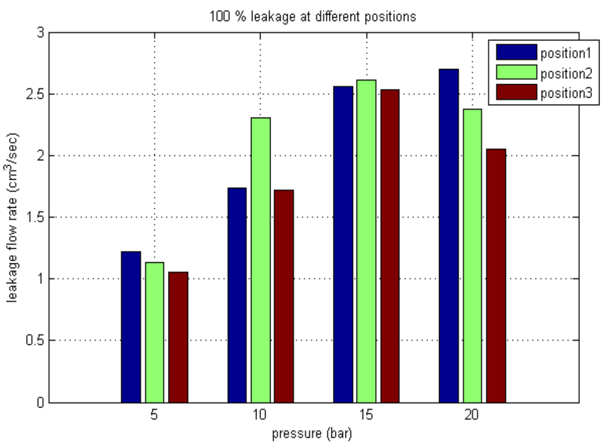

Fig -15: The leakage flow rate when the leak valve is opened by 100%.

5. CONCLUSIONS

From the results of the present study, the important conclusions are as follows:

1- The maximum leakage volume was 6.1 cm^3 when the leak valve is opened by 25% at braking line pressure of 20 bar at position 3. However; the minimum leakage volume of 3 cm^3 was recorded twice when the leak valve is opened by 25% and 75% both at braking line pressure of 5 bar at position 2 and 3 respectively.

2- The maximum safety system response time was 6.8 sec when the leak valve is opened by 25% at braking line pressure of 15 bar at position 1. However; the minimum safety system response time was 2.1 sec when the leak valve is opened by 100% at braking line pressure of 20 bar at position 1.

3- The maximum leakage flow rate of 2.7 cm^3/sec that occurs at braking pressure of 20 bar at position 1 when the leak valve is opened by 100%. However; the minimum leakage flow rate of 0.4 cm^3/sec that occurs at braking pressure of 5 bar at position 3 when the leak valve is opened by 25%.

REFERENCES

1- S. P. Jung, K. J. Jun, T. W. Park and J. H. Yoon, Development of the brake system design program for a vehicle, International Journal of Automotive Technology, 9 (1) (2008) 45-51.

2- Mahmoud, K. R. M.: theoretical and experimental investigations on a new adaptive duo servo drum brake with high and constant brake shoe factor: PhD thesis, Heinz Nixdorf Institute, University of Paderborn, 2005.

3- G. F. Mauer, “A Fuzzy Logic Controller for an ABS Braking System,” IEEE Transactions on Fuzzy Systems, Vol. 3, No. 4, 1995, pp. 381-388. doi:10.1109/91.481947

4- B. Lojko and P. Fuchs, “The Control of ASR System in a Car Based on the TMS320F243 DSP,” Diploma Thesis, Dept. of Radio & Electronics, Bratislava, 2002.

5- Tingvall,C,et al,"The Effectiveness of EPS(Electronic Stability Programme)in Reducing Real Life Accidents" In Proc 18thESV Coference 2003 Paper 261 (2003).

6- Shi Shenshen Thesis AUTOMOBILE BRAKE SYSTEM

7- http:www.thecartech.com /know Your Car /Brakes b/ Hydraulic Brake Valves-files / hydraulic-brake-valves.aspx.

BIOGRAPHIES

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