BRAKE SYSTEM DESIGN AND DELEVOPMENT FOR FORMULA SAE COMPETITION VEHICLES

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Abstract. SAE is a Society of Mobility Engineers that, in partnership with several companies in the automobile industry, promotes the Formula SAE competition. That is the biggest competition among engineering students, and started in the USA in 1981, expanding to several countries, such as Australia, Germany, Japan and Brazil. In this context, several students from various universities propose to develop formula like prototypes, to use the knowledge acquired in the academic scenario and good engineering practices. For security and control issues, SAE defines rules that must be followed by the teams. One of the main subsystems is the brake system, which must be hydraulic and composed of two independent series. The brake system is evaluated both in technical tests (technical inspection) and dynamics tests (braking). This paper shows the design and construction of a robust, effective and low-cost brake system, with well-defined criteria, from its initial conception to its manufacturing. Therefore, it is necessary to study the dimensioning and the forces that make up the entire system. The acquired data allows us to perform an experimental validation and make a comparison between the theoretical and experimental models, to understand the system and identify possible problems and evaluate its performance.

Keywords: Formula SAE, Brake system, hydraulic brakes, performance.

1 INTRODUCTION

SAE (Society of Automotive Engineers) proposes annually, at national and international levels, the FORMULA SAE competition, that stimulates students to design and manufacture a totally justified formula vehicle according to a series of rules imposed by the institution. SAE promotes this event to give the students the experience they would have in industries, making them more capable of performing engineering functions regarding aspects such as machinery and available budget.

The vehicle needs to have a hydraulic braking system composed by two independent systems, one acting on the rear axle and the other on the front axle; they will not only assure the cars performance but will also be fundamental to guarantee the pilot's safety: in case one system fails the other will still be able to reduce the car's speed. Therefore, its development must be done in a cautious way, from its conception to its manufacture.

Through vehicular dynamics equations, it is possible to obtain values like intended deceleration and locking required torque in the front and rear axles, GILLESPIE [1]. Once those are available, it is possible to define system parameters that must be adjusted to make the braking system more ergonomic and to make it fit the available budget.

Once the system is projected and manufactured, it must be validated to guarantee its adequate operation. The definition of those parameters, as well as the comparison between the theoretical results and the practical ones, obtained through experiment, will be analyzed in the present paper.

2 THEORICAL DEVELOPMENT

Once the required force to promote locking of the tires is known, the calipers need to apply an equal or greater force to the disc brakes, SEWARD [2]. To assure this, the braking system has a series of components that transmit the force applied by the pilot and amplify it.

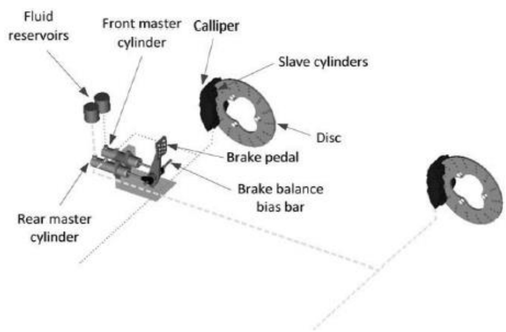

Figure 1- Brake System componentes

2.1 PEDAL

The Braking pedal is the first component that makes contact with the pilot. Its function is to amplify the load it receives. This amplification is defined by a numerical value known as pedal ratio, using mechanical equilibrium equations for bending moment.

$$\mathrm{Fp \; x \; A = Fpil \; x \; B} \tag{1}$$

$$Fp = \frac{Fpil\ x\ B}{A} \tag{2}$$

In witch A is the distance between the center of the balance bar and pivot point; B is the distance between the force application point and the pivot point; Fp is the force applied to the balance bar and Fpil is the force applied by the pilot.

However, the braking pedal, as a mechanical component, has an efficiency that takes into consideration aspects like the efficiency of the Master-cylinder’s return spring. Its typical value is 0.8, therefore:

$$Fpd = \frac{Fpil\ x\ B\ x\ 0{,}8}{A} \tag{3}$$

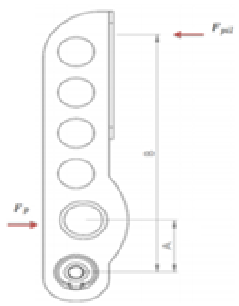

Figure 2 – Forces on pedal.

2.2 BALANCE-BAR

Once the value of the load transfer is available, it is possible to understand that the forces required to lock the front and rear wheels are different, LIMPERT [3]. Thus, the system requires a component able to distribute the pilot applied force in a nonuniform way between the two master-cylinders. This component is the balance bar.

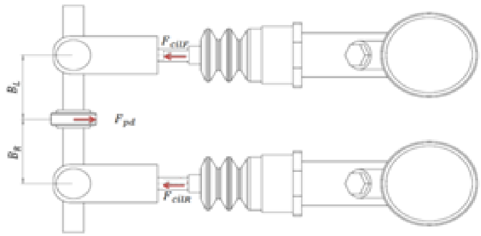

Figure 3 – Forces on balance-bar.

By knowing the applied forces and the application forces, it is possible to perform a static analysis in order to determine the forces applied to the balance bar.

$$Fpd = FcilF + FcilR \tag{4}$$

By analyzing the mechanical equilibrium equations for bending moment, it is possible to say that:

$$Br\ x\ FcilR = Bl\ x\ FcilF \tag{5}$$

Therefore, applying the results of (5) in (4):

$$Br\ x\ (Fpd - FcilF) = Bl\ x\ FcilF$$

$$Br\ x\ Fpd - FcilF\ x\ Br = Bl\ x\ FcilF$$

$$Br\ x\ Fpd = Fcil\ F\ (Bl + Br)$$

$$FcilF = \frac{Br\ x\ Fpd}{(Bl + Br)} \tag{6}$$

Therefore, applying the results of (6) in (4):

$$FcilR = Fpd - \frac{Br\ x\ Fpd}{(Bl + Br)} \tag{7}$$

In witch FcilR is the force applied to the rear cylinder and FcilF is the force applied to the rear cylinder.

2.3 MASTER CYLINDER

The master cylinder acts as a hydraulic component, and it is responsible for converting the mechanical stresses into hydraulic pressure. The forces applied to this component by the balance bar generate pressure in the braking line, that can be calculated through:

$$Pr = \frac{FcilR}{Ae} \tag{8}$$

$$Pf = \frac{FcilF}{Ae} \tag{9}$$

In witch Ae is the area of the master-cylinder's piston, Pf is the pressure in the front calipers and Pr is the pressure in the rear braking lines.

2.4 BRAKE CALIPER

By using the pressure in the brake line and the Pascal Principle, it is possible to calculate the force applied by the calipers to the disc. That component may have one or two pistons, depending on the project necessities; using a higher number of pistons results in a higher force applied to the disc, PUHN [4].

$$Pr = \frac{Fpr}{Aep} \tag{10}$$

$$Pf = \frac{Fpf}{Aep} \tag{11}$$

In witch Aep is the caliper's piston area, Fpr ´s the force applied by the rear caliper e Fpf is the force applied by the front caliper.

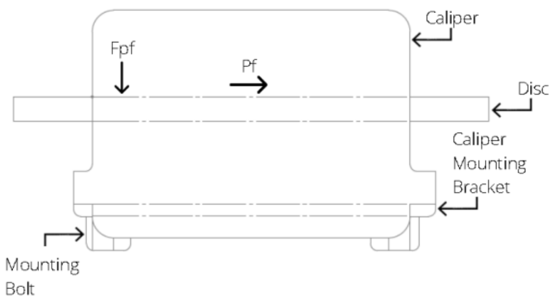

Figure 4 – Forces on caliper and disc.

3 ANALISYS AND RESULTS

The rules concerning formula SAE vehicles state that the braking system must be divided in two independent parts (rear and front). Thus, the performing of the experiment required two sensors, placed in a way that one of them is connected to the rear tubing and the other is connected to the front tubing. By doing this, it was possible measure the pressure in both lines. The reading of these values was performed bay a Raspberry Pi 0 module.

Figure 5 – Pressure sensor – front line tubing.

To perform the reading of the forces applied by the pilot, a load cell was coupled to the pedal. This was accomplished by manufacturing a special braking pad to be used in this experiment. Throughout the experiment, the measurements of the loads and the pressures were performed eleven times in each system, the rear and the front one.

The force obtained in the load cell is given in kgf and the pressure obtained by the sensor is given in bar. To make the comparison between the theoretical values, obtained through the mentioned equations, and the experimental values possible, it was necessary to convert the values into Newton and Pascal. After that, the graphics were generated (Figures 6 and 7). Those graphics allow the comparison between the values.

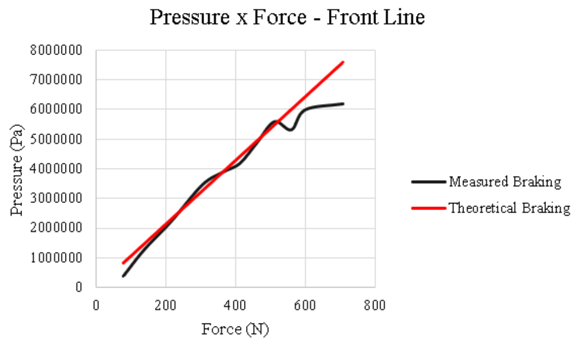

Figure 6 – Comparative graphic between front line pressures.

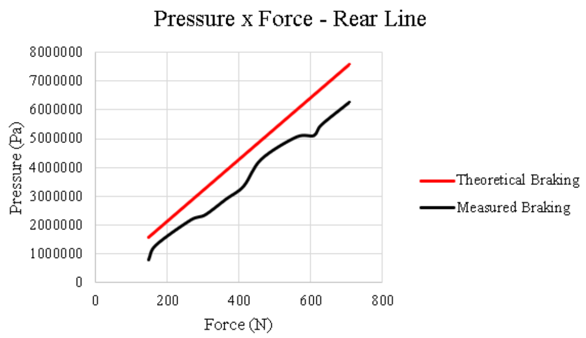

Figure 7 - Comparative graphic between rear line pressures.

The graphics show that the deviation between the theoretical and experimental values is approximately 10.85% in the front line (Figure 6) and 34.99% in the rear line (Figure 7). In figure X, at the 600N mark, the "measured braking" curve starts to deviate from the "theoretical braking" curve. That can be attributed to balance bar malfunction due to inadequate positioning or to measurement flaws.

4 CONCLUSION

The front-line results are satisfactory, taking into consideration the fact that some aspects of the braking process such as load losses due to bubbles in the system and to tubing accessories were ignored in the study. However, the analysis of the rear line showed a deviation three times greater than the front line one. That can be explained by the fact that the master cylinder acting in the rear line was not operating in ideal conditions, showing incapability to transfer the force applied by the pilot in its integrity.

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