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Analisys of the Efficiency of a Conventional Ventilated Brake Disc Compared to a Hyperventilated Disc by Machining

Análisis de la eficiencia de un disco de freno convencional ventilado con respecto a un disco hiperventilado mediante mecanizado

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Abstract

The objective of this study is to redesign a ventilated brake disc as a hyperventilated disc to compare the differences in temperature and brake distances; for this purpose, a monitoring system was installed in the vehicle which consisted of the implementation of two temperature sensors located near each disk and a data acquisition card. With the implementation of hyperventilated discs, the temperature generated by the braking friction could be reduced. The temperature values that occur between the discs when braking was monitored. To obtain the temperature values of the brake discs, road tests were conducted with different types of discs: ventilated discs on the two front wheels, hyperventilated discs on the two front wheels and mixed discs. In the mixed discs there is a ventilated disc on the right front wheel and a hyperventilated disc on the left front wheel.

Resumen

Este estudio tiene como finalidad rediseñar un disco de freno ventilado a un disco hiperventilado para comparar las diferencias de temperatura y distancias de frenado, para ello se instaló un sistema de monitoreo en el vehículo, que consistió en la implementación de dos sensores de temperatura ubicados cerca de cada disco y una tarjeta de adquisición de datos. Con la implementación de los discos hiperventilados se pudo disminuir la temperatura generada por la fricción del frenado. Se realizó el monitoreo de valores de temperaturas que se producen entre los discos al momento de frenar. Para obtener los valores de temperaturas de los discos de frenos, se realizaron pruebas de ruta con diferentes tipos de discos: discos ventilados en las dos ruedas frontales, discos hiperventilados en las dos ruedas frontales y discos mixtos. En los discos mixtos van un disco ventilado en rueda delantera derecha y uno hiperventilado en rueda delantera izquierda.

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By displaying time data of the brake discs, it was possible to conclude that hyperventilated discs have better heat dissipation, since they have better ventilation. From all the results obtained on the route tests, it was possible to visualize the temperature behavior in the discs at the moment of braking and it was evidenced that hyperventilated discs tend to heat up less than normal discs, thus leading to a decrease in time and stopping distance.

Keywords: Brake Disc, Ventilated Disc, Hyperventilated Disc, Disc Temperature.

Mediante visualización de datos en tiempo en los discos de freno se pudo concluir que los hiperventilados poseen una mejor disipación de calor ya que presentan una mejor ventilación. A partir de todos los resultados de las pruebas de rutas obtenidas, se pudo visualizar el comportamiento de temperatura en los discos al momento de frenar y se evidenció que los discos hiperventilados tienden a calentarse menos que los normales, llevando con esto a disminuir el tiempo y distancia de frenado.

Palabras clave: disco de freno, disco ventilado, disco hiperventilado, temperatura de disco

1. Introduction

As a vehicle circulates, its state varies continuously, i.e., it accelerates, brakes or turns. These phenomena are produced by a large number of forces, and their sum is known as vehicle dynamics. If the sum of all forces is zero, it means that the vehicle is at rest. If it is different than zero, it will be moving. Likewise, all these forces vary as a function of a physical magnitude called acceleration, responsible for modifying the speed and direction of any object. For example, accelerating the vehicle corresponds to a positive acceleration, and the case of braking corresponds to a negative acceleration [1].

The braking system is, undoubtedly, the most important component for the road safety of the automobile, since the total or partial stopping of the vehicle and, consequently, the integrity of its passengers, rely on it. In general, 70% of the kinetic energy produced during movement is absorbed by the front disc brakes, and the remaining by the rear disc brakes, which are often drums. These systems are based on the friction to stop the movement of the vehicle, having as operating principle the hydraulic pressure that pushes the brake pads against the cast iron disc. As a consequence, the behavior produced by this type of devices, through the kinetic energy, is creating a considerably high heat during braking, thus increasing the temperature by friction; this heat is quickly dissipated by the surrounding air by means of the convection phenomenon (heat transfer produced between masses at different temperature) [2].

The geometrical characteristics of the discs depend on the load capacity and on the operation, which are important factors at the initial design stage. In most cases, the design of the discs should avoid the overheating that arises between the brake and the pad due to the effect of friction, by appropriate selection of the physical, mechanical and chemical properties that are produced because in some cases the types of materials do not behave correctly, thus having negative effects on the effectiveness of the braking process. At the mechanical design stage in ventilated disc brakes, it is very important to analyze the behavior of the associated thermofluids (surrounding air), i.e. observing the characteristics and operation of the fluids on the disc surface, always guaranteeing the effectiveness of the braking process and the heat dissipation through the surface and the ventilation channels [3].

During the braking process, the heat produced by the friction between the brake pads and the disc is not dissipated quickly, which depends on the geometry and on the manufacturing material. Therefore, when a very hard brake is produced on the disc brake, large amount of heat may be accumulated in a short period of time, which causes high temperature gradients. In these conditions, the functionality and safety of the braking system may be compromised [4]. The disc brakes have been widely used in vehicles due to their correct behavior since they absorb 70% of the kinetic energy produced during movement, which has been its main advantage with respect to the drum brake. When repetitive brakes are produced in the brake discs the temperature increases due to the friction with the pad, thus generating temperature gradients. This heat is quickly dissipated by the surrounding air by means of the convection phenomenon (heat transfer produced between masses at different temperature). The high temperatures may cause vaporization of the brake fluid, brake wear, bearing failure, thermal cracks (fading) and vibrations. For this reason, on many occasions the performance of the system is reduced; as a result, it is very important to predict the behavior of the types of convection existing in the dissipation of heat to the environment, with the purpose of evaluating its efficiency taking into account its design and initial geometry [5].

The brake system is an essential safety system to avoid any accident when driving all types of vehicles. The problem existing in these systems is due to the overheating of its components, and thus it is indispensable to monitor the behavior of the temperature in the brake discs [6]. One of the indispensable factors for analysis and study are the temperature changes when activating the brakes. In recent times, with the technological growth, ventilated discs are being implemented, which help to reduce overheating and avoid traffic accidents to a large extent [7].

The use of these modern systems is only applied in high range vehicles, due to their greater cost with respect to a conventional system [8]. The objective of the implementation of ventilated discs in the present work is to improve the dissipation of the heat produced during the braking action, at a lower and accessible cost.

2. Materials and methods

2.1. Design of the disc

The software Solidworks was used for designing the hyperventilated disc [9], starting from a normal brake disc of a Chevrolet Dmax 4x4 vehicle.

The main axes were molded on the initial planar face, as can be seen in Figure 1, on which there will be holes and slots, key parts for developing the project, which were drawn taking into account the geometry and shape of the disc, on which we will work afterwards.

The dimensions of holes, slots, depths and distances, detailed in Figure 2, were chosen according to the criteria of the authors, which will be centered on the previously described axes.

The initial molding detailed in Figure 3 was performed considering the dimensions and details of the brake disc, with the purpose of visualizing its shapes and geometries in the software.

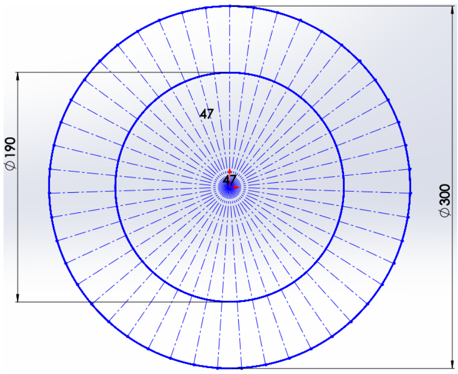

Figure 1. Delineation of the main geometrical axes

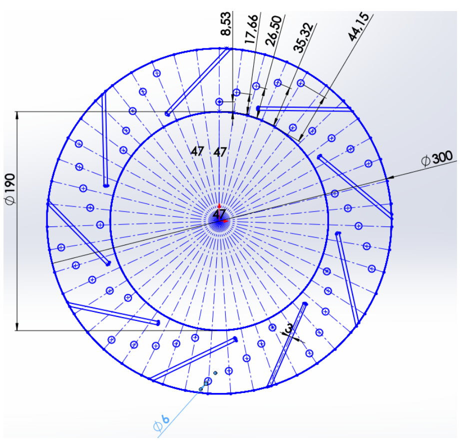

Figure 2. Drawing of holes and slots

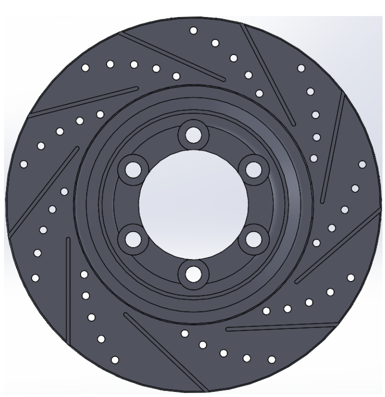

Figure 3. Molding of the ventilated disc [3]

2.2. Machining of the brake disc

In this part, the modifications previously designed with the software were machined to the normal disc. All geometrical data were sent to a CNC machining tool, in this case the milling machine, which enabled achieving a greater precision and facilitating the work. It was necessary to export all planes previously made in Solidworks, to the software Mastercam, Figure 4, that controls the CNC milling machine, a very practical software, and besides it is compatible with Solidworks [10].

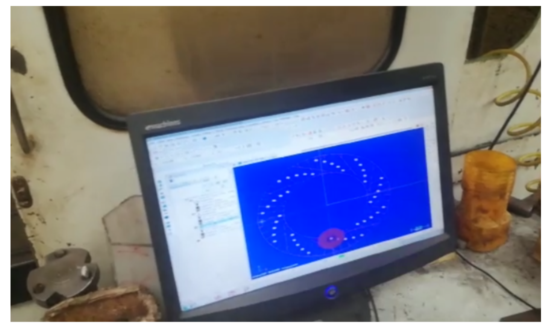

Figure 4. Allocation of the points to be drilled on the disc

After fixing the working coordinates, it was proceeded to drill the through holes that will ventilate the brake disc. Figure 5 shows the drilling and the execution of the G code.

Figure 5. Drilling of the brake disc

After drilling, it was executed the software for grinding the slots that will be employed for ventilation and for removing the chips in the disc. The depth and thickness of the slots were determined by discretion of the authors. Care was taken of not compromising the disc thickness; it was chosen a depth of 2.5 mm and thickness of 3 mm, as can be seen in Figure 6.

Figure 6. Grinding of ventilation slots

2.3. Implementation of hardware and sensors

The amount of hardware currently available in the market is significant, which enables obtaining a very important level of flexibility when searching for an appropriate configuration [11].

The Arduino card was chosen as processor for temperature monitoring and sensors (MLX90614), for acquiring the temperature data from the brake discs, as shown in Figure 7 and Figure 8, respectively.

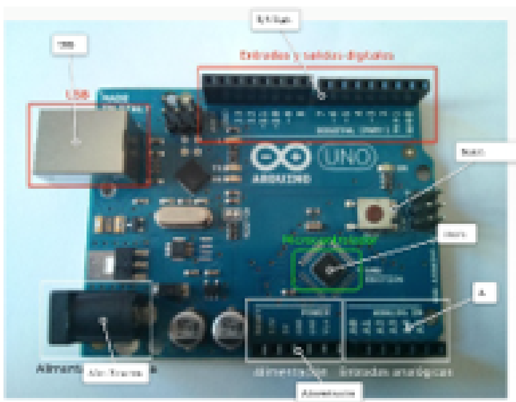

Figure 7. Arduino card

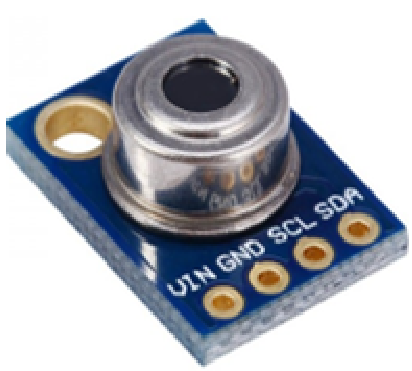

Figure 8. Infrared temperature sensor

2.4. Programming of the data acquisition software

The brake discs temperature monitoring system consists of temperature sensors, Arduino electronic board, serial communications cable and a notebook. The software LabVIEW 2017 [12] was used for programming and for assigning the parameters.

The graphical screens were modified and renamed according to the requirement of the project temperature monitoring system, resulting in the graphical screen (Figure 9).

Figure 9. Graphical screen of temperature

2.5. Implementation of discs, sensors and data acquisition system

For the correct installation of the brake discs, it is required: piston retracting tool, comparator clock, torque wrench and other tools, as seen in Figure 10.

Figure 10. Implementation of the ventilated disc

The data acquisition system for monitoring the brake discs temperature was installed using the Arduino card and distance temperature sensors (MLX90614).

For easy access and manipulation, the Arduino card was located inside the cabin of the automobile (Figure 11).

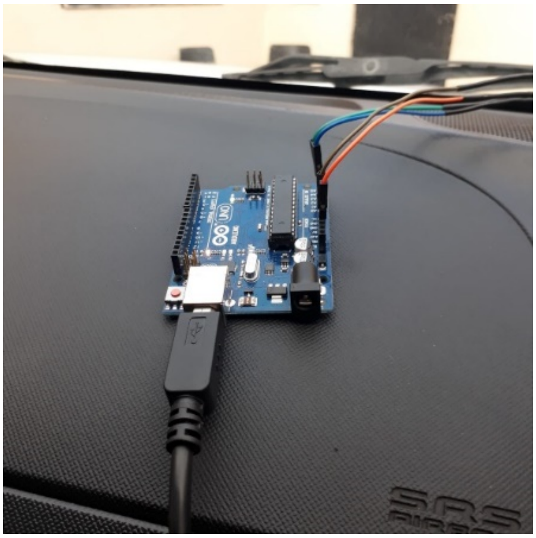

Figure 11. Location of the Arduino

The temperature sensors are installed very close to the ventilated discs, located in the protecting sheet of the brake disc which was used a support base for mounting the sensors, as seen in Figure 12.

Figure 12. Location of the temperature sensors

3. Results and discussion

Initially, the temperature of the original brake discs of the Dmax 4x4 was monitored, in an urban and interurban circuit.

Afterwards, it was carried out the acquisition of temperature data corresponding to the redesigned ventilated brake discs; the test was conducted in the same route previously selected.

At last, the temperature data were monitored, installing an original disc in the left front wheel and a hyperventilated disc in the right front wheel. In this section the temperature data with normal discs were acquired, at different vehicle speeds, in the selected route (Tambo-Cañar).

Figure 13 details the temperature data monitored with hyperventilated brake discs, obtaining a range of working temperatures between 80 °C and 100 °C.

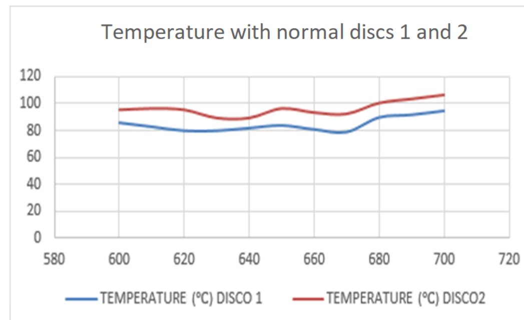

Figure 13. Temperature of the ventilated discs

For acquiring the temperature data with the original discs, the tests are conducted in the same route selected (Tambo-Cañar), and the results obtained with ventilated discs are shown in Figure 14. The obtained range of working temperature is between 90 °C and 130 °C.

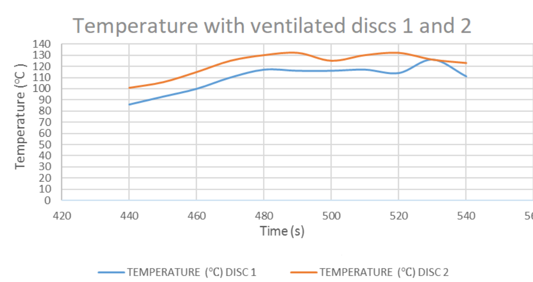

Figure 14. Temperature of the hyperventilated discs

Test of braking distance with original discs

The vehicle was tested with normal discs, under the conditions shown in Table 1.

Table 1. Test conditions and results for braking distance with conventional discs

Initial speed (km/h)	**100**
Initial time (s)	1637
Initial temperature (°C)	64
Final speed (km/h)	0
Final time (s)	1641
Final temperature (°C)	82
Braking distance (m)	37,5
Braking time (s)	4

Braking test with hyperventilated discs

Hyperventilated discs were installed in the test vehicle, and tests were conducted under the conditions shown in Table 2.

Table 2. Test conditions and results for braking distance with hyperventilated discs

Initial speedl (km/h)	100
Initial time (s)	178
Initial temperature (°C)	39
Final speed (km/h)	0
Final time (s)	181
Final temperature (°C)	55
Braking distance (m)	25
Braking time (s)	3

At last, the two previous tests of braking distance with original and hyperventilated discs were compared, and the results are shown in Figure 15.

To make the comparison plots, the initial and final times were discarded since they are associated to the period during which the program is run, and thus they are not significant values for comparing the braking distance.

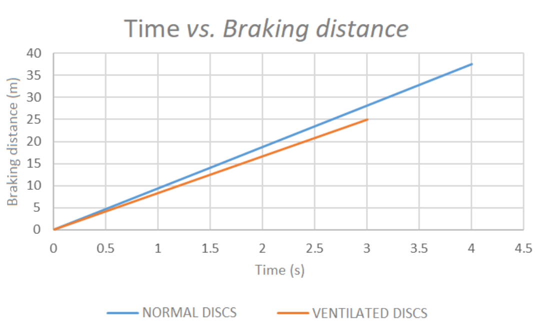

Figure 15. Comparison of braking distances of the original and hyperventilated discs

A braking distance of 37 m was obtained with the original discs, and a braking distance of 25 m with the hyperventilated discs. Considering the computational load and the operating time for mechanizing, the redesign cost with respect to the original disc represents a 30% increase of the market value.

4. Conclusions

Thanks to the Solidworks software the redesign was performed in an easy and precise manner, and thereby the disc could be further mechanized with the help of a CNC milling machine to obtain exact and reliable redesign results.

The system for monitoring the braking discs temperature enabled visualizing, in real time, the data of heat generated by the thermal loads when the vehicle is braked.

The ventilated brake discs dissipated the heat more effectively than normal brake discs, achieving better efficiency, less braking time and distance, and greater driving safety.

The redesign cost has an increment of 30% with respect to the original disc, justifying this value with the data of braking time and distance obtained in this study.

For future studies it may be analyzed the concentration of axial stresses in the modified disc, with the purpose of verifying its durability and useful life time.

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