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DESIGN AND ANALYSIS AN EFFICIENT LIGHTWEIGHT BRAKE CALIPER FOR KUIM ELECTRIC VEHICLE

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ABSTRACT

The purpose of this project was to design and fabricate an optimized caliper disc brake for KUIM electric vehicle. There are several properties of the caliper disc brake must be consider to make sure that the product that will produce have a quality from all aspects which are low noise level, life cycle cost, pollution rates, energy consumption, material consumption, provide safety and reliability, and high serviceability. The objective of this work is to design, analyze and investigate the strength and stiffness of the brake caliper during braking operation using ANSYS Workbench 15.0. This analysis is further used to identify the critical locations of low stiffness on the brake caliper and also aimed at evaluating the performance of brake caliper under severe braking conditions. Hence best suitable design is suggested based on the performance and strength criteria.

***Keywords*:** Brake calliper, Braking system, Analysis

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REKA BENTUK DAN ANALISIS CALIPER BREK YANG DIOPTIMUMKAN UNTUK KENDERAAN ELEKTRIK KUIM

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ABSTRAK

Tujuan projek ini adalah untuk merekabentuk dan mengarang brek cakera calliper yang optimum bagi kenderaan elektrik KUIM. Terdapat beberapa sifat brek cakera calliper yang mesti dipertimbangkan untuk memastikan bahawa produk yang akan menghasilkan mempunyai kualiti dari semua aspek yang tahap kebisingan yang rendah, kos kitaran hayat, kadar pencemaran, penggunaan tenaga, penggunaan bahan, menyediakan keselamatan dan kebolehpercayaan, dan kebolehpasaran yang tinggi. Objektif kerja ini adalah untuk merekabentuk, menganalisis dan menyiasat kekuatan dan kekakuan dari calliper brek semasa operasi brek menggunakan ANSYS Workbench 15.0. Analisis ini digunakan untuk mengenal pasti lokasi kritikal kekakuan rendah pada calliper brek dan juga bertujuan untuk menilai prestasi calliper brek di bawah keadaan brek yang teruk. Oleh itu, reka bentuk yang sesuai adalah dicadangkan berdasarkan kriteria prestasi dan kekuatan.

Kata kunci: Caliper Brek, Sistem Brek, Analisis

1.0 INTRODUCTION

Brakes are most important safety parts in the vehicles. Generally all of the vehicles have their own safety devices to stop their car. Brakes function to slow and stop the rotation of the wheel. To stop the wheel, braking pads are forced mechanically against the rotor disc on both surfaces. They are compulsory for all of the modern vehicles and the safe operation of vehicles. In short, brakes transform the kinetic energy of the car into heat energy, thus slowing its speed.

Brakes have been retuned and improved ever since their invention. The increases in travelling speeds as well as the growing weights of cars have made these improvements essential. The faster a car goes and the heavier it is, the harder it is to stop. An effective braking system is needed to accomplish this task with challenging term where material need to be lighter than before and performance of the brakes must be improved.

Today's cars often use a combination of disc brakes and drum brakes. For normal sedan car, normally disc brakes are located on the front two wheels and drum brakes on the back two wheels. Clearly shows that, together with the steering components and tires represent the most important accident avoidance systems present on a motor vehicle which must reliably operate under various conditions.

However, the effectiveness of braking system depends on the design itself and also the right selection of material. It is important to do some analysis on a disc brake rotor which has been designed to predict the behavior of the systems than follow with some improvements. In order to understand the behaviors of braking system, there are three functions that must be complied for all the time as mention by Smith (2002);

a) The braking system must be decelerate a vehicle in a controlled and repeatable fashion and when appropriate cause the vehicle to stop.
b) The braking should permit the vehicle to maintain a constant speed when traveling downhill.
c) The braking system must hold the vehicle stationary when on the flat or on a gradient.

Braking system is an energy converting system that converts vehicle movement into heat while on application of clamping force using friction pads on brake rotor. This is done by applying pressure on back side of piston pushing the brake pads against the rotor disc causing frictional force at contact and inhibiting the motion of the vehicle.

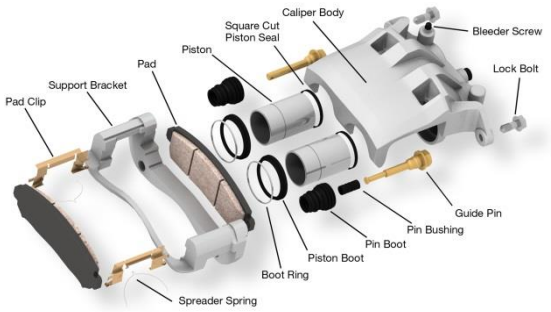

Figure 1 : Exploded of Caliper Design

The main function of the caliper is to support the brake pads and the clamping force is applied by the piston. Important aspects of a caliper is low weight but at the same time high stiffness. High stiffness and an evenly distributed pressure on the pads are necessary to achieve optimal braking force. An evenly distributed pressure results in evenly heat distribution which is crucial for wear and to avoid noise which occurs by variations in disc temperature. These characteristics are a result from the choice of material, manufacturing precision and the design of caliper.

2.0 LITERATURE REVIEW

2.1 Brake System Review

A brake is a device by means of which artificial frictional resistance is applied to moving machine member, in order to stop the motion of a machine (SAE International, 2003). A brake caliper usually made of cast iron or ceramic, is connected to the wheel or the axle. To stop the wheel, friction material in the form of brake pads (mounted in a device called a brake caliper) is forced mechanically, hydraulically or pneumatically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop.

Belhocine Ali and Bouchetara Mostefa (2013), analysed the thermomechanical behavior of the dry contact between the brake disc and pads during the braking phase. The thermal-structural analyse is then used to determine the deformation and the Von Mises stress established in the disc, the contact pressure distribution in pads.

Anders Forsman and Mikael (2009), investigated the possibility to improve the performance of the brake caliper for a GM project. The aim is to design a caliper with less amount of material but with the same stiffness. The delimitations are that the manufacturing costs should be unchanged and the design should work without modifications of the surrounding parts.

The detailed and refined finite element model of a real disc brake considers the surface roughness of brake pads and allows the investigation into the contact pressure distribution affected by the surface roughness and wear. It also includes transient analysis of heat transfer and its influence on the contact pressure distribution. The focus is on the numerical analysis using the finite element method. The simulation results are supported with measured data in order to verify predictions. An improved numerical methodology is presented by considering three-validation stages, namely, modal analysis at component and assembly levels and verification of contact analysis. Prior to that, a realistic surface roughness of the brake pad at macroscopic level is considered in the finite element model instead of assuming a smooth and perfect surface that has been largely adopted by most previous researchers. These two aspects have brought about significant improvement to the validation as well as analysis. Wear and thermal effects are other distinct aspects of disc brakes that influence contact pressure distributions and squeal generation in a disc brake assembly and they are also included in the current investigation. Transient analysis of disc brake vibration using a large FE model that includes thermal effects is carried out.

3.0 METHODOLOGY

3.1 Design Parameters and Calculations

The calculation and verification of braking force is a crucial step in the design process of an automobile as the braking system directly factors as a good control and safety feature in the product. While designing, the main objective is to generate more braking force than ideally required to account for inefficiencies in mechanical linkages and hydraulic systems.

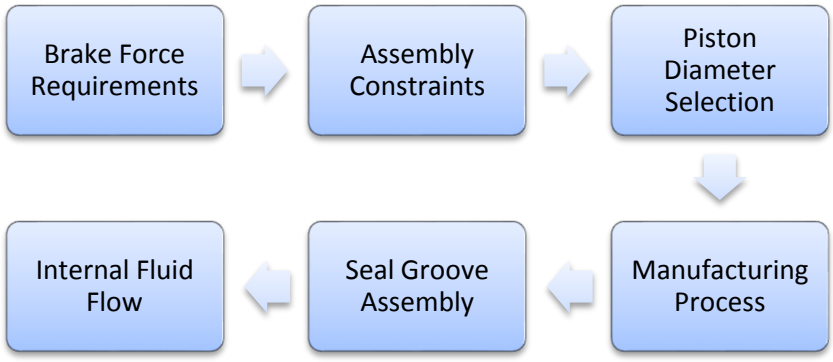

Figure 2 : Methodology for design of caliper

3.2 Material Selection Of Caliper

Caliper is a component of braking system which is used for applying the required torque on the rotor. The customised caliper housing must be lightweight and also the loads that will be coming on the housing. In the graph of tensile strength vs. Density the aluminium materials are only allowed because aluminium is lightweight and higher grade of aluminium gives us higher strength to sustain under loading. From different materials, high grad e aluminium 7075 T6 is finalised.

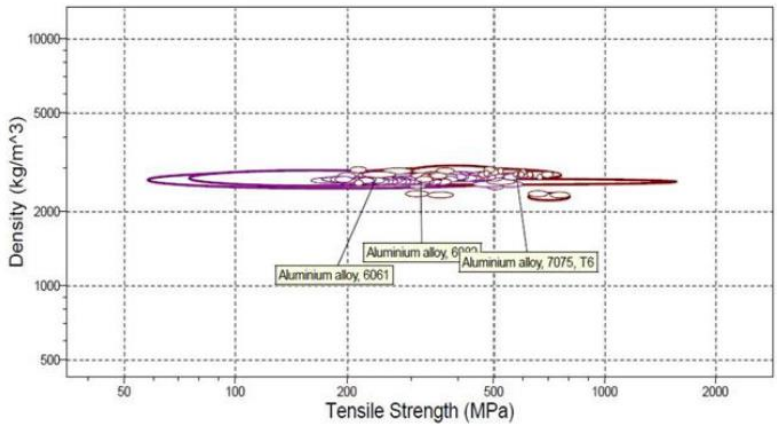

Figure 3 : Ashby chart for material selection

3.3 Bore Diameter Calculations

When the driver applies brakes, the pedal force gets converted into hydraulic pressure in the master cylinder. This pressure, which acts as an actuating force, is transferred through the brake fluid to the caliper mounted on the disc. Here the actuating force gets converted into the clamping force. Magnitude of this force depends upon the bore diameter and number of pistons in the caliper. The clamping force pushes the friction pads against brake rotor thereby generating a frictional force between them which is responsible for braking torque. The generated braking torque must be greater than the required braking torque to stop the vehicle. Required braking torque on a particular wheel is calculated from the load on the

$$Fc = \frac{Tr}{\mathrm{re}} . \frac{1}{\mu}$$

The above equation gives us the magnitude of clamping force which is applied on the rotor by the piston. The diameter and number of pistons can be decided by performing iterations based on the above equation and depending upon space availability. The piston diameter is nothing but the bore diameter of caliper. A clearance fit has to be provided between the piston and the caliper bore

in the absence of any seals. A step is also provided at the bottom of the bore to prevent the piston from touching the bottom surface of the caliper and to increase the space for the brake fluid to apply the required pressure.

3.4 Seal Groove Geometry

The pressure in the brake fluid is lead through brake lines down to the caliper. The caliper is mounted on the brake corner and holds the brake pads. The cylinder in the caliper has a seal groove where a seal fits into. This seal prevents the brake fluid from leaking out between the cylinder and the piston. During brake apply, pressure forms inside the cylinder and pushes the piston and the brake pad out towards the disc and creates friction which generate braking torque. The seal groove has a special geometric design which helps the piston to retract after braking. The seal sticks to the piston and deforms with the piston travel, see figure 3. When the pressure is removed, the seal will strive to return to its origin shape and create a roll-back of the piston. This roll-back can be controlled depending on how the groove is designed geometrically.

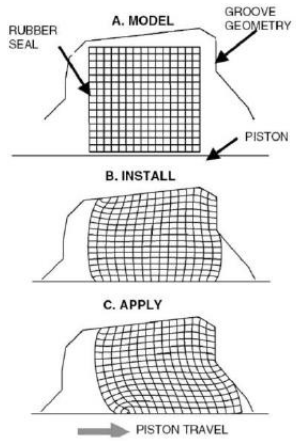

Figure 4 : Deformation of seal in seal groove

3.5 Modeling Of Caliper

Modelling of caliper was done as per requirement of the piston diameter and assembly constraints in the wheel rim. Parametric modelling was used in modelling of left and right part of caliper which is symmetric.

Figure 5 : CAD Model of Brake Caliper

4.0 STRUCTURAL ANALYSIS OF BRAKE CALIPER

4.1 Finite Element Analysis

After the numerical calculations, all the parameters such as bore diameter, seal groove, mounting, etc. are decided and then the CAD modelling of the caliper was done using CATIA V5. This model was analyzed by applying the forces and pressure. Static structural analysis of the CAD model was carried out in ANSYS 15.0. Following material parameters were considered.

Table 1 : Properties of Al 7075

No	Parameter	Value
1	Density	2700 kg/m^3
2	Young`s Modulus	72 GPa
3	Yield Tensile Strength	503 MPa
4	Ultimate Tensile Strength	590 MPa

4.2 Meshing

The different mesh parameters like aspect ratio, skewness were considered too improve the mesh quality. Out of the different element types like hex dominant, sweep etc. tetra elements were considered as they capture the curvatures more accurately than in any other method. Proximity and curvature was used in order to ensure finer mesh along the curved regions and varying cross sections.

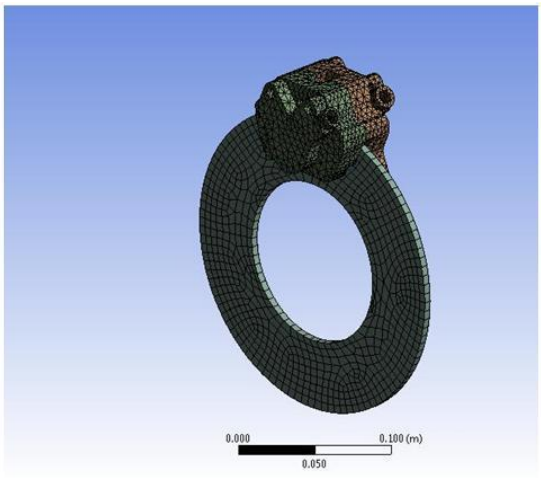

Figure 6 : Meshed Model of a Brake Caliper

Caliper body is subjected to mainly following three loads:

1. Reaction on caliper due to the hydraulic pressure applied on piston
2. Reaction on the caliper body due to clamping force
3. Frictional force on pad, transmitted to the friction pad mounts.

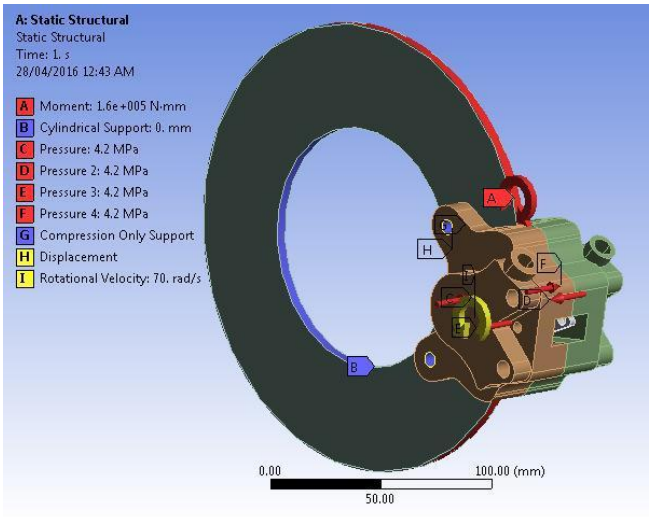

Figure 7 : Loading Conditions for Brake Caliper

The piston diameter and the bore diameter are calculated according to required braking torque. This magnitude of clamping force is applied on the rotor by the

piston. The diameter and number of pistons can be iterated according to equation depending upon the rim size i.e. space availability.

The piston diameter was selected to be 28 mm as per availability of rubber seal. The piston diameter is nothing but the bore diameter of caliper. There is clearance fit between the piston and the caliper bore in absence of any seals. A step is provided at the bottom of bore to prevent the back side of piston from touching the bottom surface of caliper and to increase the space for fluid to apply pressure.

5.0 RESULTS AND DISCUSSIONS

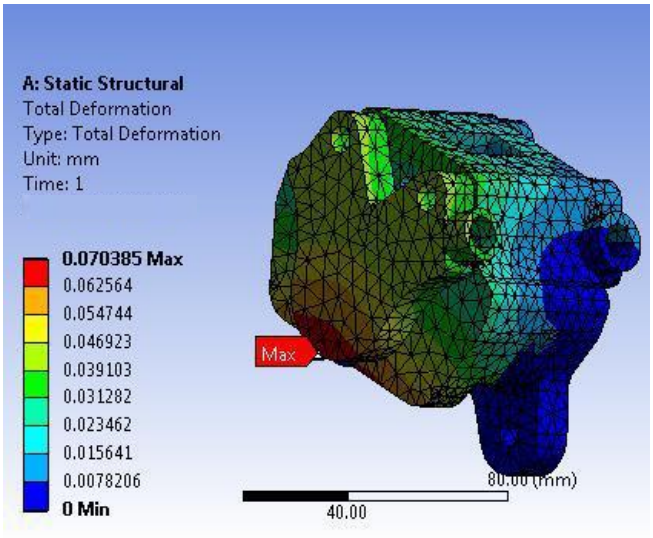

Figure 8 : Total deformation of a brake caliper

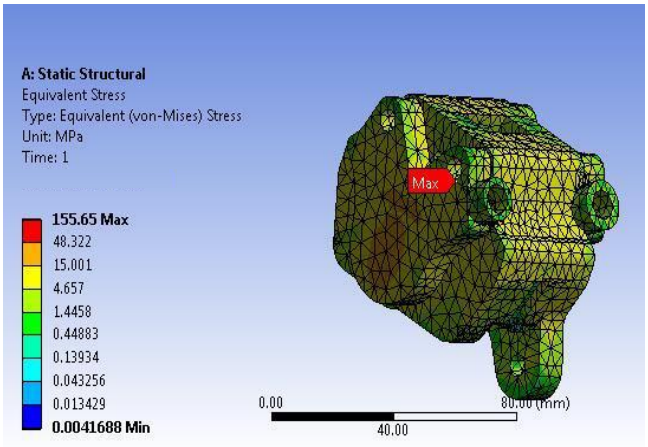

Figure 9 : Equivalent stress (von-misses) of a brake caliper

Table 2 : Deformation & Stress variations

d_{max}mm	0.070385
σ_{max} (MPa)	155.65
FOS	3.26

The stress results show that factor of safety for the designed model is within limits Thermal stresses were neglected as their effect is negligible. The parameters decided could help in further lowering the manufacturing cost and weight.

6.0 CONCLUSION

The following comments could be concluded:

1. Determination of the braking force is the most crucial aspect to be considered while designing any braking system. The generated braking force should always be greater than the required braking force.
2. The calculation of required clamping force helps us to decide the diameter and the number of pistons to be used. Space and assembly constraints are also an important factor while designing the caliper body.
3. The seal groove geometry is pivotal to the operation of the caliper as it allows the piston to retract after the required clamping force has been applied.

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BIODATA PENULIS

Muhammad Hazwan Bin Md Jamal memperoleh Ijazah Sarjana Kejuruteraan Mekanikal dari Universiti Tun Hussein Onn Malaysia dan Ijazah Sarjana Muda Kejuruteraan Mekanikal (Automotif) dari Universiti Teknikal Malaysia Melaka. Sebelum ini, beliau menjawat jawatan sebagai Dekan Fakulti Sains & Teknologi sebelum dilantik menjadi Pengarah Pembangunan di Kolej Universiti Islam Melaka.

Mohd Kadri Bin Md Salleh memperoleh Ijazah Sarjana Muda Kejuruteraan Elektrik (Sistem Kuasa) dari Universiti Teknikal Malaysia Melaka. Kini berkhidmat sebagai Pensyarah di Kolej Universiti Islam Melaka.