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Modelling of Brake Pad Disc with emphasis on dynamic analysis and deformation of structure.

Arpit Darbari [1,*] and Manu Bhargava [2]

[1] *Mobility and Automotive Management, SRH University of Applied Sciences, Berlin, Germany - 10625*
[2] *Automobile Engineering, SRM Institute of Science and Technology, Chennai, Tamil Nadu, India - 603203*

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Abstract

The aim of our investigation has been to design and model and brake rotor for a TVS N Torq Scooty. The brake rotor of TVS N Torq was reduced in thickness and diameter to reduce weight but also designed to provide better results. In the present work design, modelling and analysis of the brake rotor that we have done on Dassault SOLIDWORKS. After series of analysis, we achieved the values as follows: Stress (1.742e+08 N/m2), Displacement (1242.8mm), and factor of safety (2.2) values within the permissible limit.

Keywords: Brake Pad Disc; Dynamic Analysis; Structural Deformation; Finite Element Analysis (FEA); Thermal-Mechanical Coupling; Vibration Analysis; Stress Distribution

1. Introduction

The rotors, the round discs attached to each wheel (two in the front and two in the back), are crucial components in a vehicle's braking system. Understanding the friction mechanisms at the interface between the fixed brake pad and the revolving brake disc is complex. The creation of surface layers with characteristics different from the underlying materials is influenced by factors such as the starting material, loading conditions, temperature, and environmental context. Despite these variables, automobile engineers require consistent or at least predictable friction qualities over time, regardless of environmental changes. This design enhances braking performance by allowing faster heat dissipation, reducing thermal loads on the rotor.

High operating demands and the need to maintain brake system friction characteristics within acceptable ranges result in complex multi-component brake pad compositions, often with over 20 separate elements. Rotors convert kinetic energy (movement) into thermal energy (heat), much of which is dissipated. Brake fade, a term for this type of failure, occurs when the system cannot dissipate heat efficiently. In our work, we use a single material disc brake with varied shape plate rotors to address brake screech and improve heat dissipation and reduce squeal. The large surface area of the rotors creates friction as the callipers compress the brake pads, slowing the wheel's spin and the car's movement.

We selected three different types of disc rotors: vented and drilled, vented, and solid. These variations impact friction and heat dissipation. All braking systems aim to stop the vehicle reliably under various conditions. The difference between a good and a bad system is its performance under challenging circumstances. Using Dassault Systems' SOLIDWORKS, a solid modelling computer-aided design (CAD) and computer-aided engineering (CAE) tool, we modelled and analysed these rotors. The SOLIDWORKS program, created by Jon Hirschtick and later acquired by Dassault Systems, provided the necessary tools for detailed analysis.

* Corresponding author: Arpit Darbari.

Our design and analysis demonstrate significant improvements over current models. We reduced the weight and thickness of the rotor, making it smaller in diameter while maintaining its properties and capabilities. The achieved Factor of Safety (2.2) ensures the rotor can handle the extreme conditions considered in our analysis, such as maximum vehicle speed and braking forces. By selecting appropriate materials, the final design manages the disc's deformation and stresses effectively. These improvements suggest a reliable performance of the brake system under various operational conditions.

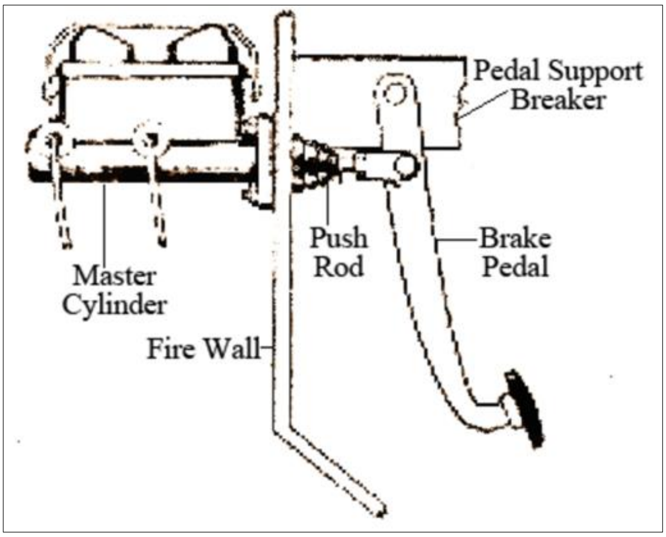

Figure 1 Brake Pedal Assembly

2. Materials and Methods

2.1. How do brakes work?

Components between the driver's foot and the wheel brakes convert the driver's force into friction force at the brake-rubbing surfaces. The actuation system is what it's called. Mechanical, hydraulic, pneumatic, or a mix of these systems can be used. Brakes are applied when the driver activates the system. A connection connects the brake pedal to the actuation mechanism, which transmits force. A push/pull rod running a single hydraulic master cylinder can serve as this linkage. Alternatively, the linkage might be a complex, adjustable balance-bar system for adjusting front and rear brake balance.

2.1.1. Types of Brake Actuation Systems

Mechanical Brakes

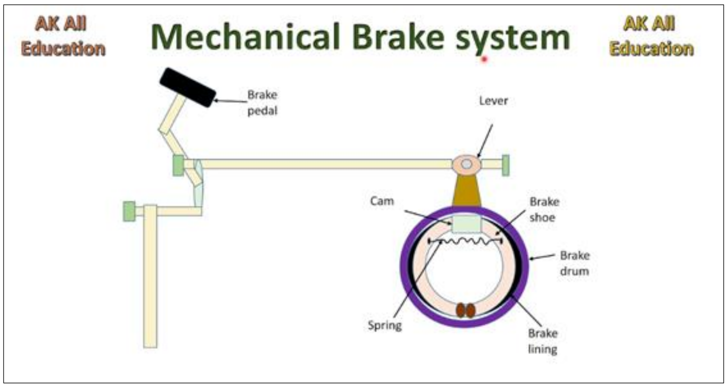

Figure 2 Mechanical Brakes

A mechanical system is the most basic brake-actuating system. When the brake pedal is pressed, it activates wires or rods that apply the brakes. In a drum brake, the mechanical connection pulls the shoes outward, whereas in a disc brake, it clamps the pads against the rotor.

Hydraulic Brakes

Hydraulically actuated systems are used in modern automobiles. The cables or rods are re- placed with fluid-filled conduits and hoses in a hydraulically operated system. Pedal linkage powers a piston in a master cylinder to pressurise the fluid inside the lines and hoses, replacing the mechanical braking system. The friction material is forced against the drum or rotor by the fluid pressure in each wheel cylinder.

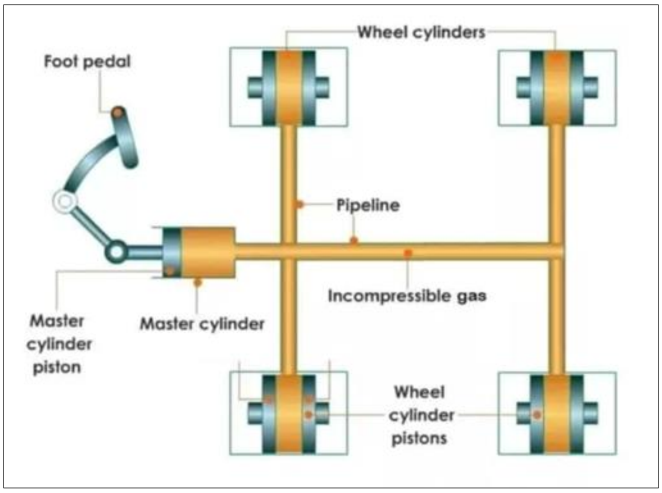

Figure 3 Hydraulic Brakes

2.2. Pneumatic Brakes

Compressed air controls the brakes in a pneumatic or air brake system. Large cars usually use air brakes. Because air is continually supplied by a compressor and stored in huge amounts, tiny leaks cannot cause a total loss of brakes in this system.

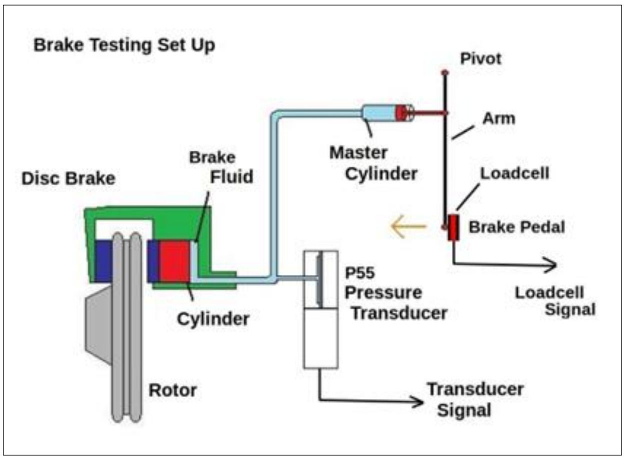

Figure 4 Pneumatic Brakes

2.3. Types of Brakes

2.3.1. Disc Brakes

The disc brake is a contemporary brake that replaces the rotor with a flat metal disc. Each side of the drum has a rubbing surface. replaced with a rotor, a flat metal disc Cast iron is commonly used for the rotor. Each side has a rubbing surface. A callipers surrounds the rotor and contains friction materials. A brake pad, puck, or liner is a disc-brake friction substance that covers the rotor on both sides. The pads are firmly clamped on the sides of the or liner by this callipers. This calliper is meant to produce friction on the rotor. Disc brakes provide the following advantages: Brake fade resistance is improved. Improved cooling Resistant to water and dirt Maintenance is reduced. For a given brake weight, a larger surface area is required. When contrast to drum brakes, disc brakes have no servo action.

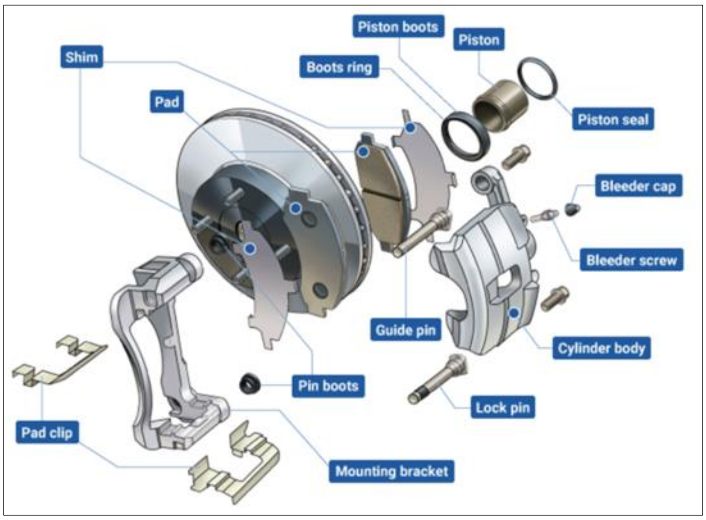

Figure 5 Disc Brakes

2.3.2. Drum Brakes

Inside the drum, internal drum brakes have a rubbing surface. They have brake shoes that, when squeezed, are forced outwards and into contact with the drum, causing the vehicle to stop owing to friction between the brake shoes and the drum. The brake drum is typically constructed of a heat-conductive and wear-resistant form of cast iron. It revolves around the axle and wheel. Brake shoes are normally welded together from two sections of steel. The friction material is either riveted or adhesively connected to the liner table. The Web is a crescent-shaped piece with various-shaped holes and slots for return springs, hold-down hardware, parking brake link- age, and self-adjusting components. The web transmits all of the wheel cylinder's application force to the lining table and brake lining. On each side of the lining table's edge, there are three V-shaped notches or tabs known as nibs. The nibs rest against the backing plate's support pads, which hold the shoes in place. There are two shoes in each brake system, one main and one secondary. The primary shoe is placed closer to the front of the car and has a different lining than the secondary shoe. Because the two shoes are frequently interchangeable, it's crucial to look for any differences. The parking brake or handbrake is coupled to the drum brake in contemporary cars.

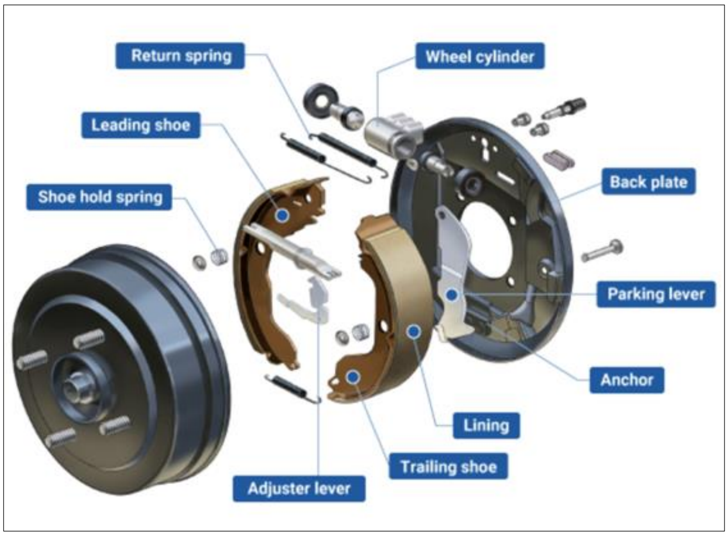

Figure 6 Drum Brakes

2.4. Brake Pads

In drum brakes, the brake pad serves the same purpose as the brake lining. Per braking disc/rotor, two brake pads are usually required. It's an element of the callipers 'assembly that wears out over time. It's made up of little bits of high-friction rubber. The type of friction material used depends on the vehicle's needs. Friction modifiers, powdered metal, binders, and fillers are among the components of brake pads. To change the friction coefficient, friction modifiers like graphite and cashew nut shells are utilised. Lead, zinc, and brass, for example, are powdered materials that boost a material's resistance to heat fading.

2.5. Types of Brake Callipers

2.5.1. Floating Callipers

Sliding callipers is another name for it. A floating calliper, as the name implies, floats on a route inside its support in response to the movement of the brake disc/rotor. Only one side of the floating callipers has a piston. It merely has a brake pad on the other hand. As a result, the floating callipers always have one piston and two brake pads. The piston is located just behind the inner brake pad. It is based on Newton's third law of motion, which states that "every action has an equal and opposite response." When you press the brake lever, hydraulic pressure pulls the piston towards the inner brake pad, which pulls the inner brake pad towards the brake disc/rotor. The response force pushes the calliper's body towards the outer brake pad at this point. The callipers provide friction on both sides of the braking disc/rotor in this manner. The braking fluid immediately enters the callipers via hydraulic route inside the callipers, which is another visible difference in floating callipers. One, two, or three pistons can be used in floating callipers.

2.5.2. The Benefits

When compared to fixed callipers, it requires fewer parts. Manufacturing it is less costly. It's really popular. Floating callipers are simpler to bleed than fixed callipers. When contrasted to the aluminium fixed callipers, it is usually composed of cast iron or steel, which adds weight and heat. The disc is stopped faster by a heavy weight than by a low weight. The other advantage is that because to their sliding nature, floating callipers can disperse heat more effectively, reducing the risk of brake fade.

2.5.3. Consequences

It takes more force to clamp the disc than a fixed calliper piston. Sliding off the rotor causes some braking torque loss. The diameter of the piston necessitates a greater volume of brake fluid. When compared to fixed piston callipers, it has a shorter life and is less durable. It's not as rigid as fixed callipers. It has the potential to boil the braking fluid if the disc overheats. It has an issue with dirt and rust causing it to stick.

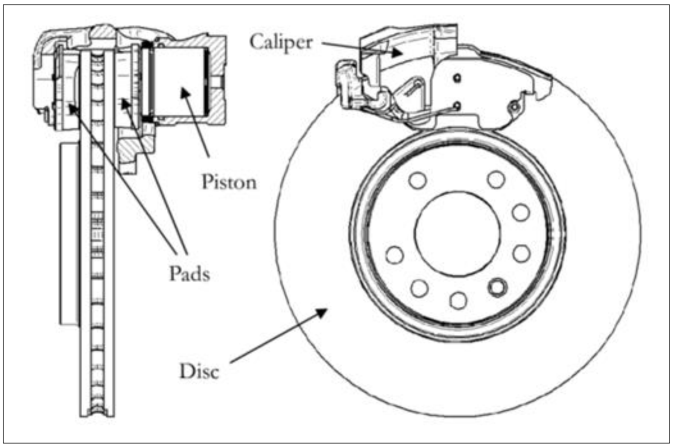

Figure 7 Floating Callipers

2.5.4. Fixed Callipers

A fixed calliper, as the name implies, does not move with the rotation of the braking disc/rotor. A permanent mounting adaptor is required for the fixed calliper. The steering knuckle is securely attached to it. Both sides of the fixed calliper have pistons. As a result, it usually features a two-piston and two-brake-pad configuration. When you squeeze the brake lever, hydraulic pressure pulls both pistons, which pulls both brake pads towards the braking disc. Finally, the brake pads adhere to the brake disc/rotor, causing friction that prevents the disc/rotor from mov- ing. The fixed calliper mechanism ensures that equal pressure is applied on both sides. Brake fluid is routed by crossover lines or steel tubing outside the calliper housing in fixed callipers. With sealed O-rings, they are guided into the calliper halves. Depending on the vehicle's needs, a fixed calliper may have 2, 4, 6, or 8 pistons. There are also three piston fixed callipers, one with two tiny pistons on one side and one with a large piston on the other.

The Benefits It produces a greater amount of braking torque than a floating calliper. Be- cause the fixed calliper does not move, there is no loss of braking torque due to sliding. It is generally made of aluminium which means it has better heat dissipation as compared to cast iron or steel calliper. Because it is constructed of aluminium, which is less prone to rust and corrosion, it does not stick. It is more rigid than a floating calliper. When compared to float- ing calliper, it has a longer life and is more durable. Consequences The cost of production is high. In comparison to the floating calliper, it has a more complicated construction and requires more moving components. Fixed callipers are only found in premium and high-performance automobiles. It takes more work to bleed fixed calliper than floating calliper.

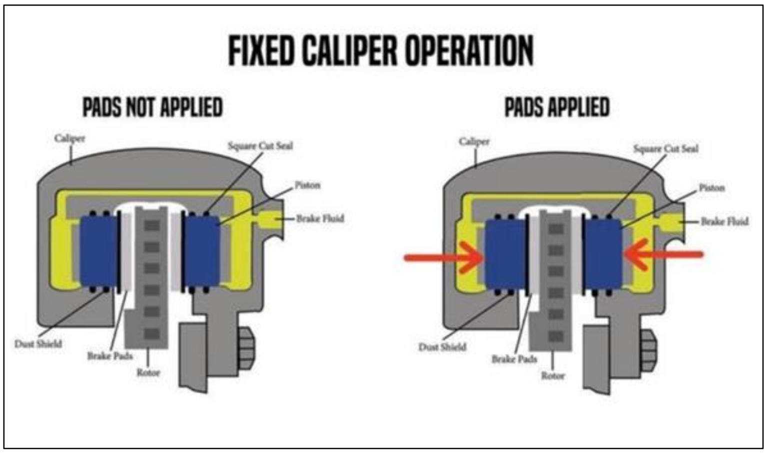

Figure 8 Fixed Callipers

2.5.5. Breaking Limits

There are limits to how quickly a vehicle can stop. The following are the brake performance limits:

Limit of force

It signifies that the driver is pushing as hard as he can with his foot and the automobile is unable to stop any faster. To put it another way, if the driver could push harder, the automobile would come to a faster halt. This limit can be changed by lowering the size of the master cylinder, changing the lining, employing power-assist brakes, and other techniques. When the brakes get hot, a force restriction might arise. This is referred to as brake fade. It's possible that the force limit you've hit is actually a temperature restriction.

Deflection limit

It is reached as the brake pedal stops at the floor or stop. This means the pedal is moving too far to get maximum efficiency from the brakes. A deflection limit can be eliminated by design changes such as stiffening the pedal-support structure, increasing master-cylinder size, installing stiffer brake hoses, changing to stiffer callipers, or other modifications. Maintenance can be eliminate a deflection limit.

Wear limit

This won't happen when brakes are new. However, if friction material is worn excessively, it may be worn out just when you need the brakes most-such as at the end of a long race. Wear limits can be eliminated or reduced by changing linings, using larger brakes, or by dissipating heat.

Temperature limit

Brakes cannot absorb the full power of an engine continuously without some time to cool. When the temperature limit is reached , you can reach a force limit, deflection limit, or greatly increase the wear at the same time.

2.5.6. Experimental Procedure

The design and analysis of TVS N-Torq brake rotor and brake pad using Dassault SolidWorks. The brake rotor radius was 101.6 mm, and it was chosen after considering the size of the brake callipers. The design of the brake rotor was based on the dimensions of the wheel hub where the brake rotor was to be fit. After considering all the dimensions, a sketch was drawn on paper, then sketched on Dassault SolidWorks.

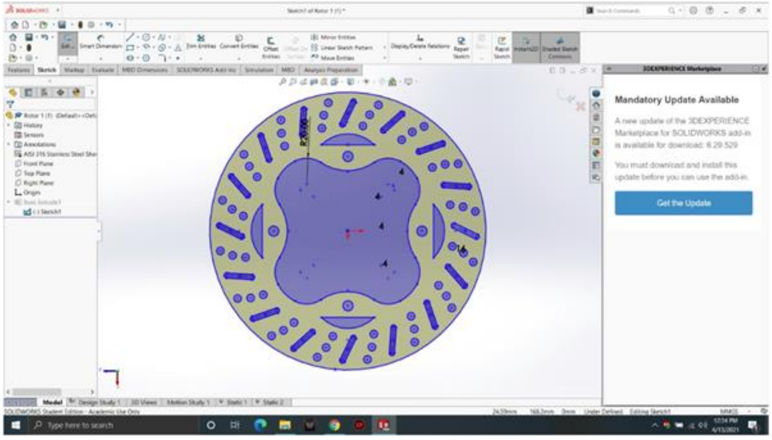

Figure 9 Brake Rotor Sketch

The above figure shows the sketch of the brake rotor, which is designed based on the dimension of the wheel hub and the brake callipers. Once the sketch was complete, the sketch was extruded by 3mm to make a brake rotor of thickness 3mm. For weight reduction, several slots and holes were made on the rotor face during the sketch itself.

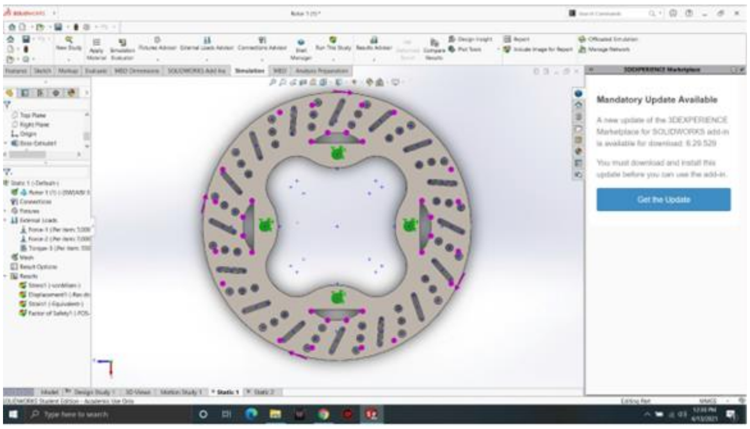

Figure 10 Model of Brake Rotor

The brake pad was also sketched and modelled by the brake callipers used. After the brake rotor was modelled, and ANSI 316 Stainless Steel material was applied to the rotor. The rotor mass was 520.76 grams.

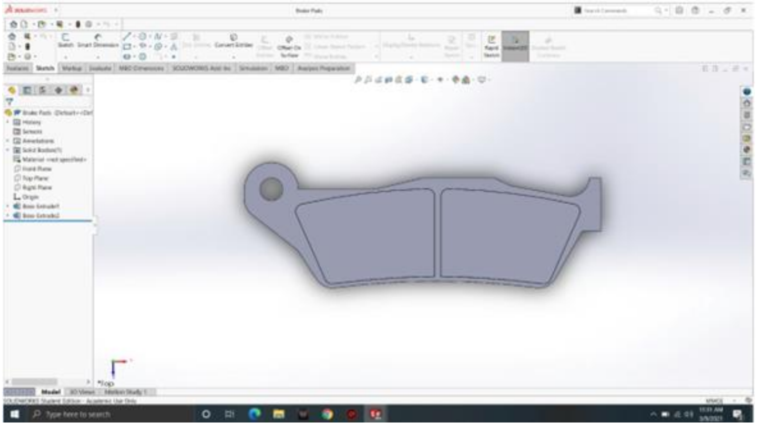

Figure 11 Brake Pad

3. Results

The analysis and simulation of the ANSI 316 Stainless Steel brake rotor of 3mm were done on Dassault SolidWorks Simulation. The following values were used to calculate the forces:

- Rotor Diameter = 203.2 mm
- Stopping Distance = 5000 mm
- Rotor Width = 3 mm
- Rotor Radius = 101.6 mm
- Tyre Diameter = 304.8 mm
- Brake Pad Width = 25.4 mm
- Piston Diameter = 25.4 mm
- Master Cylinder Diameter = 19 mm
- Frictional Coefficient Tyre/Rotor = 0.7
- Frictional Coefficient Pad/Rotor = 0.43
- Mass of the vehicle = 118 kg
- Velocity = 25 m/s = 90 km/hr

Before the analysis, the calculations related to the forces acting on the brake rotor were calculated. These are the values that were used to do the necessary calculations before proceeding with the analysis and simulation of the brake rotor.

- Throttle = 62.5 N
- Total Braking Force = 6542.392 N
- Braking Force (Each Tyre) = 3271.196 N
- Torque = 498.53 NM
- Factor of Safety (FoS) = 2.2
- R (in) = 76.2 mm
- R (out) = 101.6 mm
- R (Efficient) = 88.9 mm
- Clamping Force = 5607.76 N
- TCF = 13041.31 N
- Clamping Force (Each Tyre) = 6520.65 N

3.1. Formulas Used

- Throttle = v2 / (2 * stopping distance).
- Total Braking Force(TBF) = mass * (Throttle - (Fric Coeff. of tyre * 9.81))
- Braking Force (Each Tyre) = TBF/2.
- Torque = (B.F on each tyre * radius).
- Clamping Force = Torque / R(Efficient)
- Total Clamping Force (TCF) = Clamping Force / Fric. Coeff. Pad

- Clamping Force (Each Tyre) = TCF/2

Since the maximum torque and maximum clamping force values that the ANSI 316 Stain- less Steel brake rotor would experience were calculated are 498.53 NM and 6520.65 N, respectively. For the analysis of the ANSI 316 Stainless Steel brake rotor, the values chosen were 550 NM of Torque and 7000 N of Clamping force in order to make sure that the ANSI 316 Stainless Steel brake rotor does not fail even at values that exceed the maximum force that it would experience.

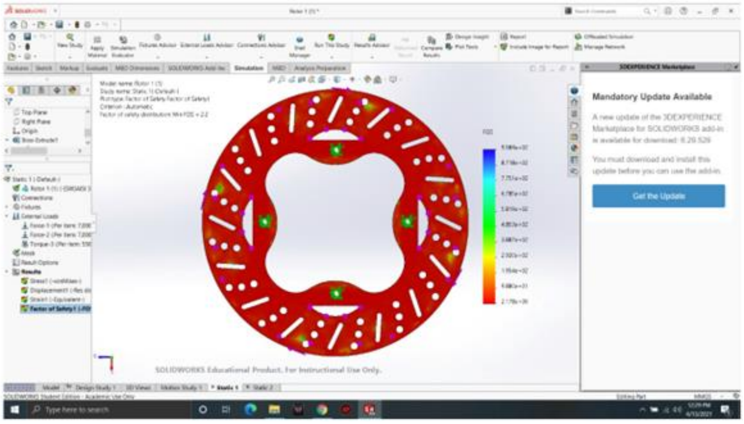

Figure 12 Stress

After the analysis the figure above shows the stress value of 1.724e+08 which is below the breaking point. The figures below shows a displacement of 1.242.8 and Factor of Safety of 2.2 simultaneously.

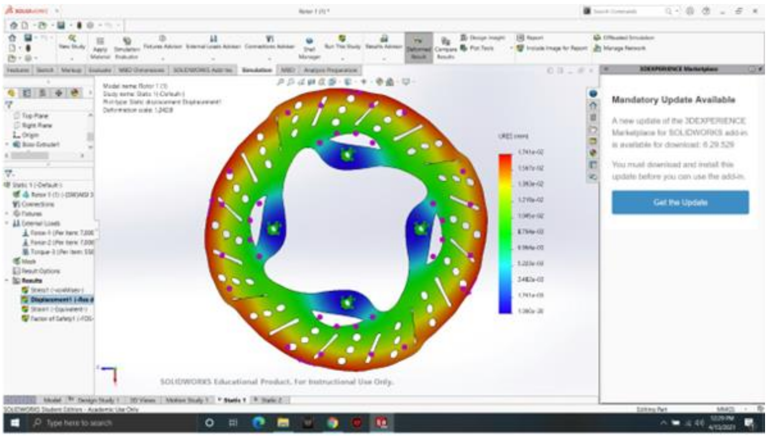

Figure 13 Displacement

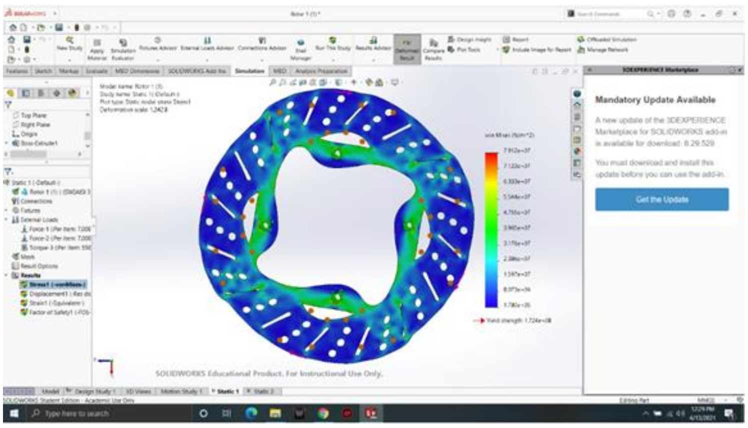

Figure 14 Factor of Safety

Table 1 TVS N-Torq Scooty Values v/s Achieved Values

S.No.	Name	Parameters of TVS N-Torq Scooty	Achieved Values
1.	Rotor Diameter	220 mm	203.2 mm
2.	Rotor Width	5 mm	3 mm
3.	Rotor Mass	885.5 gm	520.7 gm

4. Conclusion

The following conclusions are drawn from the present work: The brake rotor that we have designed is:

- 16.8mm smaller in diameter,
- 2mm less thick,
- And we have achieved 364.74 grams of weight reduction.

After such massive changes, our designed rotor can withstand forces greater than the maximum force that the rotor would experience. This brake rotor designed by us is compatible with the above conditions and can be used in the future.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Analysis and Optimisation of Disc Brake system for two-wheeler applications, Journal - International Journal of Innovative Technology and Exploring Engineering (IJITEE), Volume - Volume-9, 2019

[2] Bucher F, Dmitriev AI, Ertz M, Knothe K, Popov VL, Psakhie SG, et al. Multiscale simulation of dry friction in wheel/rail contact. Wear 2006;261(7–8):874–84

[3] Design and Analysis of a Disc Brake Rotor for Optimal Performance, Faculty of Tech- nology, School of Engineering, University of Sunderland,UK, Volume - 2019

[4] Dmitriev AI, Smolin AYu, Psakhie SG, et al. Computer modeling of local tribological contacts by the example of the automotive brake friction pair. Physical Mesomechanics 2008;11(1–2):73–84.

[5] Dmitriev AI, O sterle W, Kloß H. Numerical simulation of typical contact situations of brake friction materials. Tribology International 2008;41(1):1–8.

[6] Dmitriev AI, O sterle W, Kloß H. Simulation of mechanically mixed layer formation at local contacts of an automotive brake system. Tribology Transactions 2008;51(6):810–6.

[7] Drilled Slotted - Drilled and slotted rotors combine the drilled holes and slots for en- hanced performance. Study of thermal analysis of brake disc rotor for different disc brakes, International Journal of Mechanical Engineering and Technology (IJMET),Volume - 2009.

[8] Kemmer HA. Investigation of the friction behaviour of automotive brakes through ex- periments and tribological modeling, PhD thesis, University Paderborn, Robert Bosch GmbH, Schriftenreihe, 2002, ISBN 3-00-011230-8.

[9] O sterle W, Kloß H, Dmitriev AI. Friction control during automotive braking - experi- mental observations and simulation at the nanometer scale. Bartz W, Franek F, editors, 3rd Vienna International Conference on Nano-Technology. O sterreichische Tribologis- che Gesellschaft, ISBN 978-3-901657-32-0; 2009. p. 335–41.

[10] O sterle W, Urban I. Friction layers and friction films on PMC brake pads. Wear 2004;257:215–26.

[11] Optimization of Two-Wheeler Braking Squeal Noise Reduction using SOLIDWORKS and Finite element analysis, Journal - International Journal of Pure and Applied Mathe- matics, Volume 119, 2018.

[12] Zhang LC, Johnson KL, Cheong WCD. A molecular dynamics study of scale effects on the friction of single-asperity contacts. Tribology Letter 2001;10(1–2):23–8.

[13] Psakhie SG, Horie Y, Ostermeyer G-P, Korostelev SYu, Smolin AYu, Shilko EV, et al. Movable cellular automata method for simulating materials with mesostructure. Theo- retical and Applied Fracture Mechanics 2001;37(1–3):311–34.

[14] The mechanisms, growth, amplitude, and mitigation of brake sequel noise, Journal - Mechanical Systems and Signal Processing, Volume-152, 2021.