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DESIGN AND ANALYSIS OF A DISC BRAKE SYSTEM FOR HONDA UNICORN 150 BS-VI MOTORCYCLE

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ABSTRACT
This paper deliberates in detail the systematic design and examination of disc brake system for the Honda Unicorn 150 BS-VI motorcycle. This work involves selection of materials, computation of braking forces, and design optimization of the rotor and pads via theoretical formulas and simulation tools. From uniform pressure theory to energy-based design approach, the goal is to make sure that the product is safe, efficient, and easy to manufacture. Real-world factors such as human reaction time, thermal dissipation, and torque transmission are considered into view. It was found that the brake system can fulfill performance specifications and can be reasonably made.
Keywords: Disc brake design, Honda Unicorn 150, brake rotor, braking torque, heat dissipation, mechanical braking, automotive safety.

I. Introduction
Humans had always wanted their machines to be stronger, to go faster, to be big and powerful, small and fast, but turns out the pauses are necessary, intentional or unintentional. We have to stop these machines so that we could check and maintain them, to do replacements of parts, to increase the life of the machine and many more. And to ‘stop’ the machine’s motion we somehow needed to ‘brake’ the motion and this is where the need of the ‘brakes’ was originated.
Over the time the brakes have turned out of different kinds in different sectors to meet the specific needs. There are mechanical brakes, hydraulic, pneumatic, electric brakes, electromagnetic brakes and many more. There are also the subcategories branching through each section, as advancement and experimentations in science and engineering went on happening, we also kept in check that brakes were with par of the new faster and more stronger machines.
Mechanical brakes are of many types and come with their own advantages and limitations, it totally depends on the specific job of the brakes and design engineer to choose a specific types or combination and use the advantages to the fullest and overcome the limitations they bring inevitably
A brake is defined as a mechanical device, which is used to absorb the energy possessed by a moving system or mechanism by means of friction. The primary purpose of the brake is to slow down or completely stop the motion of a moving system, such as a rotating drum, machine or vehicle. It is also used to hold the parts of the system in position at rest.

II. Literature
The study is grounded in the principles outlined in standard mechanical design texts, such as 'Design of Machine Elements' by V. B. Bhandari and 'Clutches and Brakes' by William C. Orthwein. These works provide critical guidance on the theoretical foundation for selecting brake materials, applying uniform pressure theory, and calculating torque. Online resources including AZOM, ThyssenKrupp material databases, and manufacturer manuals further support material properties and practical constraints.
Design of Disc Brake’s Rotor (https://ijedr.org/papers/IJEDR1604140.pdf)

- This paper writes about the design and analysis of a brake rotor using SOLIDWORKS and Ansys. This was done by calculation the forces acting on a car and then selecting the suitable dimensions and material.
- Design of Machine Elements 3rd edition by V. B. Bhandari
- Clutches and Brakes Design and Selection 2nd edition by William C Orthwein

III. Braking Theory

Technically speaking, it can be said that a brake is any mechanical arrangement for using friction to absorb the energy of a moving system or mechanism. It slows down or brings to a complete halt the motion of a moving system, whether it be a rotating drum, a machine, or a vehicle. It also retains the moving parts of this system in the desired position.
It reduces speed or stops the car, and at times it also holds the vehicle still on a downhill road. The energy absorbed by the brake may be kinetic, potential, or simultaneous absorption of both types of energy. In an automobile application, the brake absorbs the kinetic energy of the moving vehicle. In hoists and elevators, the brake absorbs the potential energy released by the objects during the braking period.
Energy absorbed is converted into heat energy and then dissipated to the surroundings. This heat dissipation causes the heat problem in the brake applications.
Mechanical actuating mechanisms within mechanical brakes consist of one or some of the following:
- Levers
- Springs
- Pedals

By the shape of the friction material, mechanical brakes are further subdivided into:
- Block brake
- Internal or external shoe brake
- Disk brake
- Band brake

They are further divided into two categories concerning the direction of actuating force, namely,
- Radial brakes
- Axial brakes

Internal and external shoe brakes are radial brakes, while disk brakes are axial brakes.
Disk brakes can be observed on the front wheel of most motorcycles.
Principle of Disk Brake sector. The friction lining is attached to each pad. A calliper attached to non-rotating member exerts a force P on each pad. When the pads are pressed against the rotating disk, the friction force between the surfaces of friction lining and the disk retards the speed and finally stops the disk.
It is seen that the brake pad occupies only a small portion of the disk, where the heat is generated due to friction. On the contrary, the complete surface area of the disk is available for dissipation of heat. Since a calliper is used to exert force on the pads, this type of brake is called 'calliper' disk brake. Since the calliper contains two pads, the axial forces on two sides of the disk balance each other and leave no thrust load on the bearings.
Disk brakes have the following advantages:
(i) Disk brake is simple to install and service.
(ii) Disk brake has high torque transmitting capacity in small volume.
(iii) The inherent ability of the disk brake to dissipate heat, it is insensitive to changes in the coefficient of friction.
(iv) The disk brake is easy to control.
(v) The brake can never become self-locking.

(vi) The brake is equally effective for both directions of rotation of the disk, and gives uniform braking action.
(vii) The disk brake has 'linearity', that is, the braking torque is linearly proportional to the actuating force.
The disk brakes are never made with friction lining covering the entire circumference of the plate, because it would result in overheating. The braking pad presses only a small fraction of the circumference. There are two types of shapes for the pads of calliper disk brakes, namely,
annular
circular.
Brake capacity depends upon the following five major factors:
(i) The unit pressure between braking surfaces
(ii) The contacting area of braking surface
(iii) The radius of the brake drum
(iv) The coefficient of friction
(v) The ability of the brake to dissipate heat that is equivalent to the energy being absorbed
Energy Equation:
The braking-torque depends upon the amount of energy absorbed by the brake. When a mechanical system of mass m moving with a velocity v1 is slowed down to the velocity v2 during the period of braking, the kinetic energy absorbed by the brake is given by

$$KE = \frac{1}{2} m(v_1^2 - v_2^2)$$

3.1 Design And Calculations
Design
Material used and its property, for the friction material on the brakes, we are using:
Rigid Moulded Friction lining non asbestos - 0.47µ - 0.53µ
Physical Properties:

1.	Dynamic Friction Coefficient	0.47
2.	Static Friction Coefficient	0.53
3.	Density	1.72gr/cm^3
4.	Tensile Strength	22 N/mm^2
5.	Compressive Strength	108 N/mm^2
6.	Shear Module (G)	2700 N/mm^2
7.	Young's Module	5550 N/mm^2
8.	Poisson Coefficient	24
9.	T^0 Fading	255 ^{0}C
10.	Thermal Conductivity	0.48 W/m^{0}K
11.	Wear Rate	45 mm^3/Kwh
12.	Hardness	87Shore D
13.	Acetone Extraction	0.13%
14.	Ignition Loss	32%

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For Disc (rotor), we are using Stainless steel 340:

Sr. No.	Property	Minimum Value (S.I.)	Maximum Value (S.I.)	Units (S.I.)
1	Atomic Volume (average)	0.0069	0.0072	m^3/kmol
2	Density	7.85	8.06	Mg/m^3
3	Energy Content	106	108	MJ/kg
4	Bulk Modulus	134	151	GPa
5	Compressive Strength	205	310	MPa
6	Ductility	0.3	0.5	
7	Elastic Limit	0.15	0.3	MPa
8	Endurance Limit	175	195	MPa
9	Fracture Toughness	119	228	$MPa \cdot m^{.0.5}$
10	Hardness	1700	2100	MPa
11	Loss Coefficient	0.00095	0.0013	
12	Modulus of Rupture	205	415	MPa
13	Poisson's Ratio	0.265	0.275	
14	Shear Modulus	74	81	GPa
15	Tensile Strength	365	825	MPa
16	Young's Modulus	190	200	GPa
17	Latent Heat of Fusion	205	285	kJ/kg
18	Maximum Service Temperature	1023	1198	K
19	Melting Point	1673	1793	K
20	Specific Heat	490	530	J/kg·K
21	Thermal Conductivity	14	19	W/m·K
22	Thermal Expansion	16	18	µm/m·K
23	Resistivity	65	77	10^{-8} ohm·m

Some initial parameters that are considered and some are calculated (worst case scenario under working limit is considered while calculation):
System is, Honda Unicorn 150 BS-VI bike + 2 riders + luggage

Parameter	Value	Remark
Gross weight of the system	285 kg	139 kg, kerb weight of the bike, 70 x 2 = 140 kg, 2 passenger weight, and 6 kg of luggage load.
Max speed of the system	30 m/s	This is at 8000 rpm of engine (1000 rpm less than redline of engine) on 5th gear (gear ratio = 0.97) Wheel rpm = 6000 rpm (75% of engine rpm)
Total Energy of the system	19,5,214 J (kgm2/s2)	Summation of linear kinetic energy of bike and rotational kinetic energy of wheels. (Energy equation)

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3.2 The Disc

The disc is the reason why these types of brakes got their name, the disc, brake pads (as well as caliper) all have the same linear velocity, the brake pads and caliper are rest with respect to each other, linearly and rotationally, but the disc and brake pads are only relatively at rest linearly, but not rotationally.
So, for the brake pads the only system they have to bring to rest is "rotating" disc.
The disc has 3 major and defining dimensions, as follows

1. The outer diameter D
2. The inner diameter d
3. The thickness t

So, to start designing, we have to know beforehand something about the situation and take simple, straightforward and practical steps as we move forward. The above mentioned are not the only dimensions related to disc but as far as "rotating" disc is concerned these are the major and base dimensions.

With the above assumptions, now going to use some standard results to arrive at the dimensions mentioned above (some assumptions and practicality kept in mind), which are already being experimentally verified, and we shall just trust and use them by changing only the input parameters in the context of our problem (unicorn 150 motorcycle).

The first restriction is by the space, the place we are going to fit or mount our rotor. We have to be practical and rely on past experiences and judgements because time, money, and manufacturability are the next biggest hurdles.

But a general ratio of inner to outer radius of disc is given in that book as,

- Radii Ratio

As we have restriction on inner radius as we would mount it on outer rim of the wheel hub, going forward with the above relation we go with the following dimensions.

1. INNER DIAMETER

The disc which is mounted on the wheel, with 6 fasteners, fastening the disc at inner radius and wheel at outer radius of wheel hub.
So, the inner diameter is equal to wheel diameter.

- Inner diameter of disc d = wheel hub diameter (0.15 m)

2. OUTER DIAMETER

The outer radius is given by the radii ratio

- Outer radius = 250 mm

3. THE THICKNESS

Considering the space constrains and visual inspection of the actual disc, the 5mm thickness is optimum.

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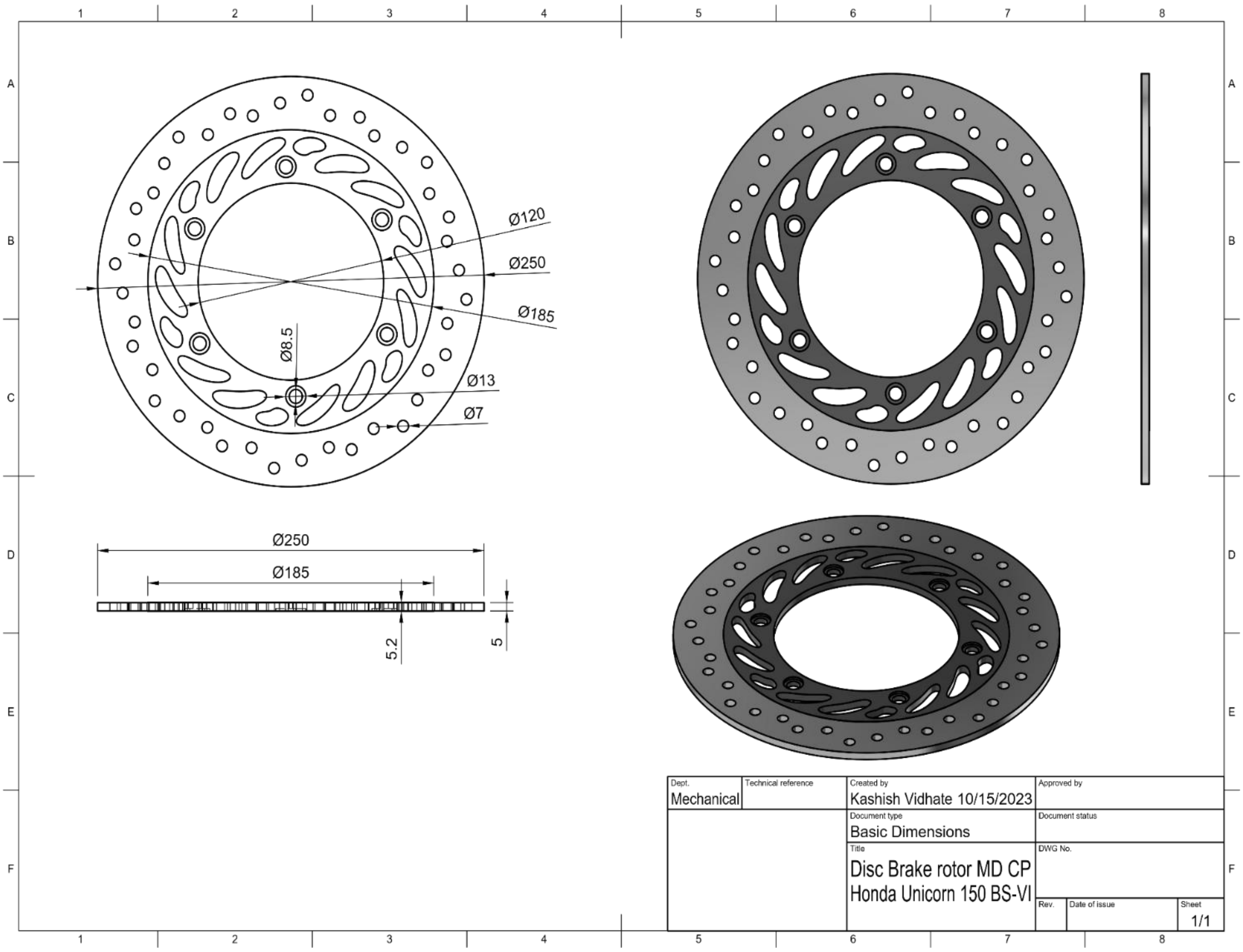
- Thickness = 5 mm



Some physical properties of the disc / rotor that are taken from the fusion 360 software itself , CAD software, are as follows
Area - 0.081 m^2
Density - 7850.00 kg / m^3
Mass - 1.246 kg
Volume - 0.0001587 m^3
Physical Material Steel
Appearance Stainless Steel - Polished
Moment of Inertia at Center of Mass (kg m^2)
Izz = 0.012

4. THE BRAKE PADS

The actual element that does the braking action when the brake lever is pulled, the brake pads are the one that actually presses the rotating disc rotor and friction material and absorbs the rotating energy of disc and turn it into heat.
The repeated action of the braking is the reason why friction material on the pads fades away.
In use the brake pads used generally are either circular or annular, the annular brake pads are used more often because they provide generally more torque that the circular brake pads [2]

5. OUTER RADIUS

The outer radius of caliper is equal to the outer radius of the disc rotor, because Braking torque is directly proportional to effective radius of braking and effective radius is directly proportional to outer radius.

Therefore, the outer radius = 125 mm

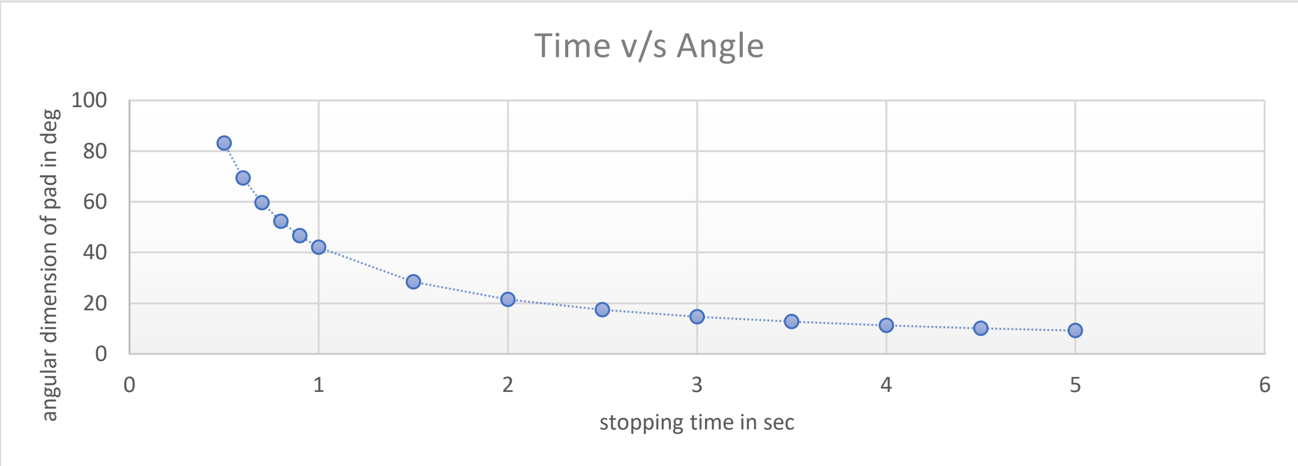
6. INNER RADIUS

Inner radius = 92.5 mm

7. ANGULAR DIMENSION

The minimum angle would be 40 degrees if the vehicle would have to be stopped in 1 sec, which is worst case scenario for a bike moving at 30 m/s speed, the actual value approaches 42 degrees the standard considered and available in market is 10 cm x 3 cm x 1 cm for 45 degrees.

theta = 45 degree.



Given Parameters:

Outer Radius (r_o) = 0.125 m
Inner Radius (r_i) = 0.0925 m
Angle (θ) = 45° = 0.7854 rad
Dynamic Friction Coefficient (μ) = 0.47
Maximum Pressure (p_{max}) = 1820 Pa

<u>Pressure Distribution For Uniform Wear:</u>

$$p = p_{max}\left(\frac{r}{r_i}\right)$$

Average radius, r = (r_o + r_i) / 2 = (0.125 + 0.0925) / 2 = 0.10875 m
p = 1820 × (0.10875 / 0.0925) = 2139.73 Pa

<u>Activation Force, Caliper Disk Brake, Annular Sector Pad:</u>

$$F = p_{max} r_i \theta (r_o - r_i)$$

F = 1820 × 0.0925 × 0.7854 × (0.125 - 0.0925) = 4.30 N

<u>Torque, caliper disk brake annular sector pad:</u>

$$T = \mu p_{max} r_i \frac{\theta}{2}(r_D^2 - r_i^2)$$

T = 0.47 × 1820 × 0.0925 × (0.7854 / 2) × (0.125^2 - 0.0925^2) = 0.22 Nm

<u>Activation Force, Annular Contact Disk Brake, Uniform Wear:</u>

$$F = 2\pi p_{max} r_i (r_0 - r_i)$$

F = 2π × 1820 × 0.0925 × (0.125 - 0.0925) = 34.38 N

<u>Torque, Annular Contact Disk Brake, Uniform Wear:</u>

$$T = \mu p_{max} \pi r_i (r_0^2 - r_i^2)$$

T = 0.47 × 1820 × π × 0.0925 × (0.125^2 - 0.0925^2) = 1.76 Nm

<u>Activation Force, Annular Contact Disk Brake, Uniform Pressure:</u>

$$F = \pi p (r_0^2 - r_i^2)$$

F = π × 1820 × (0.125^2 - 0.0925^2) = 40.42 N

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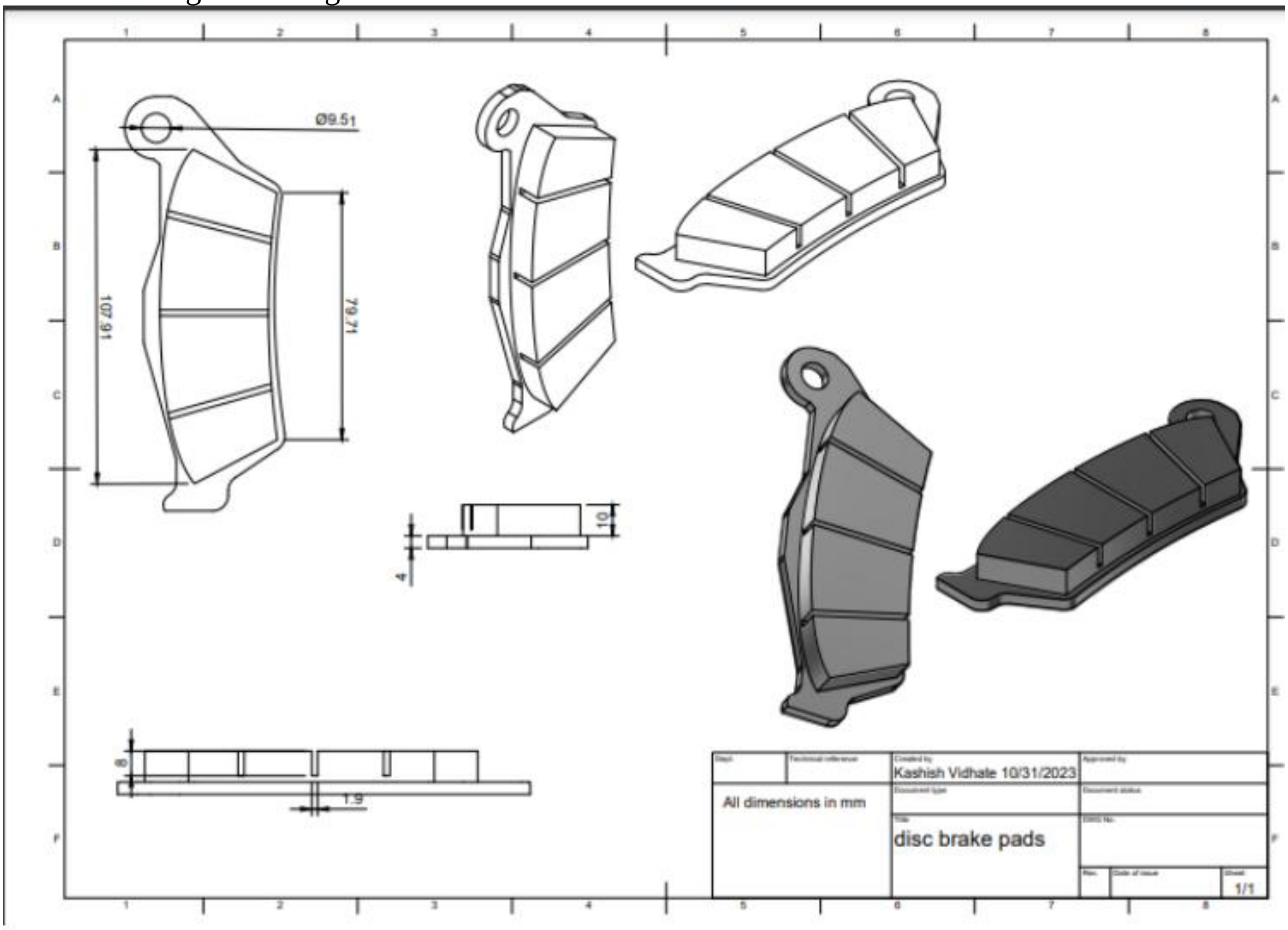
Torque, Annular Contact Disk Brake, Uniform Pressure:

$$T = \frac{2}{3}\pi\mu p(r_0^3 - r_i^3)$$

T = (2/3) × π × 0.47 × 1820 × (0.125^3 - 0.0925^3) = 2.08 Nm
The total kinetic energy produced by the vehicle and need to be absorbed by the brakes, using energy equation
Mass = 245 kg …. (145 + 100)
Initial velocity = 30 m/s
Final velocity = 0 m/s
Disc rotor material = cast iron
Disc rotor weight = 1.1 kg



8. THE CALIPER
The caliper supplied with the brake pad sizes is as follows:
The total area of the pistons is ~ 3167 mm^2, which provides an approximate radius of one piston head ~ 22 mm
The materials most commonly used are cast iron and aluminum alloy, they are fixed on the top left corner in relation to the disc center with 2, 13 mm hex head threaded bolt directly to the front wheel suspension cylinder
And employs an 8 mm plain bolt as a pin to secure the pads

IV. Results And Discussion

1. Braking Distance Calculation:
- The braking distance determined for the Unicorn 150 using the formula [(Max speed of the bike/10)2]*0.4 came out to be 4.35 meters. This conversion assumes immediate brake application.

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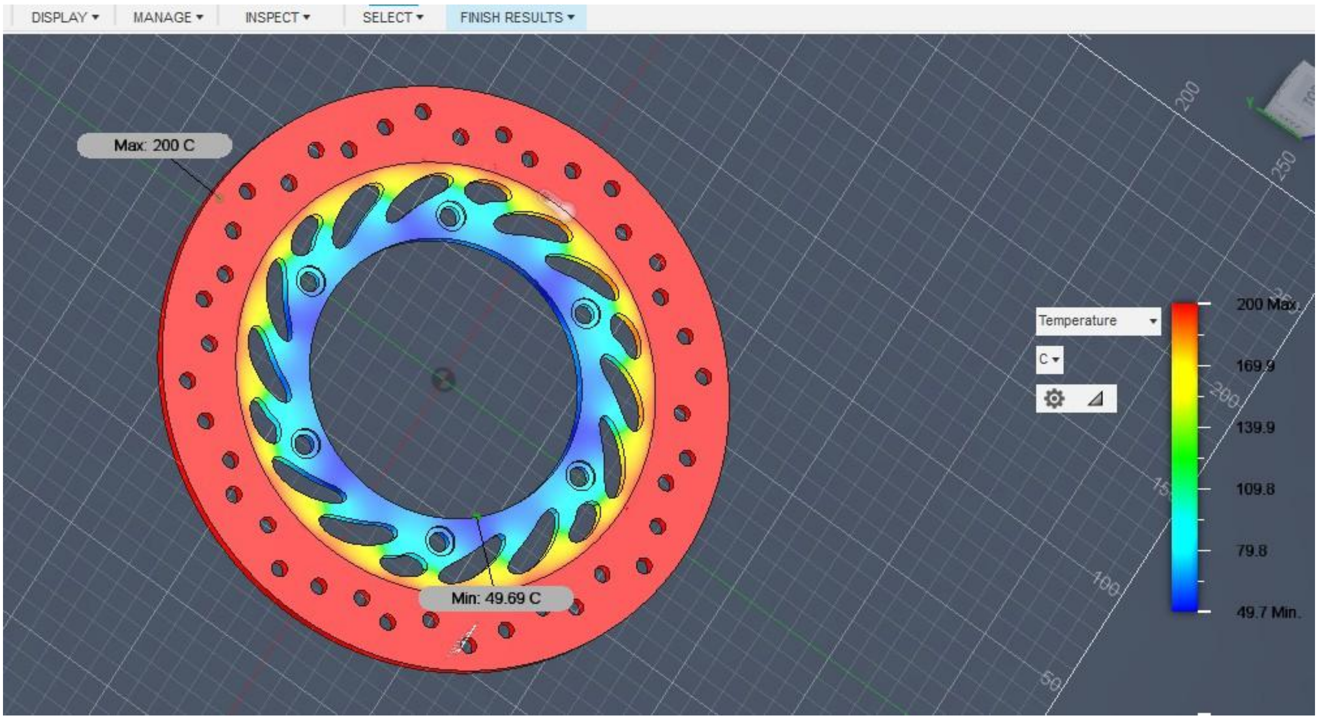
2. Stopping Distance Calculation:
- With the average reaction time considered to be 1 second, the total stopping distance was calculated to be 37.35 meters, reaction distance plus braking distance. In essence, this considers the real scenario, including rider reaction time.
3. Retardation and Braking Force:
- The necessary retardation for the safe stop of the bike was found to be -14.57 m/s2.
- The braking force required to create such retardation was calculated to be 466.43 Newtons (N).
4. Brake Design:
- Both the front and rear brakes of the Unicorn 150 are ventilated disc brakes. The total braking force required is divided equally on both discs, therefore, generating a braking force of around 233.21 N on each disc.
5. Pressure on the Brake Pad:
- Taking the outer diameter as 240 mm and the inner diameter as 130 mm, the brake pad area is 127911 mm2.
- From here, the pressure on the disc is calculated at 0.00182 MPa.

Property	**Value**
Area	0.081 m^2
Density	7850.00 kg / m^3
Mass	1.246 kg
Volume	0.0001587 m^3
Physical Material	Steel
Moment of Inertia	0.012 Kgm^2



<u>Assumptions and Rationale</u>:
1. Reaction Time:
- A typical human reaction time of 1 second was assumed. This assumption is being made to compensate for the delay between when the decision to brake is made and when the brakes are actually applied in realistic situations.

2. Brake Force Distribution:
- The force of braking is equally shared by the front and rear discs, provided the vehicle has an even weight distribution during braking.

Why it's close to realistic approach:
- It takes into consideration practical aspects such as human reaction time,
- Braking force and pressure on the brake pad were realistically computed to provide safe and effective braking performance.
- Sharing braking force between front and rear discs provides stability and control during braking.

Validation

To confirm the results and verify the effectiveness of the brake system, real-world testing and simulations must be performed. Feedback from riders and brake performance tests under different conditions, including wet or slippery roads, can be used to confirm the calculations and design.

Potential Improvements:

1. Material Selection: Investigating new materials for the brake pads and discs can enhance performance and minimize wear and tear.
2. Anti-lock Braking System (ABS): Integration of ABS technology can improve brake control and avert wheel lock-up, thereby enhancing safety overall.
3. Heat Dissipation: Improvement of heat dissipation mechanisms can avoid brake fade under prolonged or hard braking.

Manufacturability:

The conceived disc braking system may be produced with available technology and automotive industry typical materials. There are, nevertheless, some further engineering and testing that must take place in order to adjust the conception and qualify it to comply with safety criteria and performance demands before it could be mass produced.

In summary, the intended disc brake system for the Unicorn 150 reflects a holistic consideration of braking performance against real-world conditions and safety. Ongoing testing, verification, and possible enhancements ensure further optimization and refinement of the design.

V. Conclusion

The investment in designing a disc brake system for the Unicorn 150 in this project has paid off with a high level of focus on safety and practicality. The results of the calculations, taking real-world conditions into consideration, validate the accuracy and viability of the design. The value of this project is its adherence to improving motorcycle safety with a well-considered and viable brake system. Ongoing testing and tuning will be necessary to verify the system is safe and will function reliably under different conditions.

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