

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 8, August 2018

Design and Optimization of Disc Brake Rotor

Deepansh Mathur¹, Anshul Maheshwari², Abhishek Sharma³, Chandan Kumar⁴, Ashish Nayar⁵,
Rajendrasingh chundawat⁶

Student, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, Rajasthan, India¹

Student, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, Rajasthan, India²

Student, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, Rajasthan, India³

Assistant Professor, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, Rajasthan, India⁴

Associate Professor, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, Rajasthan, India⁵

Assistant Professor, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, Rajasthan, India⁶

ABSTRACT: Friction the term we want to keep minimum at several places for energy saving requirements whatsoever helps us to save our lives too. Brake discs plays a crucial role in automotive when it comes to driver safety. While establishing the target specification for a product development, major factor is material selection as wide variety of composites and ceramic material is available we had to be economical cum worth-ful. In our research work we are using AISI 1045 steel material after having a discussion on properties and market survey we found it best considerably. Use of CAD and CAE softwares like Solidworks and ANSYS helped us in product design stages. Considering safety a foremost thing simultaneously focusing on weight reduction a 50% of weight reduction achieved with a innovative design, has reduced the inertia that causes improvement in stopping distance. Static and transient analysis was performed and use of S-N curve for the material accounts the maximum number of successfully completed fatigue cycle. Use of disc in BAJA's ATV gives a opportunity of testing our project with successfully completing the brake test under critical limits and qualifying the endurance race. All calculations are based on ATV.

KEYWORDS: Optimization, Meshing, Degree of freedom, Static Analysis, Transient Analysis

NOMENCLATURE: ATV (All-Terrain vehicle), CAD (Computer Aided Design), TMC (Tandem Master Cylinder), COG (Centre of gravity),

I. INTRODUCTION

A brake is a mechanical device that uses frictional resistance to retard a motion by absorbing kinetic energy from and convert it into heat energy. The disc brake is a type of braking system that uses a disc rotor is connected to the axle of wheel and a set of friction material called as brake pads (mounted on a component called brake caliper) is forced usually by hydraulic pressure against both sides of disc which causes it to stop with the help of friction.

A proper braking system should have following properties:

- The stopping distance of the vehicle should be minimum.
- All the wheels should be locked at the time of hard braking.
- The system must be leak proof.
- Braking properties must not fade with constant prolonged application.
- The weight of system should be low.

This paper deals with shape and size optimization of rotor of disc brakes using static structural and transient thermal analysis. The purpose of this study is to design a disc brake rotor for front wheels of the ATV participating in

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 8, August 2018

BAJA SAEINDIA 2018 which can sustain braking force and simultaneously dissipating the heat generated into surroundings.



Fig. 1. Disc Brake Assembly

II. LITERATURE SURVEY

1. T. D. Gillespie A book of **Fundamentals of Vehicle Dynamics** an overall guide to design a automobile used for the better understanding of braking system, its performance improvements and for braking calculation. It covers from the very basic coordinating system, acceleration performance system, braking performance, road loads, ride, suspension, tires.

2. R. Limpert, A book of **Brake Design and Safety** purely guide of brake fundamentals, braking systems, automatic brake control, analysis design and analysis of friction brakes helps us to revise our concepts and correct our mistakes. Calculation of braking system was done on the basis of the book.

3. BAJA SAEINDIA Rulebook 2018, as it mentioned a disc rotor developed fully from the zero basis using the product development steps, disc was tested as a part of BAJA ATV- All terrain vehicle braking system under critical limits and achieved the target constraints. Rulebook, a set of every minute data being used to design the whole vehicle and guides thoroughly.

4. S. R. Abhang and D. P. Bhaskar, Associate Professor Department of Mechanical Engineering, SRES College of Engineering, Pune University, Kopargaon, India, discusses the problems occurs in brake system during braking like Squealing, scarring, excessive rusting, cracking. It helps us to give a whole of braking calculation with the proper assembly of braking system and assumed data makes a calculation of forces generated torque at pads, net heat flux and other parameters. Use of ANSYS was also done to mesh the disc and thermal analysis was performed to get the real time view of disc under circumstances.

5. Y.H. Mishra, V. R. Deulgaonkar and P. A. Makasre works at JCOE Kuran, starts with a overview how technology changing the world today and brief about disc brake rotor system assembly and describes about material selection for disc brake rotor among comparison of steel, aluminium and its alloy like magnesium, titanium. It helps us to choose us the best suitable material under current scenario considering our object of work. An assumed data was used to calculate working force, stress, torque generated, brake distance and its calculation. Use of wide ranging calculation was done to understand the braking phenomenon and for comparison.

6.A. Maleque, S. Dyuti and M. M. Rahman from Department of Manufacturing and Materials Engineering, International Islamic University Malaysia, Kuala Lumpur, Malaysia has a wide research on material selection through exhaustive method and comparative analysis starts with steps of material selection chooses six materials into consideration and provides using Digital Logic Method (DLM) assigns numbers using product- process matrix.

7. P. kllungchang, P. Deshattiwar, K. Menjo, Ruikar, S. Kumar, R. K. Shrivastava from department of mechanical engineering presents a thermal analysis of brake disc comparatively same work as ours. Design aspects used for

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 8, August 2018

braking calculation and also to better understand finite element analysis and ANSYS. It describes about material selection, FEA limitations and advantages and thermal analysis of brake disc through iterations.

8. J. Rakesh, A. Raj, K. Anush, D. Debayan, J. Pawan, R. Saurav from Department of Mechanical Engineering, NIT Durgapur presents Structural and Thermal Analysis of Disc Brake using Solidworks with a objective of calculating values of shear stress, total deformation, convective heat transfer coefficient and temperature distribution on disc brake. It presents structural and thermal analysis of disc brake rotor using FEA, CAD and ANSYS and shows the variation of time with respect of time. A proper calculation has been done using available data.

9. Palmer, Edward, Mishra, Rakesh and Fieldhouse from University of Huddersfield, presents a computational fluid dynamic analysis on the effect of front row pin geometry on the aero-thermodynamic properties of a pin-vented brake disc This work has very clearly demonstrated that the mass distribution of the disc affects heat transfer through the brake disc considerably. From the discussion it is clear that, as hypothesized in previous work the first row of pins has the most significant effect on the flow field through the disc (as shown by the change in static pressure through the rotor) and hence the mass flow rate and the heat transfer rate from the disc. The second row has the next-largest effect and the third row only a small effect on the thermo-aerodynamic performance of the disc.

10. .S. Sarkar, P. Rathod, A. J. Modi from different institutes internationally presents a Research Paper on modeling and Simulation of Disc Brake to Analyse Temperature Distribution using FEA. It tests the brake discs at different speeds and gives conclusion through different graphs and curves. Disc has its standard dimensions.

III. BRAKING CALCULATION & METHODOLOGY

1. CALCULATION [3]

Mass of vehicle (M) = 265 kg
Coefficient of friction b/w tyre and road (m) = 0.7
Diameter of disc (d) = 150 mm
Diameter of caliper piston ($D_{caliper}$) = 30 mm
Brake pad width (w_i) = 30 mm
Bore diameter of TMC (D_{TMC}) = 20.63 mm
Coefficient of friction between pad and disc (m') = 0.45
Wheelbase (l) = 1422.4 mm (56 inch)
Radius of tyre (R_{TYRE}) = 292.1 mm
Height of COG (h) = 529.336 mm (20.84 inch)
Static weight at front = 39% of M
Deceleration (d) = 6.86 m/s²

2.1.DYNAMIC WEIGHT AT FRONT

$$W_{Dynamic} = W_{Static} + \frac{h * M * d}{l * g}$$

$$W_{Dynamic} = 103.35 + \frac{20.84 * 265 * 6.86}{56 * 9.81} = 172.382 \text{ kg}$$

2.2.FRictional FORCE

$$F_{Frictional} = \frac{\mu * W_{Dynamic} * g}{2}$$

$$F_{Frictional} = \frac{0.7 * 172.382 * 9.81}{2}$$

2.3.BRAKING FORCE

$$R_{effective} = \frac{D_{Disc} - R_{Pad}}{2}$$

$$R_{effective} = \frac{150 - 30}{2} = 60 \text{ mm}$$

$$F_{Braking} = \frac{F_{Friction} * R_{Tyre}}{R_{effective}}$$

$$F_{Braking} = \frac{591.873 * 292.1}{60} = 2881.435 \text{ N}$$

2.4. Clamping Force

$$F_{Clamping} = \frac{F_{Braking}}{2 * \mu'}$$

$$F_{Clamping} = \frac{2881.44}{2 * 0.45} = 3201.594 \text{ N}$$

2.4 HEAT CALCULATION

Assuming that all the kinetic energy is converted into heat energy due to braking action.

2.4.1. MAXIMUM KINETIC ENERGY

$$E = \frac{mv^2}{2} = 0.5 * (0.61 * 265) * 16.672^2 = 22460.37 \text{ W}$$

2.4.2.BRAKING TIME

Using equation, $v = u + at$
Deceleration = $mg = 0.7 * 9.81 = 6.867 \text{ m/s}^2$

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 8, August 2018

i.e. Acceleration = -6.867 m/s^2
Hence, $0 = 16.67 + (-6.867t)$
Braking time = $t = 2.5 \text{ s}$

2.4.3. HEAT FLOW/ POWER

$$P = \frac{E}{t} = \frac{22460.37}{2.5} = 8984.148 \text{ J/s}$$

IV. MATERIAL SELECTION AND PROPERTIES [5], [6], [8]

The material selection is an essential part in every product development process. There are usually three type of materials used for brake rotors, cast iron, steel and aluminium alloy. Aluminium among these have excellent thermal conductivity but have very less yield strength, on the other hand steel have better thermal conductivity and yield strength than cast iron with nearly same density so, plain carbon steel of grade AISI 1040 (EN8) is selected. The mechanical and thermal properties of a typical EN8 steel is shown in Table.

4.1 CAST IRON

Metallic iron containing more than 2% dissolved carbon within its matrix (as opposed to steel which contains less than 2%) but less than 4.5% is referred to as grey cast iron because of its characteristic colour. Considering its cost, relative ease of manufacture and thermal stability, this cast iron (particularly, gray cast iron), is actually a more specialized material for brake applications particularly the material of choice for almost all automotive brake discs. To work correctly, the parts must be produced at the foundry with tightly monitored chemistry and cooling cycles to control the shape, distribution.

4.2 PLAIN CARBON STEEL (AISI 1040 or EN 8)

Steel in comparison to cast iron has a slightly greater density but on the other hand it possesses significantly more yield strength, thermal conductivity and specific gravity than cast iron. Also it provides faster manufacturing process by using high precision machining operations. Thus it possesses potential to reduce the weight of brake rotor for the same specification as with cast iron.

4.3 ALUMINIUM ALLOY COMPOSITES

Aluminium alloy based metal matrix composites (MMCs) with ceramic particulate reinforcement have shown great promise for brake rotor applications. These materials having a lower density and higher thermal conductivity as compared to the conventionally used gray cast iron but the repeated braking of the AMC brake rotor lowered the friction coefficient μ and caused significant wear of the brake pad. The friction properties of the AMC brake disc are thus remarkable poorer than those of conventional brake disc.

Table 1. Properties of AISI 1040 (EN8) steel

Density (g/cm^3)	7.845
Yield Strength (MPa)	415
Tensile Strength (MPa)	620
Thermal Conductivity (W/m-K)	51.9
Specific heat capacity (J/kg-K)	510.8
Young Modulus (MPa)	2.09×10^5

V. FINITE ELEMENT METHOD

It is a numerical technique for finding the approximate solutions to boundary value problems for partial differential equations. It uses subdivision of a whole problem domain into simpler part, called finite elements and solve the

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 8, August 2018

problem by minimizing an associated error function. The subdivision of the whole domain has several advantages as stated below:

1. Accurate representation of the complex geometry.
2. Inclusion of dissimilar material property.
4. Easy representation of the solution.
5. Capture of the local effects.

For analysis of structural and thermal characteristics of the disc, ANSYS 19 (Student Version) is used.

VI. MESHING[7], [8], [9]

Meshing of the disc represents discretization of the component in order to reduce the degree of freedom from infinite to finite. For analysis both 2-dimensional and 3-dimensional meshing can be done, depends on the degree of accuracy required. For our purpose 3D meshing is done to obtain high accuracy. It is done with tetragonal shape elements having total nodes and elements as 28886 and 15868 respectively. The meshed structure of the disc is shown in fig.2.

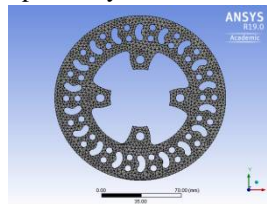


Fig.2. Meshing of designed disc

6.1 Wrapping factor

Wrapping factor also known as wrapping angle. Assume a paper is being folded in such a way that creates two adjacent triangles that the angle between the planes of the triangles assuming both cannot be ever in a single plane, called as wrapping angle.

6.2 Aspect Ratio

Aspect ratio defines ratio of the dimension of the elements. As it is known quadrilateral elements were used for deformation study, so the aspect ratio varies from 1-3, assuming all the elements are not same in size.

6.3 Maximum Corner Angles

While meshing it is impossible to cover every curvature or extremity of the design. It can be treated as a limitation of simulation. Angle made by this phenomenon is corner angle.

Table 6.1 Meshing properties

Number of nodes	6853
Number of elements	6062
Element method	Quadrilateral dominant
Element order	Linear
Free face mesh type	All Quad

6.4 Element quality

The element quality defines the relation between elements with the ideal element shape.

6.5 Factor of safety

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 8, August 2018

F.O.S. was the important concern to maintain throughout the task and we have far more factor of safety than risk consideration.

6.6 Fatigue life [10]

Disc has crossed one million fatigue cycles using the S – N curve for the respective material.

VII. LOADING AND BOUNDARY CONDITIONS

7.1 STATIC STRUCTURAL ANALYSIS

A static structural analysis determines the displacements, stresses, and forces in structures or components due to mechanical loading. For this the brake mount points are kept fixed and braking force is applied on the pad area on the disc as shown in fig.3.

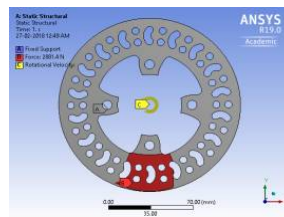


Fig. 7(a). Boundary conditions for static structural analysis.

7.2 TRANSIENT THERMAL ANALYSIS [11], [12]

Transient thermal analysis depends on the amount of heat flow through both sides of the disc and the film coefficient. It has been found the film coefficient depends on the velocity of air flowing around disc. So for the velocity of 16.67 m/s^2 , the film coefficient is taken as $34.6 \text{ W/m}^2\text{-K}$. The initial temperature of the disc is kept as 22°C . The boundary conditions are shown in fig.4.

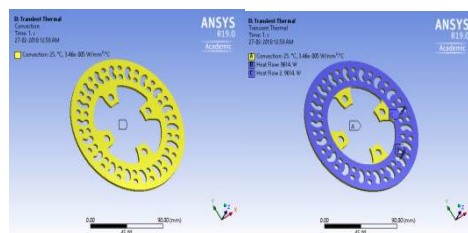


Fig. 7(b). Boundary conditions for transient thermal analysis.

International Journal of Innovative Research in Science, Engineering and Technology

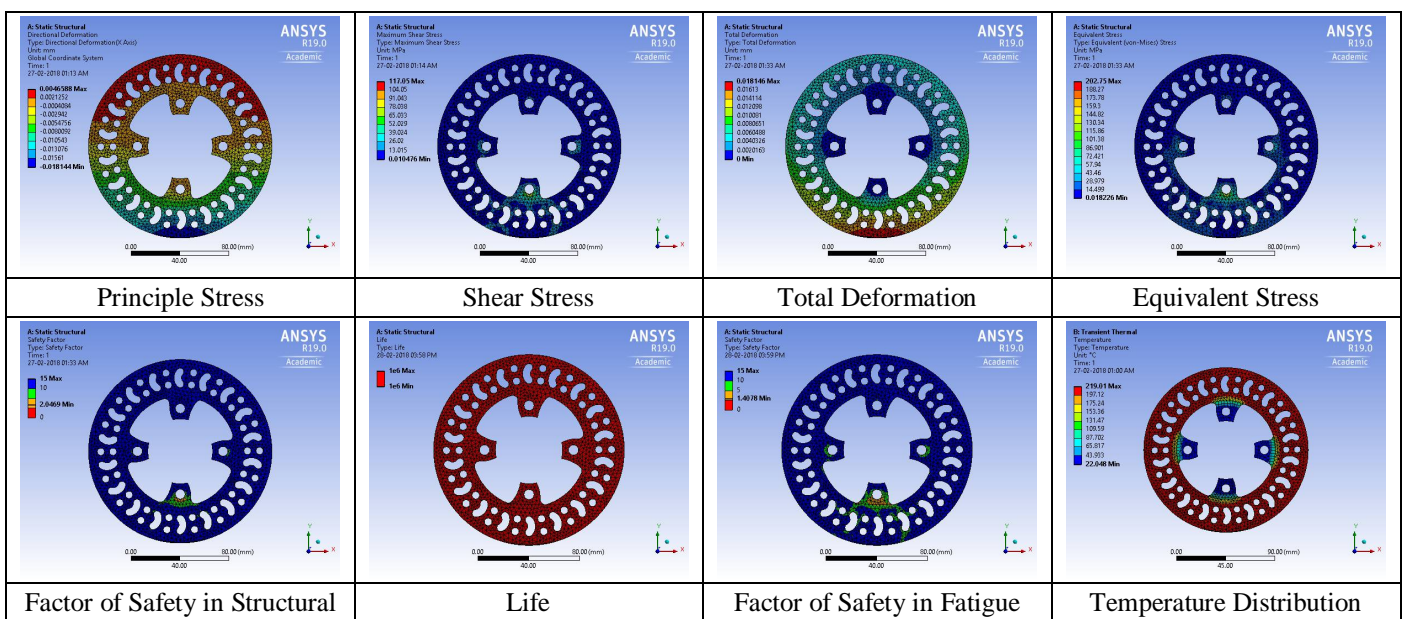
(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 8, August 2018

VIII. RESULT

Results indicated performance of disc according to the testing consideration. It includes scrutiny of all possible variables.



The results are summarized under table 2. as follows.

Table 2. Overall Results

S.No.	Parameter	Value
1.	Maximum total deformation (mm)	0.018
2.	Maximum equivalent stress (MPa)	202.75
3.	Maximum principal stress (MPa)	119.77
4.	Maximum shear stress (MPa)	117.05
5.	Factor of safety	2.046
6.	Maximum temperature attained (°C)	219.01
7.	Life of disc (cycles)	10 ⁶

IX. ACKNOWLEDGEMENTS

The authors are thankful to group members and Professors for their inclination and we would like to thank the anonymous reviewers for their comments which were very helpful in improving the quality and presentation of this paper.

X. CONCLUSION

This project work has provided an excellent opportunity and experience, to use limited knowledge. It help to gain a lot of practical knowledge regarding planning, purchasing, assembling and machining while doing this project work. The

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 8, August 2018

work is a good solution to bridge the gates between institution and industries. The work is completed with the limited time successfully.

The key outcomes of the work are as follows:

1. A weight reduction of 50% compared to a standard OEM part has been achieved through this design which helps to reduce rotational inertia, hence helps in increasing the braking efficiency.
2. Design of this is made in such a way such that to withstand under braking forces and high temperature generated while hard braking and also under repetitive cyclic loading scenario.
3. The prototype of the design was installed in an ATV (All-Terrain Vehicle) and was found that the wheels are locked completely at the time of braking as per norms of BAJA SAEINDIA 2018.

REFERENCES

- [1] S. R. Abhang and D.P.Bhaskar, Design and Analysis of Disc Brake, *International Journal of Engineering Trends and Technology*, 8, (4), 165-167, 2014.
- [2] Y.H. Mishra, V.R. Deulgaonkar and P.A. Makasre, Design and Optimisation of Disc Brake Rotor (For Two Wheeler), *International Engineering Research Journal*, 288-300, 2016.
- [3] BAJA SAEINDIA Rulebook 2018.
- [4] T. D. Gillespie, Fundamentals of Vehicle Dynamics, *Society of Automotive Engineers, Inc.*, 400 Commonwealth drive Warrendale 45-76, 1992.
- [5] R. Limpert, Brake Design and Safety 3rd Edition, *Society of Automotive Engineers*, 22-122, 1963, (ISBN: 978-0-7680-3438-7).
- [6] P. kllungchang, P. Deshattiwar, K. Menjo, RUIKAR, S. Kumar, R. K. Shrivastava, Thermal Analysis of Brake Disc, *SlideShare/Engineering*, 2016.
- [7] M.A. Maleque, S.Dyuti and M.M. Rahman, Material Selection Method in Design of Automotive Brake Disc, *Proceedings of the World Congress on Engineering*, 3, 2010 (ISBN: 978-988-18210-8-9).
- [8] Solidworks Student Edition 2015
- [9] J. Rakesh, A. Raj, K. Anush, D. Debayan, J. Pawan, R. Saurav, Structural and Thermal Analysis of Disc Brake using Solidworks and Ansys, *International Journal of Mechanical Engineering and Technology*, 7, (1), 66-77, 2016
- [10] http://www.efunda.com/formulae/solid_mechanics/fatigue/fatigue_highcycle.cfm
- [11] Palmer, Edward, Mishra, Rakesh and J. D. Fieldhouse, A computational fluid dynamic analysis on the effect of front row pin geometry on the aerothermodynamic properties of a pin-vented brake disc, *Proceedings of the Institution of Mechanical Engineering Part D of Automobile Engineering* 22, (7), 1231-1245, 2008.
- [12] S. Sarkar, P. Rathod, A. J. Modi, Research Paper on Modeling and Simulation of Disc Brake to Analyse Temperature Distribution using FEA, *International Journal for Scientific Research & Development*, 2, (3), 492-494, 2014.