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COUPLED THERMAL AND STRUCTURAL ANALYSIS OF PETAL SLOTTED AND CIRCULAR DRILLED DISC BRAKE ROTOR

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Abstract - *This paper deals with motorcycle disc brakes of 2 arrangements - Circular drilled and Petal slotted. These are 2 very common disc brake options available in the two wheeler market of India. This paper covers the coupled thermal and structural analysis of both of them and has attempted to discuss the results in a way that makes it possible for even an average person or customer to understand. Brakes are a very important part of any vehicle, thus one must be educated about brakes, and what kind is the best for them. This paper discusses the differences between the two types of disc brakes with ANSYS WORKBENCH 2021 R2 analysis to back the arguments.*

Key Words: **ANSYS, Automobiles, Brakes, Disc brakes, Structural analysis, Thermal analysis**

1.INTRODUCTION

Brakes are the most integral part of any machine with wheels. The basic concept behind brakes is that they convert the kinetic energy of the moving vehicle into heat energy with the help of friction. Be it a car, bike or even an aircraft. While disc brakes are becoming more and more common in the automotive industry, there are many different types of disc brakes that people don't know about. There are drilled, slotted, drilled and slotted, regular shape or wave/petal disc with each having some advantage over the other. Thus, this analysis of a circular drilled disc and a petal slotted disc will put forward a lot of information, and answer a lot of questions regarding which is sturdier, more durable, dissipates heat faster and ultimately, show which is better and why, with proper reasons because both of these are widely offered in the 2 wheeler market in India. I strongly suggest that customers be aware of such things before buying their next vehicle. Not only this, but this paper can be helpful to many students and other academicians looking to study or design new disc brakes for any purpose be it academic, commercial or personal.

2. METHODOLOGY

Design: Both the designs are inspired from real life examples of disc brakes available in the Indian two wheeler market. However, some modification had to be done on the rotors, to extrude the region where the brake pads will come in contact with the disc. The circular drilled disc and the petal slotted disc are both 200mm in diameter and considered to be made from stainless steel entirely. The circular disc is inspired from the version available in bikes like Yamaha and Suzuki, whereas the petal disc is an exact copy of the TVS bikes option.

Procedure: The same procedure was followed for both the discs. First, I imported the disc CAD model into Design Modeler of ANSYS Workbench after selecting the Steady-state thermal analysis. There I differentiated the region where the disc pads actually come in contact with the disc by extruding the particular zone minutely. From here, the disc was ready for analysis. With the help of ANSYS Mechanical, I conducted thermal analysis of the disc, particularly temperature distribution and heat flux observed. After this I added static structural analysis to the results of the first thermal analysis. It's called coupling because the second analysis will now also consider the effects of the first analysis during its analysis. Thus, the total deformation and stress analysis done on the disc is considered to happen while the disc is undergoing braking and experiencing all the heat.

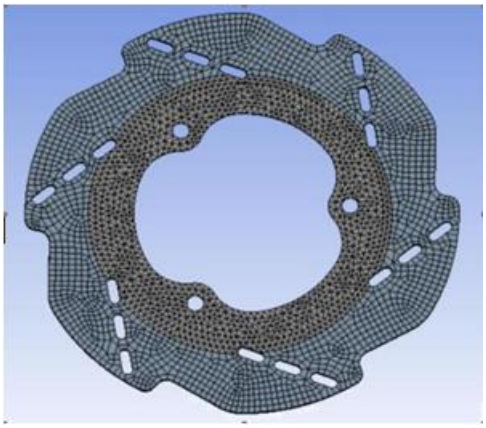

Fig -1: Petal slotted disc after meshing

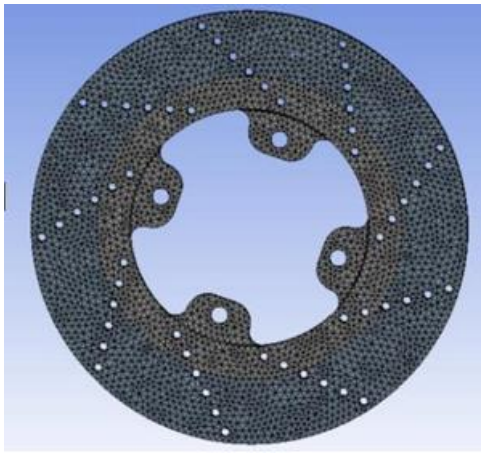

Fig -2: Circular drilled disc after meshing

3. RESULTS AND DISCUSSIONS

Both the discs are considered to be entirely made of stainless steel. In market variants, stainless steel or cast iron is used. The physical properties of stainless steel used in the analysis are:

Table -1: Stainless steel properties

Density	7.75e-06 kg/mm^2
Young's Modulus	1.93e+05 MPa
Poisson's Ratio	0.31
Bulk Modulus	1.693e+05 MPa
Shear Modulus	73664 MPa
Isotropic Secant Coefficient of Thermal Expansion	1.7e-05 1/ °C
Isotropic Thermal Conductivity	0.0151 W/mm-°C
Specific Heat Constant Pressure	4.8e+05 mJ/kg-°C

For the thermal analysis, the conditions for both discs were given as:

Temperature at the brake pad region = 100° C, convection region of the disc was given to be the entire body and ambient air was considered 22° C. The aim was to find the solution of temperature distribution and total heat flux. The results are as follows:

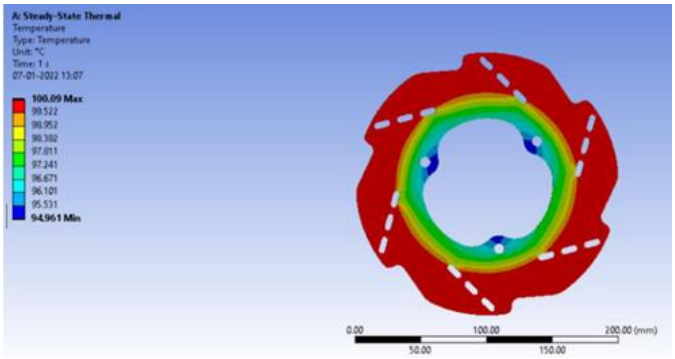

Fig -3: Temp distribution of Petal slotted disc

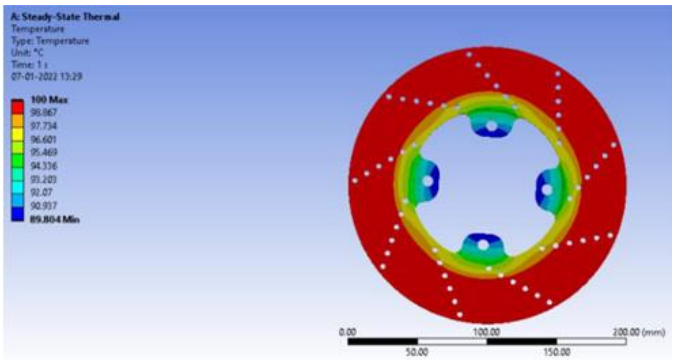

Fig -4: Temp distribution of Circular drilled disc

Observing the simulation and results, one can conclude that after braking, when the temperature at the brake pad region reaches a 100° C, the circular drilled disc did a better job at lowering the temperature across its surface than the petal slotted disc in the initial duration of the braking. The circular disc has a lower minimum temperature by 4° C at the connection points, which slightly suggests that initially the circular disc dissipates the temperature across its body slightly better, as both the discs have a similar 96 - 97° C temp in the middle region, thus there is no considerable difference apart from the temperature difference at the very small region near the connection points. Although this only gives us an idea of the initial reaction of the body to that temperature.

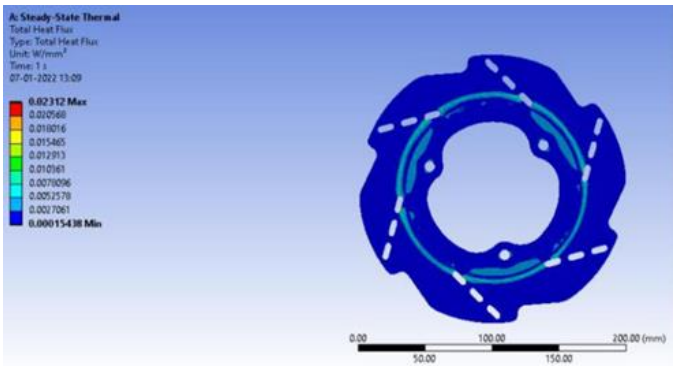

Fig -5: Total Heat Flux of Petal Slotted disc

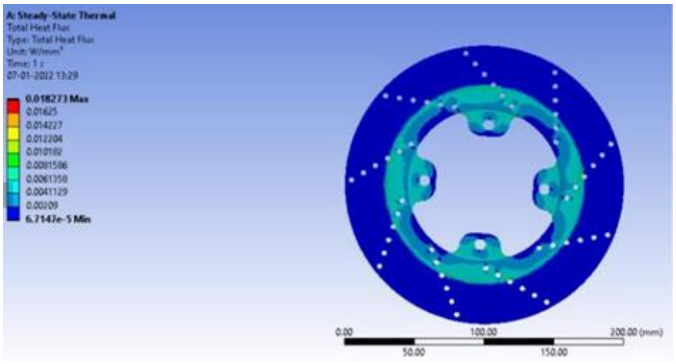

Fig -6: Total Heat Flux of Circular drilled disc

Now, moving over to the total heat flux analysis results. The results are quite complex, because one can see a good amount of heat flux on the circular drilled disc, even better than petal slotted disc at first glance. However, one can't ignore the max and min heat flux readings. The disc pad region on the circular drilled disc is 67,838 mm^2 and on the petal slotted disc 67,903 mm^2. This is the region in both the cases where the heat flux is minimum. A simple calculation of area*heat flux per unit mm^2 tells us that the petal disc has almost three times the flux in that region than the circular one. Also, the results show that the petal disc has more uniform heat flux over its surface, whereas the circular disc mainly has heat flux in the interior region (non-brakepad region). Thus, the petal disc has higher and more uniform total heat flux over its surface which is better, meaning that the disc is radiating more heat energy from its surface and can cool itself better. Hence, it is showing better braking performance and longer life of disc.

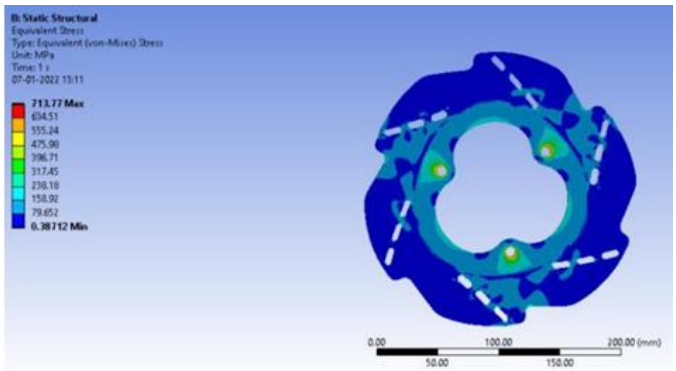

Fig -7: Petal Disc Equivalent (Von Mises) Stress

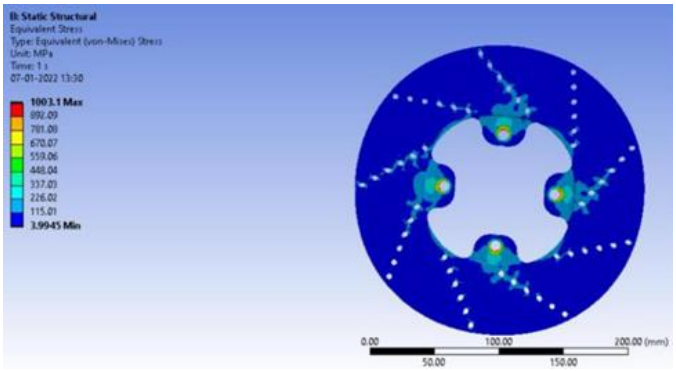

Fig -8: Circular Disc Equivalent (Von Mises) Stress

After importing the load of the thermal analysis in the structural analysis, I got some really good results. For the structural analysis, the conditions for both discs were given as: Rotational velocity = 40 rad/s

Fixed Support given at the screw points pressure from disc pad on each side = 0.5 MPa First, taking a look at equivalent Von Mises stress, the results are quite confusing. With one glance at the screenshots, one could say that the petal disc undergoes much lower maximum and minimum values of stress. However, a better look at the results and readings makes it more complex. The region around the screws that connect the disc to the wheel, undergo the maximum stress in both cases. In the petal disc it is 713.77 MPa, while in the circular disc it is considerably higher at 1003.1 MPa. This increased stress could cause problems with the disc and even the nuts and bolts used to hold it in place. The stress in regions away from the screw zones, is higher by an average of 3.6 MPa in case of the circular disc. This creates a little conflict on which one is better, as the petal disc has higher stress on the middle region. I personally feel, that we can call the petal disc the winner here despite undergoing a little more stress on the majority of its body. The highlight difference is in the connection nut-bolt zone, it undergoes much lower stress, and that makes using the petal disc a more viable option, because it will clearly have a longer life than the circular drilled disc setup and ensure better structural and connection integrity. Even the nuts and bolts used will undergo much less stress in case of the petal disc, thus ensuring their long life too.

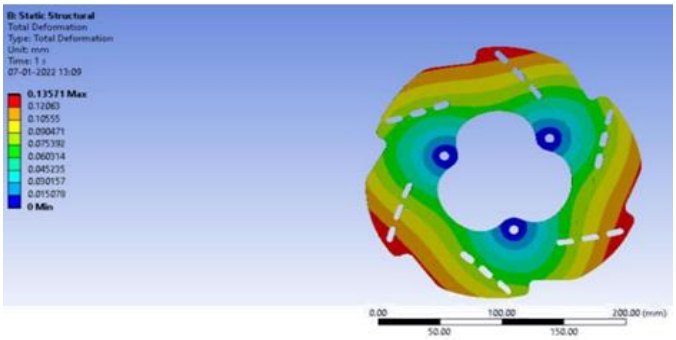

Fig -9: Petal disc total deformation

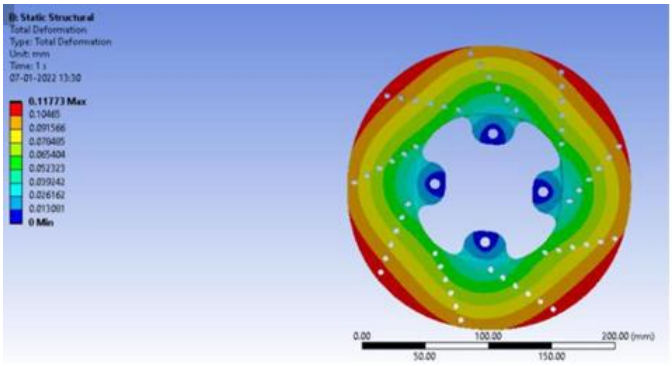

Fig -10: Circular disc total deformation

Studying the total deformation on both the discs, we can say that the maximum deformation is lesser in the circular disc. The difference is of 0.017 mm, which is somewhat considerable. However, the deformation in the circular disc happens in such a manner that it cause the disc to acquire a square shape, whereas on the petal disc the deformation doesn't affect the actual shape of the disc. The deforming action on the petal disc is more ideal than the circular one. Still, in the life of these discs, we won't be able to find much practical difference as they'll perform similarly as per deformation is concerned, because they are made of high quality stainless steel.

4. ABBREVIATIONS AND ACRONYMS

CAD – Computer Aided Design

5. LIMITATIONS

This paper is concerned with 2 very specific disc rotors. This is not just about a circular disc and a petal disc, this paper dwells over a really efficient circular drilled disc similar to what is used by the Japanese companies like Yamaha and Suzuki in India, and a well - designed petal slotted disc used by TVS and Honda in its vehicles. Thus, this paper doesn't just compare the effects of the disc shape on the braking performance. It rather gives us a direct analysis and comparison between 2 efficient disc brake rotors based on shape and drilling/slotting collectively. Hence this study is not a general study, but a specific one.

6. CONCLUSIONS

The paper puts forward a lot of information about the two disc brakes. From the provided research, we can infer that thermally, the petal slotted disc is better than the circular drilled in terms of total heat flux whereas it is more or less the same in temperature distribution after initial braking. In terms of structural properties, petal slotted disc again comes out on the top with lower overall Von Mises stress and less area of deformation. The final conclusion is that the petal slotted disc is slightly better than the circular drilled disc for your automobile as it offers longer life, durability and braking properties. Not only this, but it is supposedly lighter too as it uses less material to be manufactured. The wavy pattern also allows more contact with the ambient air, allowing for better cooling and less material overall.

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