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A Comprehensive Literature Survey On Heat Dissipation From Brake Disk Surface

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Abstract : The brake disk, a key element of disc brake systems, experiences elevated temperatures during braking events due to the conversion of kinetic energy into heat. Prolonged exposure to high temperatures can lead to reduced braking performance, increased wear and tear, and, in extreme cases, even structural damage. This comprehensive literature survey delves into the multifaceted aspects of heat dissipation from brake disk surfaces, a critical domain within automotive engineering. The primary focus is on understanding and enhancing the thermal performance of brake disks, given their pivotal role in ensuring vehicle safety and efficiency. Researchers across various studies have emphasized the intricate challenges associated with braking systems, especially concerning heat generation during braking events. The overarching theme of these studies is the imperative role of material selection, design optimization, and innovative configurations in augmenting the heat dissipation capabilities of brake discs. This survey provides a consolidated overview of the current state of research in this domain, highlighting the complexities involved and pointing towards promising avenues for future advancements in automotive brake system technologies.

***IndexTerms* -** braking systems, braking performance, heat generation, thermal performance, automotive engineering, automotive brake system.

1. INTRODUCTION

The braking system of a vehicle is a critical component that undergoes intense thermal stresses during operation. One of the primary challenges faced by automotive engineers is the efficient dissipation of heat generated at the brake disk surface. As vehicles continue to evolve with increased performance capabilities, the demand for braking systems that can handle higher energy loads and provide enhanced safety has become more pronounced. The brake disk, a key element of disc brake systems, experiences elevated temperatures during braking events due to the conversion of kinetic energy into heat. Prolonged exposure to high temperatures can lead to reduced braking performance, increased wear and tear, and, in extreme cases, even structural damage. To address these challenges, there is a growing need to explore innovative methods to improve the heat dissipation rate from the brake disk surface.

To bring a vehicle to a halt, the braking system plays a vital role in dissipating kinetic energy. This is achieved through the application of friction, transforming the vehicle's forward motion into thermal energy or heat. Operating on a hydraulic system, the brakes leverage the force applied to the brake pedal, translating it into sufficient force to engage and stop the car. The braking process involves the conversion of kinetic energy into heat, a phenomenon facilitated by the friction between a stationary brake pad and a rotating disk or drum. This friction occurs as the pad glides past the disk, akin to the warmth generated by rubbing hands together on a chilly day.

Halting a car generates substantial heat at each wheel, capable of boiling a liter of water in a mere 7 seconds. Brake temperatures can soar to approximately 500°F during routine usage, escalating to 1000°F under intense or repetitive braking conditions. The brake disk or drum serves as a heat sink, absorbing up to 80% of the heat generated during the braking process. Remarkably, it also acts as an efficient radiator, dissipating heat as it spins through the air en route to the subsequent stop.
Given that the front of the vehicle bears the brunt of the weight during braking, front brakes assume a predominant role. Consequently, many vehicles feature disc brakes on the front axle and drum brakes on the rear. Disc brakes excel in performance due to their capacity to generate friction when brake calipers compel the pads to grip the rotors. The brake rotors undergo a self-cleaning and drying process as the brake pads make contact with them, and the entire braking system is exposed to the air, ensuring effective cooling. Rear drum brakes offer advantages in terms of cost-efficiency and the seamless integration of a mechanical emergency/parking brake system.

2. LITERATURE SURVEY

(Jafari & Akyüz, 2021)[1] proposed that ventilated brake discs offer superior heat dissipation capabilities compared to solid discs, making them preferable for automobile applications. The study focused on investigating the optimal design of a brake disc with radial vanes, considering nine design parameters, including the shape, geometry, and number of cooling fins. Utilizing the Taguchi design of experiments, numerical simulations were conducted using the Finite Element Method to analyze detailed airflow and temperature distribution in the disc, accounting for adjoining components such as pads, rim, tire, and dust shield. The research revealed that the ventilation gap width significantly influenced brake disc cooling, with a 21% decrease in cooling time observed as the ventilation gap increased from 8 mm to 14 mm. Additionally, a 10% reduction in cooling time was noted with an increment in the channel width between two adjacent vanes (inverse of vane numbers from 43 to 30) and the twist point from 225 mm to 266 mm. In descending order of importance, the fin angle, inner and outer diameters of the fin, dust shield, bell link, and disc material were identified as factors affecting the cooling performance of ventilated discs.

(Pinca-Bretotean et al., 2021)[2] emphasised the brake disk's critical role in the braking mechanism was emphasized, highlighting its responsibility to slow or stop the vehicle's wheels while efficiently dissipating the heat generated in the process. The study aimed to develop a disk brake model using CATIA V5, followed by finite element analysis (FEA) conducted by ANSYS 19. The computational thermo-mechanical study within a hydraulic brake system provided insights into heat flow behavior during brake testing and simulations. Two cases were analyzed, and the study involved experimental evaluations of a hydraulic brake system to validate the simulation models. Through ten successive brakes, both numerical and experimental tests were conducted, allowing a comparison of temperatures to verify the models. The findings from the study contribute to a better understanding of heat distribution and flow within and around a brake disk, emphasizing the importance of combining numerical simulations with experimental tests for comprehensive validation.

In the recent study conducted by (Jacob Moses et al., 2020) [3] an innovative brake pad was developed utilizing a combination of basalt fiber and glass fiber to replace the conventional use of asbestos. The primary objective of this research was to investigate the physical properties and wear behavior of brake pads reinforced with basalt fiber. The experiment involved the production of newly formulated basalt brake pad materials, designated as BB1, BB2, and BB3, using ten different ingredients through conventional methods. Various parameters, including friction coefficient, porosity, hardness, specific gravity, water swell, and heat swell, were measured to assess the performance of these materials. The obtained results were then compared with commercially available brake pads in the market. The findings indicated that the BB2 formulated sample exhibited superior properties compared to others, highlighting the effectiveness of basalt and glass fibers as suitable reinforcements for brake pad systems.

(Zhang, Zhang, Wei, et al., 2020) [4] addressed the challenge of high temperatures faced by copper-based brake pads during emergency braking of high-speed railway trains. They introduced a novel copper-based brake pad and investigated its tribological properties in the temperature range of 400–800 °C using a pin-on-disc tribometer equipped with a heating chamber. The study revealed that the self-designed copper-based brake pad outperformed commercial counterparts, displaying higher mean friction coefficient and less fluctuation under various test conditions. The friction coefficient remained within the range of 0.35–0.45 at temperatures up to 600 °C. At 800 °C, the failure mechanism was associated with the oxidation resistance of graphite and the high-temperature strength of the copper matrix. The disappearance of graphite due to severe oxidation led to a loss of lubrication on the friction surface, while copper oxidation and softening weakened the copper matrix's ability to support the friction surface. This highlighted the importance of enhancing the oxidation resistance of graphite and the high-temperature strength of the copper matrix for designing high-performance copper-based brake pads.

(Zhang, Zhang, Wu, et al., 2020) [5] investigated the braking performance of copper-based brake pads with varying carbon fiber (CF) content using a reduced-scale dynamometer. The introduction of CF significantly impacted the microhardness and plastic deformation resistance of the tribo-film. Nano CFs, possessing higher specific surface energy and the ability to react with iron to form cementite, played a crucial role in supporting the friction surface and strengthening the tribo-film. In the range of 0–1.2 wt% CF, the brake pad containing 0.4 wt% CF demonstrated the best wear resistance and the most stable friction coefficient (0.357–0.372) during continuous high-speed emergency braking. This emphasized the role of CF in enhancing wear resistance and stabilizing friction coefficients under demanding braking conditions.

In the study conducted by (Sri Karthikeyan et al., 2019) [6] advancements in brake technology were explored, particularly addressing the historical use of asbestos fiber in brake pads, which posed significant environmental and health risks. The conventional asbestos fiber, when worn down during braking, released harmful dust into the surroundings and brake housing. This presented a hazard during brake maintenance, as workers could unknowingly inhale asbestos dust when accessing the brake housing. To mitigate these risks, the researchers introduced a novel brake pad material using natural fibers such as jute, KENAF, and aloe vera, along with additives like epoxy resin and hardener. The incorporation of these fibers aimed to create brake pads with improved properties, offering an eco-friendly alternative and reducing health risks for both workers and the environment.

(Zhang et al., 2019b) [7] introduced Al_2O_3 fiber into copper-based brake pads to enhance braking performance under high-speed and heavy-load conditions. The study utilized a reduced-scale dynamometer and a specially designed braking testing procedure to assess samples with and without Al_2O_3 fiber. Results indicated that Al_2O_3 fiber primarily contributed to increasing the friction coefficient at lower braking speeds and pressures, while stabilizing the friction coefficient at higher speeds and heavier loads. Furthermore, the addition of Al_2O_3 fiber significantly reduced brake pad wear, and the sample with Al_2O_3 fiber exhibited lower maximum temperatures during braking. The study also highlighted the correlation between braking properties and the composition of the tribo-film.

In another investigation by (Zhang et al., 2019a) [8] the fade behavior of copper-based brake pads during emergency braking of high-speed railway trains was studied through accelerated fade experiments. The continuous emergency braking led to fatigue cracks in the friction layer and the softening and flow of the copper-rich phase on the surface layer. This resulted in the formation of a friction layer composed of alternating copper-rich and iron-rich phases. The softening copper-rich phase acted as a solid lubricant, reducing clamping force on hard particles and subsequently decreasing friction resistance. The accumulated damage and rapid transfer of the friction layer weakened brake pad tolerance, leading to a more rapid fade in the friction coefficient.

(Modanloo & Talaee, 2018)[9] delved into the importance of temperature in designing brake systems for high-speed vehicles. Specifically focusing on advanced disk brakes for trains with velocities of 350 km/h, the researchers developed a thermal conduction model. The model considered two types of frictional heat loads—uniform pressure and uniform friction—along with time-dependent convective boundary conditions. Solving the governing heat conduction equation in cylindrical coordinates using the method of separation of variables combined with Duhamel integral, the study provided accurate temperature profiles in brake disks. This analytical solution demonstrated the ability to estimate temperature distribution in brake disks under various conditions.

(Ahmed & Algarni, 2018)[10] analyzed the impact of design modifications incorporating radial grooves on the performance and thermal behavior of disc brakes was analyzed. Utilizing additive manufacturing with 3D printed maraging steel, the researchers focused on temperature distribution across the disc surface under various conditions such as rotor speed, braking pressure, and braking time. Direct Metal Laser Sintering (DMLS) was employed to introduce radial grooves, enhancing the surface area for improved heat dissipation and stress reduction during braking. These grooves acted as cooling channels, effectively managing temperature fluctuations under dynamic running conditions. Transient structural and thermal analysis using ANSYS software helped investigate temperature variations across the disc, considering induced heat flux. Finite Element-based thermo-structural analysis determined thermal strains induced in the disc due to abrupt temperature changes. The results indicated that the incorporation of radial grooves stabilized the thermal performance of the disc brake, mitigating issues related to thermal fatigue and potential rupture. Experimental outcomes aligned well with Finite Element thermal analysis, highlighting the efficacy of Direct Metal Laser Sintering in enhancing disc brake performance, especially at higher speeds and temperatures.

In another study by (Rudramoorthy et al., 2018) [11] the focus was on analyzing the frictional heat-induced high temperatures on brake disc surfaces. The project aimed to replace traditional brake discs with lightweight materials to assess their performance under severe braking conditions in cars. Given the automotive industry's emphasis on lightweight vehicle design, replacing heavy brake discs with materials offering high strength and rigidity became crucial. The CES granta material selection software aided in selecting suitable materials for disc brakes, considering weight reduction and performance. Using the ANSYS package for finite element analysis, the researchers determined temperature increases, stress variations, and deformation across the disc brake. The study compared materials like cast iron, steel, and Aluminum metal matrix composite, evaluating their stiffness, strength, and predicted stress and temperature distributions.

(Hugar & Kadabadi, 2017)[12] presented a study focusing on the design and thermal analysis of disc brakes to minimize temperature. The analysis involved different slot shapes on disc brake rotors for various vehicles, aiming to optimize the thermal conductivity of the disc brake rotor. The study specifically conducted thermal analysis on the disc brake rotor of a Bajaj Pulsar 220, exploring different slot shapes to reduce weight and enhance thermal conductivity. In a work by (Newase, 2017) [13], the focus was on the two-wheeler brake system, where the material used for disc brakes ranged from alloy martensitic stainless steel to carbon-carbon composites and grey cast iron. The study aimed to address structural and wear issues by conducting analytical calculations to obtain parameters such as temperature, heat flux, and heat generated. The steady-state thermal analysis of a two-wheeler disc rotor was performed to evaluate braking performance under various conditions. Mathematical inputs, thermal loads, and calculations of different parameters for thermal analysis were conducted, with the design and analysis carried out using SolidWorks 15 and ANSYS 14.5, respectively.

(Gupta et al., 2017)(Gupta et al., 2017) conducted an in-depth analysis focusing on the crucial role of brakes as a major automotive component, emphasizing the need for continuous advancements to enhance road safety. The study specifically delved into the thermal dynamics of disc brakes, recognizing the generation of heat during braking and the critical necessity to dissipate this heat rapidly to maintain a consistent temperature of the brake disc. The objective was to minimize thermal fatigue in the brake disc material. The researchers employed the commercial Ansys Finite Volume-based CFD Solver for a comprehensive thermal analysis of different regions and materials of disc brakes. The investigation centered around a brake disc from an all-terrain vehicle, considering three materials: Grey Cast Iron, Aluminum, and High-Speed Steel. Additionally, modifications were introduced to the disc surfaces for each material, incorporating various hole shapes such as circular, elliptical, oblique-circular, oblique-elliptical, and vanes vents.
(Abebe et al., 2016)(Abebe et al., 2016) addressed the significance of the brake disc rotor within the disc brake assembly, emphasizing its role in decelerating or stopping the vehicle. The study recognized that the application of brakes leads to an increase in the brake disc's temperature, subjecting it to thermal stresses. The researchers underscored the need for meticulous design and material selection to prevent premature failure of the disc brake. The analysis involved both analytical and finite element methods to study temperature and thermal stress distribution in the brake disc. Four distinct materials were chosen for examination: cast iron, maraging steel, Aluminum metal matrix composites (ALMMC), and E-Glass. Using vehicle specifications, parameters such as brake torque, heat flux, and single-stop temperature were calculated. Maximum temperatures and principal stresses were determined for each material through both analytical and finite element analyses. The comparative analysis revealed that ALMMC exhibited lower temperatures and stresses, leading to the conclusion that ALMMC is the most suitable material among the four considered for brake disc applications.

(Jaiswal et al., 2016)[16] underscored the critical role of the braking system as a fundamental safety component in modern vehicles. Brakes play a pivotal role in absorbing the kinetic energy of rotating parts, such as wheels, and dissipating this energy in the form of heat to the surrounding atmosphere, thereby decelerating or halting the vehicle. When brakes are applied to the disc brake, they are subjected to substantial stress, making them susceptible to structural and wear-related issues. To enhance performance and longevity, the study advocates for a comprehensive approach involving structural, stress, and thermal analyses to identify low-stress materials. The primary objective of the research is to model and analyze stress concentration, structural deformation, and thermal gradients in a disc brake. The disc brake is designed using Solidworks, and the analysis is conducted using ANSYS Workbench R 14.5.

(Patil et al., 2016)[17] delved into the exploration of the potential applications of magnetorheological (MR) brakes in the automotive sector. MR brakes exhibit superiority over conventional hydraulic brakes in terms of response time, although the technology is still in its maturation phase. The article specifically focuses on the thermal analysis of an MR brake (MRB) proposed for an e-bicycle, aiming to estimate the temperature rise of the MR fluid during braking maneuvers. It is crucial to ensure that the temperature of the MR fluid remains within the specified operating range. The study provides detailed insights into the finite element analysis (FEA) model of the proposed MRB and outlines the analysis methodology. The transient analysis incorporates the IS brake fade test for two-wheelers and real-world cycling conditions typical of Indian urban environments. The findings of the analysis reveal that the temperature of the MRB remains within the operating range of the MR fluid, thereby satisfying the thermal requirements. Experimental results further validate the outcomes of the analysis.

(Dadi et al., 2015)[18] conducted an in-depth study on disc brakes, essential devices for slowing or halting wheel rotation in vehicles. The research specifically focused on the repetitive braking events that generate heat during each braking occurrence. Through Transient Thermal and Structural Analysis of the Rotor Disc of Disk Brake, the study aimed to assess the performance of a car's disc brake rotor under severe braking conditions, contributing valuable insights for disc rotor design and analysis. Utilizing ANSYS Workbench 14.5, the study involved disc brake modeling and analysis to explore the thermo-mechanical behavior during the braking phase. Employing coupled thermal-structural analysis, the investigation aimed to identify deformation and Von Mises stress in both solid and ventilated disc configurations with two different materials. A comparative analysis between analytical and Finite Element Method (FEM) results was conducted, revealing values below allowable thresholds. Consequently, the study recommended an optimal design, material, and rotor disc based on performance, strength, and rigidity criteria.

(Alnaqi et al., 2015)[19] delved into the critical consideration of thermal behavior in the design phase of a disc brake. Unlike many researchers employing full-size brake dynamometers or pin-on-disc rigs for experimental evaluations, this paper proposed a scaling methodology to assess the thermal performance of a disc brake at a reduced scale. The resulting small-scale disc brake offered advantages such as lower cost and reduced development time. The validity of the proposed scaling methodology was established by comparing results obtained from full and small-scale discs using a conventional brake dynamometer. Additionally, a two-dimensional axisymmetric transient thermal finite element model developed with Abaqus software assisted in validating the scaling methodology. Numerical simulations affirmed the equivalency of thermal performance between full and small-scale discs, endorsing the proposed scaling methodology and aligning well with experimental results. The study concluded that this scaling methodology serves as a valuable tool for evaluating disc brake thermal performance in the early stages of design.

(Kumar & Sabarish, 2014)[20] conducted an investigation revealing that disc (rotor) brakes undergo significant thermal stresses during routine braking and encounter even higher thermal stresses during intense braking scenarios. The project's objective was to design and model a disc, employing CATIA for 3D modeling. Structural and thermal analyses were then performed on the disc brakes, considering three materials: stainless steel, cast iron, and carbon-carbon composite. Structural analysis aimed to validate the strength of the disc brake, while thermal analysis focused on assessing thermal properties. Comparative evaluations were carried out for deformation, stresses, temperature, and other factors across the three materials to determine the most suitable material. CATIA, a widely used 3D modeling software, facilitated the design process, while ANSYS, a general-purpose finite element analysis (FEA) software package, enabled numerical analysis using the finite element method.

(Belhocine & Bouchetara, 2014)[21] delved into the thermomechanical behavior during the dry contact between brake discs and pads in the braking phase. Employing the ANSYS11 software, the simulation strategy aimed to identify factors related to the geometric design of the disc for the installation of ventilation systems in vehicles. The thermal-structural analysis involved coupling to determine deformation, Von Mises stress in the disc, and the distribution of contact pressure on the pads. Results obtained from this analysis were found to be satisfactory when compared to those reported in specialized literature. In another study (Belhocine & Bouchetara, 2013)[22] analyzed the thermal behavior of full and ventilated brake discs in vehicles using the computing code ANSYS. The modeling of temperature distribution in the disc brake aimed to identify factors and parameters relevant during the braking operation, including braking type, geometric disc design, and the material used. Numerical simulations, employing a sequentially thermal-structural coupled method based on ANSYS, evaluated stress fields, deformations, and contact pressure on the pads. The simulation results demonstrated satisfactory agreement with findings from specialized literature.

(Reddy et al., 2013)[23] focused on the modeling and assessment of both solid and ventilated disc brakes utilizing Pro-E and ANSYS. They developed finite element (FE) models of the brake disc using Pro-E and conducted simulations through ANSYS, employing the finite element method (FEM). Their research involved a Coupled Analysis, integrating both structural and thermal analyses, to evaluate the strength of the disc brake. In the structural analysis, they determined displacement and the ultimate stress limit for design. Simultaneously, in the thermal analysis, they calculated thermal gradients, heat flow rates, and heat fluxes by varying different cross sections and materials of the disc. Comparative evaluations were performed, considering displacement, stresses, nodal temperatures, and other parameters for three different materials to recommend the most suitable material for an FSAE car. (Ghadimi et al., 2013) [24] addressed the need for enhanced braking performance due to the high speeds of trains. The frictional heat generated during braking operations leads to adverse effects on the brake system, including brake fade, premature wear, thermal cracks, and variations in disc thickness. The study focused on the thermal analysis of the wheel-mounted brake disc R920K for the ER24PC locomotive. They simulated the brake disc and fluid zone as a 3D model with a thermal coupling boundary condition. Laboratory simulations of the braking process were conducted, and the experimental data were used to validate the simulation results. Interestingly, the maximum temperature during braking was observed in the middle of the braking process, rather than at the braking endpoint. Additionally, a significant lagging effect was noted for fins temperature, resulting in limited cooling at the beginning of the braking.

(Singh & Shergill, 2012)[25] delve into the analysis of heat generation and dissipation in a car's disc brake during panic braking and subsequent release, utilizing computer-aided engineering software to assess three different materials for the rotor disc. The primary aim is to explore and scrutinize the temperature distribution on the rotor disc during operation using COMSOL MULTIPHYSICS. Employing finite element analysis techniques, they predict the temperature distribution on the brake disc and identify the critical temperature of the brake rotor disc. All three heat transfer modes (conduction, convection, and radiation) are thoroughly examined. The results highlight distinct temperature distributions for different materials under the same car deceleration during panic braking. Consequently, a comparative analysis is conducted, recommending the best material for brake disc fabrication based on the rate of heat dissipation.

(Jiang et al., 2012)[26] conducted an investigation on the potential reduction of mass in high-speed trains by utilizing a brake disk composed of SiC network ceramic frame-reinforced 6061 aluminum alloy composite (SiCn/Al). The study focused on thermal and stress analyses of the SiCn/Al brake disk during emergency braking at a speed of 300 km/h, incorporating airflow cooling. Employing finite element (FE) and computational fluid dynamics (CFD) methods, the study comprehensively analyzed all three modes of heat transfer—conduction, convection, and radiation—alongside the design features of the brake assembly and their interfaces. The findings suggested that the utilization of higher convection coefficients achieved through airflow cooling not only diminished the maximum temperature during braking but also mitigated thermal gradients. The efficiency of airflow cooling was evident in the faster removal of heat from the hotter parts of the disk, reducing the risk of hot spot formation and disc thermal distortion. The highest temperatures recorded after emergency braking were 461 °C and 359 °C without and with considering airflow cooling, respectively. The equivalent stress reached 269 MPa and 164 MPa without and with airflow cooling, respectively. However, it was noted that the maximum surface stress might surpass the material yield strength during emergency braking, leading to plastic damage accumulation in a brake disk without cooling. Notably, the simulation results exhibited consistency with experimental findings, validating the accuracy of the conducted analysis.

(Duzgun, 2012)[27] identified that brake discs commonly face overheating issues, adversely impacting braking performance, particularly under continuous braking conditions in vehicles. To address this concern, the study explored the use of ventilation applications on brake discs to significantly enhance brake system performance by mitigating disc heating. The research investigated the thermal behaviors of ventilated brake discs with three different configurations under continuous brake conditions, focusing on heat generation and thermal stresses using finite element analysis. The obtained results were then compared with those of a solid disc. The findings revealed a notable reduction in heat generation on solid brake discs, reaching a maximum of 24% with the implementation of ventilation applications. The experimental study provided finite element temperature analysis results ranging between 1.13% and 10.87%. However, it was observed that thermal stress formations were higher in ventilated brake discs compared to solid discs. Despite the increased thermal stresses, the overall benefits of reduced heat generation demonstrated the potential advantages of ventilation applications in addressing overheating issues in brake discs.

3. DISC BRAKES

Disc brakes are a common type of braking system used in vehicles, providing efficient and reliable stopping power. They are widely employed on the front wheels of most modern cars and often on the rear wheels as well. Disc brakes offer superior performance compared to drum brakes, particularly in terms of heat dissipation and responsiveness.

Components of Disc Brakes

- **Brake Rotor (Disc):**

The brake rotor, commonly referred to as the disc, is a flat, circular metal component mounted on the wheel hub. It rotates with the wheel and is the primary surface on which the braking action occurs.

- **Brake Caliper:**

The brake caliper is a housing that contains pistons and brake pads. It is positioned on either side of the brake rotor. When the brake pedal is pressed, hydraulic pressure is applied to the pistons inside the caliper, causing them to squeeze the brake pads against the rotating disc.

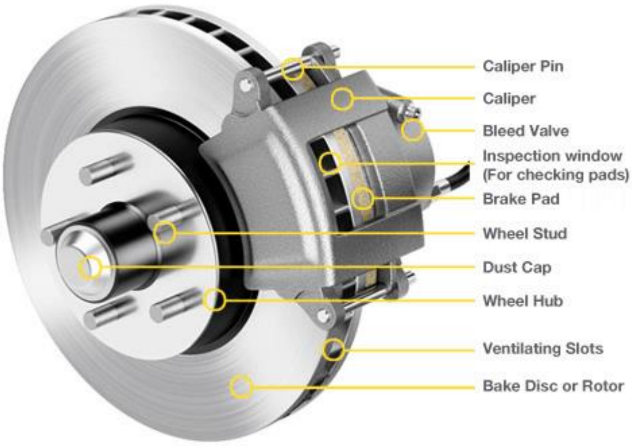

Figure -1 A Disk Brake

- **Brake Pads:**

Brake pads are friction materials attached to the inner side of the caliper. When the caliper pistons apply force, the brake pads make contact with both sides of the brake rotor, creating the friction necessary to slow down or stop the vehicle.

- **Caliper Pistons:**

The caliper contains one or more pistons that move in response to hydraulic pressure. These pistons force the brake pads against the rotor when activated, creating the friction needed for braking.

Working of Disc Brakes

- **Brake Application:**

When the driver presses the brake pedal, hydraulic pressure is generated in the master cylinder. This pressure is transmitted through brake lines to the caliper.

- **Caliper Activation:**

The hydraulic pressure in the caliper activates the pistons. The pistons extend, forcing the brake pads against the brake rotor on both sides.

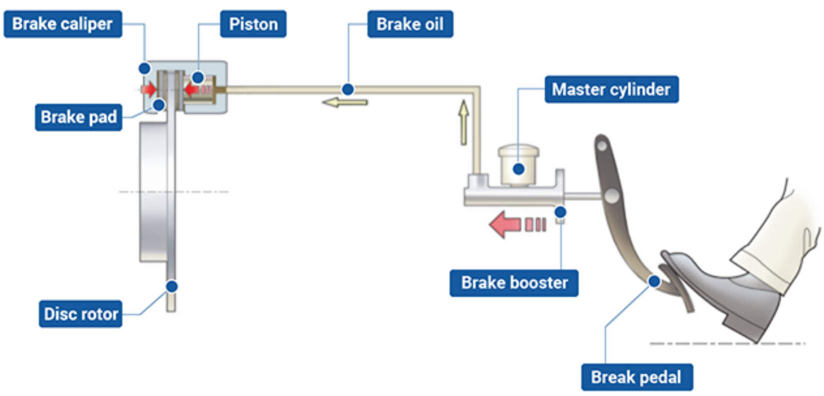

Figure -2 Working of A Disk Brake

- **Friction Generation:**

As the brake pads make contact with the rotating brake rotor, friction is generated. This friction transforms the kinetic energy of the moving vehicle into thermal energy or heat.

- **Slowing Down or Stopping:**

The generated friction creates a braking force that slows down or stops the rotation of the brake rotor. This, in turn, reduces the speed of the connected wheel and the vehicle.

- **Heat Dissipation:**

Disc brakes excel in dissipating heat. The design of the brake rotor allows for efficient heat transfer to the surrounding air. Ventilation channels or slots in the rotor enhance heat dissipation, preventing brake fade and maintaining braking performance under demanding conditions.

- **Release and Rotor Clearance:**

When the driver releases the brake pedal, the caliper pistons retract, allowing the brake pads to release from the rotor. This clearance prevents constant friction and ensures that the wheels can rotate freely when not braking.

The advantages of disc brakes include better heat dissipation, shorter stopping distances, and improved responsiveness compared to drum brakes. Their design allows for effective cooling, making them suitable for high-performance and heavy-duty applications. While disc brakes are commonly used on the front wheels of vehicles, some vehicles feature disc brakes on all wheels to enhance overall braking performance.

Types Of Disc Brakes

Disc brakes are of different types depending on the geometry, construction, calipers, position of calipers, number of calipers, etc. The type used depends on the application, braking power, material, vehicle design, etc.

Based on the type of calipers

i. Fixed Caliper Disc Brake

A fixed caliper disc brake is a high-performance braking system commonly utilized in sports and high-end vehicles. Unlike the floating caliper design, the fixed caliper is rigidly mounted to the vehicle's suspension, providing superior braking efficiency and responsiveness. Key components of a fixed caliper disc brake include the stationary caliper, pistons on both sides of the brake rotor, brake pads, and the rotating brake rotor. The design eliminates lateral movement in the caliper, ensuring direct and even pressure distribution on both sides of the rotor.

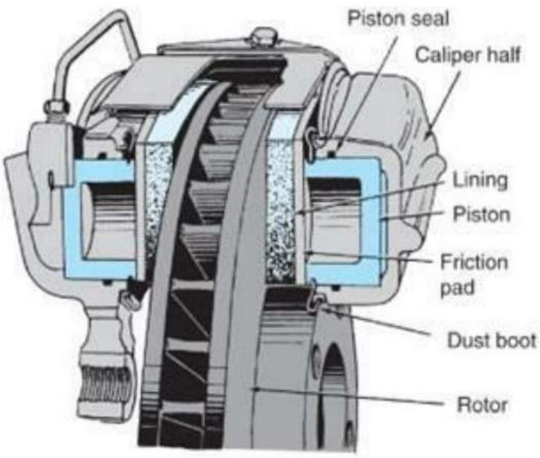

Figure -3 Fixed Caliper Brakes

When the brake pedal is pressed, hydraulic pressure activates the pistons, causing the brake pads to engage the brake rotor. The resulting friction converts kinetic energy into heat, slowing down or stopping the vehicle. Upon release of the brake pedal, the hydraulic pressure decreases, allowing the caliper pistons to retract and creating clearance for the wheel to rotate freely.

Fixed caliper disc brakes offer advantages such as increased braking efficiency, reduced brake fade, enhanced heat dissipation, precise control, and aesthetic appeal. The rigid caliper design provides stability and reliability, making it a preferred choice for enthusiasts and high-performance applications, although it may be more complex and costly to manufacture than floating caliper designs.

ii. Floating Caliper Disc Brake

A floating caliper disc brake is a widely used braking system known for its simplicity and cost-effectiveness. Unlike fixed caliper designs, a floating caliper moves laterally during braking, engaging only one side of the brake rotor. While it may not match the high-performance characteristics of fixed caliper brakes, it provides reliable braking for everyday driving scenarios.

The key components of a floating caliper disc brake include the floating caliper, piston, brake pads, and the brake rotor. The caliper, which houses the brake pads, is designed to slide laterally on guide pins or bushings when hydraulic pressure is applied. Typically, a single piston on one side of the caliper initiates this movement, causing one brake pad to engage with one side of the brake rotor.

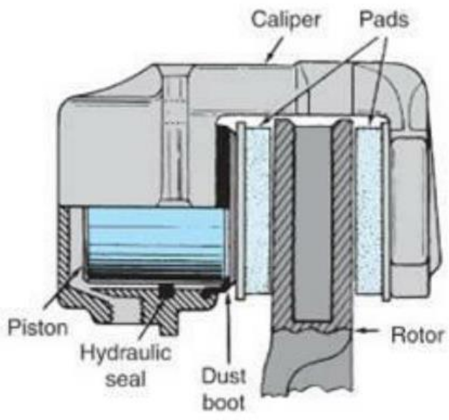

Figure -4 Floating Caliper Brake

During braking, when the driver presses the brake pedal, hydraulic pressure prompts the caliper to move laterally. This lateral movement brings one brake pad into contact with one side of the brake rotor, generating the necessary friction to slow down or stop the vehicle. The ensuing friction converts kinetic energy into thermal energy or heat, facilitating the braking process.

One of the advantages of floating caliper disc brakes lies in their simplicity and cost-effectiveness. The design is easier to manufacture and maintain compared to fixed caliper brakes. Additionally, the floating caliper's lateral movement is forgiving in terms of wear and tear. Floating caliper disc brakes are particularly well-suited for everyday driving scenarios. While they may not deliver the high-level performance required for sports or high-performance vehicles, they provide adequate and reliable braking performance for standard driving conditions. This makes them a common choice in various passenger vehicles where cost-effectiveness and simplicity are key considerations.

In summary, the floating caliper disc brake, with its lateral movement and straightforward design, serves as a practical and cost-efficient braking solution for everyday driving needs, emphasizing reliability and ease of maintenance.

iii. Sliding Caliper Disc Brake

The sliding caliper disc brake, also known as a single-piston or floating single-piston caliper, is a widely adopted braking system recognized for its simplicity, cost-effectiveness, and efficient design. This brake system employs a caliper that moves laterally on guide pins or bolts during braking, engaging one brake pad with the brake rotor.

The key components of a sliding caliper disc brake include the sliding caliper, a single piston, brake pads, and the brake rotor. When the driver applies the brake pedal, hydraulic pressure is generated, causing the piston to move and initiate the lateral sliding motion of the caliper. This movement brings one brake pad into contact with one side of the brake rotor, generating the necessary friction for braking.

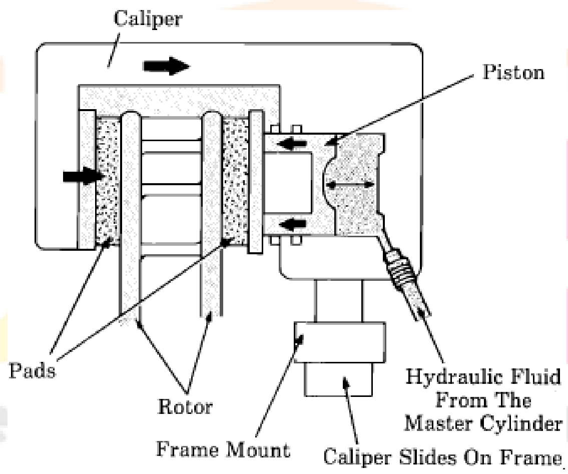

Figure -5 Sliding Caliper Brake

Advantages of sliding caliper disc brakes include cost-effectiveness, simplicity, and reliability. They are generally more affordable to manufacture and maintain compared to more complex brake designs. Their straightforward construction enhances reliability and ease of maintenance, making them suitable for various vehicles. While they may not offer the same high-performance characteristics as some other brake systems, sliding caliper disc brakes provide adequate braking performance for everyday driving scenarios, rendering them a common choice in many passenger vehicles. In summary, the sliding caliper disc brake exemplifies a practical and economical braking solution that effectively meets the demands of routine driving.

Based on Design

i. **Ventilated Disc Brakes:**

Ventilated disc brakes, also known as slotted or cross-drilled disc brakes, feature additional channels or holes in the brake rotor. These channels provide improved heat dissipation and better performance under high-stress conditions.
The ventilation channels or holes allow air to flow through the disc, promoting enhanced cooling. This design minimizes brake fade, a phenomenon where prolonged and intense braking causes a reduction in braking performance due to excessive heat buildup. Ventilated disc brakes are commonly found in high-performance and sports cars, as well as heavy-duty vehicles where braking systems undergo substantial stress.

Advantages:

a) **Heat Dissipation:** Improved ventilation facilitates efficient heat dissipation, preventing brake fade and maintaining consistent braking performance.
b) **Reduced Weight:** The design with holes or slots often results in a lighter disc, contributing to reduced unsprung weight, which can benefit overall vehicle handling.

ii. **Slotted Disc Brakes:**

Slotted disc brakes feature grooves or slots on the surface of the brake rotor. These slots aid in expelling gas, dust, and water that may accumulate between the brake pad and rotor during braking. Slotted disc brakes find applications in various vehicles, including those driven in demanding conditions or environments where effective cooling and consistent braking are essential. The slots also help to maintain a consistent brake pad surface, preventing uneven wear and improving overall brake efficiency.

Advantages:

a) **Improved Pad Bite:** The slots provide a fresh braking surface during each engagement, enhancing pad bite and responsiveness.
b) **Enhanced Cooling:** Similar to ventilated disc brakes, slotted disc brakes facilitate improved heat dissipation, contributing to better thermal performance.

iii. **Drilled Disc Brakes:**

Drilled disc brakes have holes drilled through the surface of the brake rotor. These holes are designed to dissipate heat and reduce the overall weight of the disc. The holes also contribute to aesthetic appeal, giving a distinctive look to the braking system. While drilled disc brakes offer advantages in terms of heat dissipation and appearance, they may be more prone to stress and cracking, particularly in extreme driving conditions. Therefore, their application is often more common in street-driven or light performance vehicles.

Advantages:

a) **Effective Heat Dissipation:** The drilled holes aid in efficient heat dissipation, preventing overheating during intense braking.
b) **Aesthetic Appeal:** The visual aspect of drilled disc brakes is often appreciated by automotive enthusiasts, contributing to the overall aesthetics of the vehicle.

iv. **Carbon Ceramic Matrix Disc Brakes:**

Carbon ceramic matrix disc brakes utilize advanced materials, including carbon fiber-reinforced ceramic composites. These discs offer exceptional heat resistance, reducing brake fade and improving overall braking performance. Carbon ceramic matrix disc brakes are often employed in high-end sports cars, luxury vehicles, and racing applications where superior heat resistance and weight savings are crucial.

Advantages:

a) **High Heat Tolerance:** Carbon ceramic matrix disc brakes can withstand higher temperatures compared to traditional iron or steel discs, making them ideal for high-performance and racing applications.
b) **Reduced Weight:** These discs are significantly lighter than their traditional counterparts, contributing to overall weight reduction and improved handling.

v. **Standard Solid Disc Brakes:**

Standard solid disc brakes consist of a simple, solid disc without additional slots, holes, or ventilation channels. These are the most basic and commonly used disc brakes. Standard solid disc brakes are widely used in everyday passenger vehicles, where the braking demands are typical and do not require the enhanced performance features of other disc brake types.

Advantages:

a) **Simplicity:** Standard solid disc brakes are straightforward in design, making them cost-effective and easy to manufacture.
b) **Reliability:** While they may lack some of the features of ventilated, slotted, or drilled disc brakes, solid discs provide reliable braking performance for everyday driving.

The choice of disc brakes depends on the specific requirements of the vehicle and its intended use. Ventilated, slotted, and drilled disc brakes offer enhanced performance features, making them suitable for high-stress conditions, performance vehicles, or those driven in demanding environments. Carbon ceramic matrix disc brakes cater to the most demanding applications where weight reduction and extreme heat tolerance are critical. Standard solid disc brakes, while lacking some advanced features, remain reliable and cost-effective for everyday driving scenarios. Ultimately, the selection of disc brakes involves a trade-off between performance, cost, and specific application needs.

4. CONCLUSION

The literature survey provides a comprehensive overview of research conducted on disc brakes, focusing on their thermal and structural analysis, material selection, and various methodologies employed for performance evaluation. The studies discussed highlight the critical role of disc brakes in ensuring vehicle safety, emphasizing the need for continuous advancements to address issues related to heat generation, thermal stresses, and structural wear during braking events. A relevant research gap lies in the need for standardized approaches to disc brake evaluation, particularly in thermal performance testing methodologies. This gap is critical for enhancing the reliability and efficiency of disc brake systems, aligning with the broader goal of improving vehicle safety and performance. Further exploration of standardized evaluation methods can contribute significantly to advancements in disc brake technology.

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