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A Review on Thermal Distribution Analysis of Dry Contact Motorcycle Disc Brake System

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ABSTRACT

Braking system is an active safety system use to slow down and stop the vehicle from moving. During braking phase, the kinetic energy of the vehicle will be converted to heat energy due to frictional action of the brake system. The generated heat flux due to the frictional effect is ideally dissipated to environment to avoid reduction of the coefficient of friction brake pad. The heat generated have tendency to vaporize the brake fluid and the surface of brake pad and disc brake rotor will experience rough surface that can cause thermal judder. The non-uniform contact cycle during braking will create localized Thermo-Elastic Instabilities (TEI) at disc brake surface. The localized TEI action at friction ring may develop thermal problem called hot spots and other thermal deformation. It is crucial to study the brake system to avoid in heavy injury and fatally. This paper intends to review the thermal distribution analysis that had been done by previous researchers in optimizing the design of the brake disc system. The review also includes the type of materials and geometries that potentially increase the performance of the brake disc system.

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INTRODUCTION

Nowadays, two wheel vehicles have become the main transportation choice over four wheel vehicles in many countries around the world. People prefer to use motorcycle as their mean of transportation because it is more economical and more flexible in maneuvering during heavy traffic (E.I. Vlahogianni *et al*., 2012). However, if they have slight contact with other vehicle or obstacle and loss maneuvering control, it may cause wheel skid issue or sliding, which can contribute into serious injury or fatality (C.W.Yuen *et al*., 2014). Thus an active safety system is very crucial to reduce and prevent road accident (R.Srani *et al*., 2011).

According to Malaysia Road Safety Department, in 2010, the statistic had recorded 120,156 motorcycles accident cases which is about 24% of increment compared to the year 2005 (R.Srani *et al*., 2011). This statistic should be taken seriously because motorcycle's accident will always lead to heavy injury and casualty. Therefore, it is very important to consider prevention method to reduce the bad consequences in the future (R.J. Talib *et al*., 2003). Aside from the rider role in preventing an accident, the active accident prevention method such as improving current design or system of the brake is very important to be studied and enhanced to reduce the accident cases (P.Seiniger *et al*., 2012).

Braking system is an active safety system which helps to slow down or stop the motorcycle when needed during riding, thus it helps to prevent a road accident (F.Todoschini *et al*., 2014). The conventional braking system had been divided into two individual brake systems which is a rear brake system and front brake system.

There are several aspects that were studied such as brake pad materials, rotor's geometry, mechanical of material used properties and its thermal influences towards braking phase. Study on brake disc is usually concerned about the frictional behavior which affects the thermal dissipation rate (M. Eltoukhy, 2008).

The thermal properties such as heat flux generated, temperature distribution, rotor's geometry influences and thermal conductivity materials are the usual parameters studied by previous researchers (Ali Belhocine and M. Bouchetra 2012).

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The study shows that heat generated due to friction during braking is ideally dissipated to environment to avoid the reduction of the friction coefficient between disc brake and brake pad (Faramaz Talatti and Salman Jalalifar 2009).

The increase of temperature of the brake components can lead into the brake fluid vaporization. This phenomena may affect braking performance and could lead to braking problem (Uyyuru R.K., Surappa M.K., Brusethaug S, 2007) Also, the frictional heat between both sides of the brake disc can cause thermoelastic deformation at the pad which will change contact pressure distribution (Mosleh M. *et al*., 2004). The non-uniform contact cycle during braking will create localized Thermo-Elastic Instabilities (TEI) at disc brake surface (Lee., K. J and Barber, J. R., 2014). Thermal deformation can initiate other major problem such as variation of friction coefficient for the brake pad, brake fade and vapor lock (Bakar, A.R. *et al*., 2010).

Thus, this paper intends to highlight the effect of thermal distribution factors towards the motorcycle's braking performance during braking phase.

Braking Performance:

Disc brake system is constructed based on disc shape that mounted together with wheels and brake pad mounted at brake caliper (N. Balasubramanyam and Prof. Smt. G. Prasanthi 2014). During braking, frictional heat was generated due to sliding contact of brake disc and brake pad. The surface of the contact area may alter the contact pressure distribution which caused thermoelastic deformation (Faramaz Talatti and Salman Jalalifar 2009). The development of local high temperature gradient is called "hot spot" (Altuzarra, 2002). The localized hot spots will cause high local stress that lead to material degradation and failure (Jang. Y. H. *et al*., 2007). This couple thermo-mechanical process is called hermoelastic instability (TEI) (Lee K. J and Barber, 1994)

Localized thermoelastic instability phenomenon (TEI) is a phenomenon which generating intermittent hot bands around the rubbing path which may cause hot spots that commonly happen at friction ring surface as an effect of thermal judder. Barber (1969) and Choi (2003) had studied about transient thermoelastic analysis which is concerning localized thermoelastic phenomenon (TEI) while Zagrodzki (1990) and Eggleston (2000) studied relationship of thermal judder phenomenon.

The braking system can be influenced by three main factors brake system (drum brake system or disc brake system), rotor's geometry (vented disc or solid disc) and material used for disc brake. The basic principle of heat transfer occurred during braking was represent by the figure 1. Aside from heat conduction mechanism, the braking also involve heat convection and radiation mechanism which transferring the heat conduction to surrounding (M. Eltoukhy, 2008).

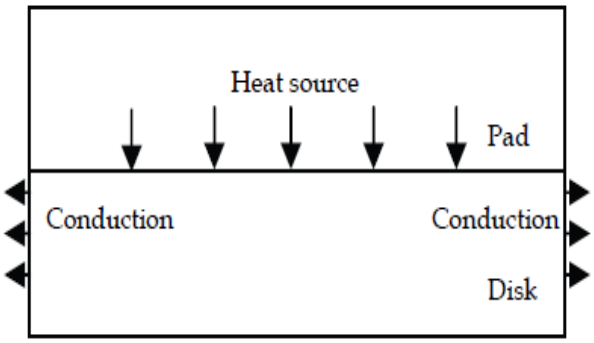

Fig. 1: Heat transfer boundary conditions (M. Eltoukhy, 2008).

Types Of Braking System:

There are two types of conventional brake mechanism system which are drum brake system and disc brake system. Drum brake system concept are producing force inversely toward the direction of the rotating brake drum using a set of shoes or pad which will produce friction that can decelerate the wheel's motion. Thus it will slow down and stop the motorcycle movement (E.I. Vlahogianni *et al*., 2012). The disc brake system is constructed by combining several components such as couple of brake pad that mounted at brake caliper and connected to wheel or the axle. (Ali Belhocine and M. Bouchetra 2014). Normally the disc pad is made of cast iron or ceramics. During braking, a frictional material at brake pad is forced mechanically toward brake disc which connected directly to the wheel then decelerate movement and stop the motorcycle (E.I. Vlahogianni *et al*., 2012).

Disc brake system for motorcycle is preferred than drum brake system due to its high frictional force which makes it faster that produce shorter braking distance (N. Balasubramanyam and Prof. Smt. G. Prasanthi 2014).

Disc Brake Geometry:

Ostermeyer (2001) studied the relationship of wear produce of contact area between brake disc and brake pad. Study showed the wear behavior affect the

coefficient of friction which cause the fading effect when the destruction rate was started to growth cross the disc thickness to the other brake disc surface. This phenomenon can lead the brake disc to failure. Thus the brake disc geometry is essential to sustain the life of the brake disc

Researchers had divided the disc brake geometry into two main categories that is solid disc brake and vented disc brake. The classification is made based on their geometry that is without ventilated shape or with ventilated (T.C. Chartterley *et al*. (1999), Bakar, A.R. *et al*. (2010), and Ali Belhocine and M. Bouchetra (2012)

Solid disc brake is a type of disc brake which its geometry is standard flat surface disc that do not have notches or grooves as shown in figure 2. It had more surface area contact with brake pad compare with vented disc (M. Eltoukhy, 2008). However it tend to have larger effect of localized thermo-elastic Instabilities (TEI) (Barber, 1969 and Choi, 2003) problem. This is also caused brake fade and pad glazing compare with vented disc due to not having appropriate airflow to distribute the heat generated to surrounding (Hudson, M. D. and Ruhl, R. L., 1997).

Fig. 2: Solid Disc Brake (Talati and Faramarz, 2009)

Vented disc as its name called, is referred to the type of the geometry of the disc brake which having ventilated pattern which air will flow through the ventilated slot thus the heat will be dissipated much faster compare with solid disc. Three types of the ventilated disc that had been studied experimentally by H.B. Yan *et al*. (2014) is Pin-fins ventilated disc, Radial vanes, and curves vanes as shown in figure 3.

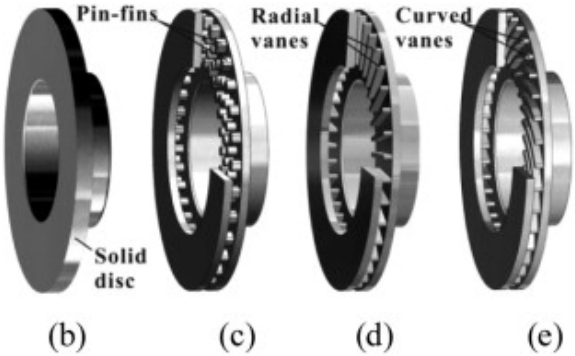

Fig. 3: Schematic illustration of car disc brake system (b) solid disc brake type (c) - (e) ventilated brake discs type pin-fins, radial vanes and curved vanes (T.C. Chartterley *et al*., 1999)

A ventilated disc had more advantage compared to solid disc in term of weight and its convective heat. It having ventilation vane so it can easily control the increment of its temperature as this will result low occurring of thermal problem such as brake fade, variation of the pad friction and vapor lock (Mosleh *et al.,* 2004 and Uyyuru *et al.,* 2007). Although it has more advantages than solid disc, it also has some disadvantages such as lower thermal capacity and the higher temperature rise when the braking is applied repeatedly over some period (Boz M and Kurt A, 2007). Those in designing and choosing of the ventilated disc, one must also concern about its thermal capacity and thermal

deformation factor in order to optimize the brake disc design (Valvano and Lee, 2000).

Kang and Cho (2012) had analyzed of the geometry in motorcycle disc brake affect towards the surface of the rotor disc. They found that ventilated disc brake had better performance on heat dissipation compare with solid disc brake (Kang and Cho, 2012).

Researchers also relate the design of the rotor geometry with aerodynamic cooling to get high performance disc brake system (McPhee and Johnson DA (2007), Wallis.L *et al.,* (2002) and Johnson DA *et al*., (2003)).

Jung *et al*., (2012) had done an analysis technique which can estimate the rise in temperature during braking phase with the thermal deformation occurred during the phase. Park had constructed mathematical modeling which main heat flux parameter wanted to be find using decelerating parameter of 130km/h to 0 km/h. Jung *et al*., (2012) had found that the shape of cross section played an important factor in optimizing the braking performance which was proved by the response surface analysis method which had been done.

Ali Belhocine *et al*. (2014) had studied the thermomechanical behavior of the friction effect dry contact of disc brake rotor. The author studied using grey cast iron material composition using two model of disc brake. The two types were full solid disc brake rotor and ventilated type of disc brake. The author concluded that ventilated disc was having more efficient in dissipating heat compare with solid disc.

M. Eltoukhy (2008) also had done analysis on the relationship of brake disc geometry towards the performance of braking. He found that ventilated disc was having better performance in term of dissipation heat compare with solid disc brake. The author also compared two types of ventilated brake disc design that were perforated and notched disc where the temperature distribution rate and the heat flux produced for both geometry were observe through Finite Element Analysis (FEA). It shown that perforated disc had higher heat temperature distribution rate and heat flux produced compared to notched disc brake.

Disc Brake's Materials:

Material selection play crucial role during conceptual design of the disc brake system (Joachim-Ajao and Barber,1998). Based on previous research, brake disc rotor is normally made from cast iron and sometimes it used reinforced carbon or ceramic matrix (Wang and Surappa (1998) and Shaoyang Zhang and Fuping Wang (1998). Each composition influences the thermal conductivity of the disc brake. In general, the thermal conductivity of brake pad should be lower than thermal conductivity of disc (Kd > Kp) (Ali Belhocine and M. Bouchetra 2012).

Guru Murthy Nathi *et al.,* 2012. had analyze the brake disc performance between Cast Iron, Stainless steel 302 annealed and Aluminum 2014-T6 material. The author concluded that Cast iron was the better materials for heat dissipation of the disc brake compare to the other two studied materials (Guru Murthy Nathi *et al.,* 2012).

Ali Belhocine *et al.,* (2012), had also analyzed the ventilated disc brake of rotors using three different types of cast iron as shown in figure 5. The results show that the temperature decreased was on the direction of median plane of the disc when reaching minimal value. It showed cast iron (FG15) had the lowest of the maximum temperature compare with other two types of cast iron (FG20 and FG25 Al). Thus, they suggested that cast iron FG15 is the better performance material in distributing the temperature to surrounding compare with other two cast irons.

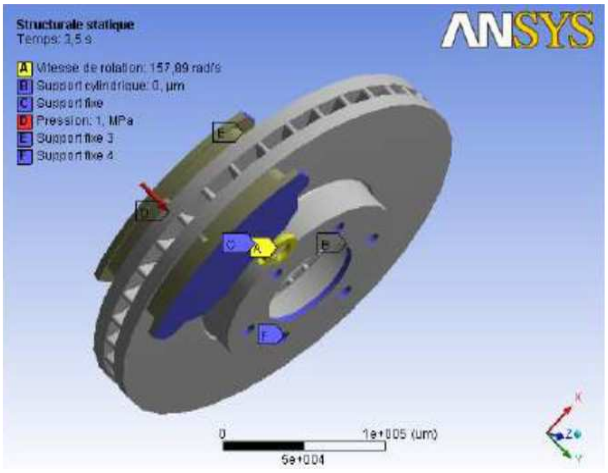

Fig. 5: Boundary conditions and loading imposed on the disc pads (Ali Belhocine and M. Bouchetra 2014).

M. Eltoukhy (2008) had studied on thermoelastic contact problem with frictional heat generation during braking by using finite element analysis (FEA). The author used five types of materials called grey cast iron (grey iron grade 250), high-carbon grade iron, compact graphite iron (CGI), Aluminum metal matrix composites (Al-MMC's) and ceramic brakes (SiC Al-MMC). Aluminum metal composite or ceramic brake were preferred to be selected to be fabricated as brake disc rotor as compared with other four materials in term of thermal dissipation rate during braking. Both Aluminum metal composite and ceramic brake provided evenly distributed temperature than carbon-carbon composite which can prevent localization of heat.

Thilak VMM *et al*. (2011), had conducted a transient coupled thermal and structural analysis of a disc brake using new materials which aim to improve the performance and efficiency of the braking. Aluminium base metal matrix composite and High Strength Glass Fiber composites was introduced during the study. Both materials shows good friction and wear behavior compared with cast iron disc which was more preferred to be applied for future brake disc fabrication (Thilak VMM *et al*. ,2011).

Faiz Ahmad *et al*. (2013) had done experimental analysis by comparing the reduction of coefficient of friction material during braking for Aluminum Composites and cast iron of brake disc. The wear rate for both materials has determined by comparing the progress of reduction of coefficient of friction. Thus, it influenced the brake performance. Aluminum Composites was found to be having less reduction of coefficient of materials during braking compare to conventional brake disc (Faiz Ahmad *et al*., 2013).

Discussion And Conclusion:

Based on the review, braking performance is higher if they can be an excellent heat transfer mechanism. It is includes high heat flux generation during the braking and faster heat distribution to surrounding.

There are three major factors that influence the effectiveness of the heat transfer during braking phase that is:

1) Types of brake

The review shows that disc brake is having better heat transfer mechanism as compare to drum brake system.

2) Types of materials

Type of materials used influenced the rate of heat dissipation during braking. Aluminium composite potentially used to be the next material used for disc brake system as it has less reduction of coefficient of friction. This can increase the life cycle of the brake disc.

3) Types of brake disc

From studied, ventilated disc brake is proved to be better performance compare with solid disc brake because the design will allow air to flow through the ventilated hole which helps to distribute the heat generated to surrounding faster than the solid disc. Ventilated disc design include either perforated or notched disc. Perforated disc is chosen to be more effective design for ventilated disc. It has better heat transfer mechanism as compare to notched disc in term of temperature distribution and heat flux produce.

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REFERENCES

Ali Belhocine, Mostefa Bouchetara, 2012. "Thermal analysis of a solid brake disc" Applied Thermal Engineering, 32: 59-67.

Ali Belhocine, 2014. Mostefa Bouchetara,"*Structural And Thermal Analysis of Automotive Disc Brake Rotor*, " Archieve of Mechanical Engineering, LXI: 1.

Altuzarra, O., E. Amezua, R. Aviles and A. Hernandez, 2002. "Judder vibration in disc brakes excited by thermoelastic instability," Eng. comput, 19(4): 411-430.

Bakar, A.R.A., H. Ouyang, L.C. Khai and M.S. Abdullah, 2010. "Thermal Analysis of a Disc Brake Model Considering a Real Brake Pad Surface and Wear," International Journal of Vehicle Structures & Systems, 2(1): 20-27.

Barber, J.R., 1969. Thermoelastic instabilities in the sliding of conforming solids, *Proc. R. Soc.* A312 381–394.

Choi, J.H. and I. Lee, 2003. Transient thermoelastic analysis of disk brakes in frictional contact, Journal of Thermal Stresses, 26: 223-244.

Choi, J.H. and I. Lee, 2004. Finite element analysis of transient thermoelastic behaviors in disk brakes, *Wear*, 257: 47-58

Yuen, C.W., M.R. Karim and A. Saifizul, 2014. The Scientific World Journal, pp: 1-9.

Cueva, G., A. Sinatora, W.L. Guesser and A.P. Tschiptschin, 2003. Wear resistance of cast irons used in brake disk rotors, Wear, 255: 1256-1260.

Joachim-Ajao, D., J.R. Barber, 1998. Effect of material properties in certain thermoelastic contact problems, ASME J. Appl. Mech., 65: 889-893.

Vlahogianni, E.I., G. Yannis and J.C. Golias, 2012. Accident: analysis and prevention.

Eggleston, D., 2000. Thermal Judder, *EURAC Technical Bulletin*, pp: 34056.

Todeschini, F., M. Corno, G. Panzani and S.M. Savaresi, 2014. European Journal of Control, 20(2): 79-86.

Faiz Ahmad, S.H. Jason Lo, Muhammad Aslam, Ahmad Haziq, 2013." Tribology Behaviour of Alumina Particles Reinforced Aluminium Matrix Composites and Brake Disc Materials", The Malaysian International Tribology Conference 2013, MITC2013, Procedia Engineering, 68: 674-680.

Faramarz Talatti, Salman Jalalifar, 2009. "Analysis of Heat Conduction in a disc brake system," Heat Mass Transfer, 45: J047-1059 DQ1 10.1007/s009-0476-y.

Guru Murthy Nanthi, T.N. Charyulu, K. Gowtham, P Satish Reddy, 2012. "Coupled Structural/Thermal Analysis of Disc Brake" International Journal of Research in Engineering and Technology (IJRET), 01: 04.

Yan, H.B., Q.C. Zhang, T.J. Lu, 2015. "An X-type lattice cored ventilated brake disc with enhanced cooling performance" International Journal of Heat and Mass Transfer, 80: 458-468.

Hudson, M.D. and R.L. Ruhl, 1997. "Ventilated Brake Rotor Air Flow Investigation, " SAE Technical Paper, 106(6): 1862-1871.

Jang, Y.H. and S.H. Ahn, 2007. "Frictionally-excited thermoelastic instability in functionally graded material," Wear, 262: 1102-1112.

Johnson, D.A., B.A. Sperandei, R. Gilbert, 2003. Analysis of the flow through a vented automotive brake rotor. J Fluids Eng., 125: 979-986. doi:10.1115/1.1624426

Jung, S.P., Y.G. Kim and T.W. Park, 2012. "A Study on thermal characteristic analysis and shape optimization of a ventilated disc," Int. J. Precis. Eng. Manuf., 13(1): 57-63.

Kang, S.S. and S.K. Cho, 2012. "Thermal deformation and stress analysis of disk brakes by finite element method Journal of Mechanical Science and Technology," 26(7): 2133- 2137.

Lee, K.J. and J.R. Barber, 1994. "An Experimental Investigation of Frictionally-Excited Thermoelastic Instability in Automotive Disk Brakes Under a Drag Brake Application," J. Tribol, 116: 409-414.

Eltoukhy, M. and S. Asfour, 2008. Braking Process in Automobiles: Investigation of the Thermoelastic

Instability Phenomenon, Modelling and Simulation, Giuseppe Petrone and Giuliano Cammarata (Ed.), ISBN:978-3-902613-25-7, InTech, Available from: http://www.intechopen.com/books/modelling_and_simulation/braking_process_in_automobiles__investigation_of_the_thermoelastic_instability_phenomenon

McPhee, A.D., D.A. Johnson, 2007. Experimental heat transfer and flow analysis of a vented brake rotor. Int J Thermal Sci., 47(4): 458-467. doi:10.1016/j.ijthermalsci.2007.03.00619.

Mosleh, M., P.J. Blau, D. Dumitrescu, 2004. "*Characteristics and morphology of wear particels from laboratory testing of disc brake materials*," J Wear, 256: 1128-1134.

Balasubramanyam, N. and Prof. Smt. G. Prasanthi, 2014. "Design and analysis of disc brake rotor for a two wheeler", International Journal of Mechanical and Industrial Technology (IJMIT), 1(1): 7-12.

Ostermeyer, G.P., 2001. On the dynamics of the friction coeffi- cient. J Wear., 254(9): 852-858. doi:10.1016/S0043-1648(03) 00235-7

Seiniger, P., K. Schroter and J. Gail, 2011. Accident; Analysis and Prevention, 44(1): 74-81.

Sarani, R., A. Roslan and N. Saniran, 2011. 'Statistics and Accident Characteristics Involving Motorcycles in Malaysia.

Talib, R.J., M.F. Mustafa, S. Kemin and R. Kasiran, Jurnal Teknologi, 38: 1-13.

Wang, R.M. and M.K. Surappa, 1998. Microstructure and interface structure studies of SiCp-reinforced Al (6061) metal-matrix composites Materials Science and Engineering. A, 254(1-2): 219-226.

Palani, R., 2011. "Transient thermal and structural analysis of the rotor disc of disc brake," International Journal of Scientific & Engineering Research, 2: 8.

Shaoyang Zhang, Fuping Wang, 2007. Comparison of friction and wear performances of brake material dry sliding against two aluminum matrix composites reinforced with different SiC particles, Journal of Materials Processing Technology, 182: 122-127.

Thilak, V.M.M., R. Krishnaraj, M. Sakthivel and K. Kanthavel, M.G. Deepan marudachalam, R.K. Uyyuru, M.K. Surappa, S. Brusethaug, 2007. "*Tribological behaviour of Al-Si-SiCp composites/automobile brake pad system under dry sliding conditions*," *J Tribol Int.*, 40(2): 365-373.

Valvano, T. and K. Lee, 2000. "An Analytical Method to Predict Thermal Distortion of a Brake Rotor," SAE Technical Paper, 109(6): 566-571.

Wallis, L., E. Leonardi, B. Milton, P. Joseph, 2002. Air flow and heat transfer in ventilated disk brake rotors with diamond and tear-drop pillars. Numer Heat Transf Part A 41:643–655. URL: http://openurl.ingenta.com/content?genre=article&issn=1040-778 2&volume=41&issue=6-7&spage=643&epage=655

Zagrodzki, P.K., B. Lam, E. Al Bahkali and J.R. Barber, 2001. Nonlinear transient behavior of a sliding system with frictionally excited thermoelastic instability, Journal of Tribology, 123: 699-708.