



THERMAL STRESS EFFECT ON DISC BRAKE ROTOR FOR NGV VEHICLE

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**MASTER OF MECHANICAL
ENGINEERING (ENERGY
ENGINEERING)**

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FACULTY OF MECHANICAL ENGINEERING

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**A report submitted in accordance with requirement of the Universiti Teknikal
Malaysia Melaka (UTeM) for the award of Master of Mechanical Engineering
(Energy Engineering)**

Faculty of Mechanical Engineering

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APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality as a partial fulfillment of Master of Mechanical Engineering (Energy Engineering).

Signature :

Supervisor Name :

Date :

DECLARATION

I declare that this report entitled “Thermal Stress Effect On Disc Brake Rotor For NGV Vehicle” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name :

Date :

ABSTRACT

Braking system is one of the safety aspects in vehicle design that is very important to stop a vehicle safely and avoiding an imminent collision with another vehicle, person or obstacle. During braking operation, most of the kinetic energy is converted into thermal energy and thus increases the disc temperature. Excessive temperature with poor heat dissipation would causes problems such as cracking, coning and brake pad failure. Therefore it is important to have sound knowledge on temperature distribution and thermal stress so that the designed brake will fully function. This study was conducted with a focus on the effect of thermal stress and temperature distribution behaviour on ventilated disc brake with various loading of the NGV vehicle. Steady state and transient response are used to predict the temperature distribution, deformation as well as stresses during the worst and extreme braking condition. Finite element analysis approached is conducted to identify the temperature distributions and behaviours of disc brake rotor in steady state and transient response. ANSYS software is used to perform the thermal analysis and predict the temperature distributions and behaviours at various loads. Results from both steady state and transient response are compared so that the result will assist the automotive industry in developing optimum and effective disc brake rotor.

ABSTRAK

Sistem brek merupakan salah satu daripada aspek keselamatan dalam reka bentuk kenderaan yang sangat penting untuk menghentikan kenderaan dengan selamat dan mengelakkan dari berlakunya pelanggaran dengan kenderaan lain, orang atau halangan. Semasa operasi membrek, kebanyakan tenaga kinetik ditukar kepada tenaga haba dan dengan itu meningkatkan suhu cakera. Suhu yang berlebihan dengan pelepasan haba yang lemah akan menyebabkan masalah seperti keretakan, perubahan bentuk kepada kon dan kegagalan pad brek. Oleh itu adalah penting untuk mempunyai pengetahuan luas tentang taburan suhu dan tegasan haba supaya brek yang direka dapat berfungsi sepenuhnya. Kajian ini dijalankan dengan memberi tumpuan kepada kesan tingkah laku tekanan dan taburan suhu haba ke atas cakera brek berongga dengan pelbagai bebanan terhadap kenderaan jenis NGV. Tindakbalas keadaan mantap dan keadaan berubah dengan masa digunakan untuk meramal taburan suhu, perubahan bentuk dan juga tegasan semasa keadaan membrek yang paling teruk dan melampau. Langkah analisis unsur terhingga dijalankan untuk mengenal pasti taburan suhu dan tingkah laku cakera brek dalam tindakbalas keadaan mantap dan keadaan berubah dengan masa. Perisian ANSYS digunakan untuk melaksanakan analisis terma dan meramalkan taburan suhu dan tingkah laku pada pelbagai beban. Keputusan daripada kedua-dua tindakbalas keadaan mantap dan keadaan berubah dengan masa dibandingkan supaya hasilnya akan membantu industri automotif dalam membangunkan cakera brek yang optimum dan berkesan.

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TABLE OF CONTENTS

	PAGE
APPROVAL	i
DECLARATION	ii
ABSTRACT	iii
ABSTRAK	iv
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS	vi
LIST OF FIGURES	ix
LIST OF TABLES	xv
LIST OF SYMBOLS	xvii
LIST OF APPENDICES	xxii
 CHAPTER	
1. INTRODUCTION	1
1.0 Background	1
1.1 Problem Statement	3
1.2 Objective	6
1.3 Scope of the Projects	7
1.4 Thesis Outline	8
 2. LITERATURE REVIEW	 9
2.1 Introduction	9
2.2 The Evolution of Brake System	10
2.3 Brake System Operation	14
2.3.1 Weight Transfer	14
2.3.2 Brake Distance	16
2.3.3 Heat Dissipation	18
2.3.4 Brake Operation and Components	20
2.3.5 Disc Brake Components	23
2.3.5.1 Disc Brake Callipers	24
2.3.5.2 Brake Pad	25
2.3.5.3 Ventilated Disc Brake	27
2.3.6 Brake Disc Description and Advantages	31
2.4 NGV Vehicle	32
2.5 Review of Previous Research	34
2.6 Finite Element Analysis	37
2.6.1 FEA Software: ANSYS	39
2.7 Heat Transfer Theory	41
2.8 Finite Element Method: Steady State and Transient Analysis	46
2.9 Manufacturing	51
 3. RESEARCH METHODOLOGY	 54
3.1 Introduction	54
3.2 Research Methodology	55
3.2.1 Preparation Sample and Literature Review	57
3.2.2 Measurement of Disc Brake	57
3.3.3 Material Selection	62
3.3.4 3D Modelling Using SOLIDWORKS Software	64

3.3.5	Load Analysis	66
3.3.6	Finite Element Modelling and Simulation With ANSYS Workbench	66
3.3.6.1	Steady State Thermal Analysis Setup	66
3.3.6.2	Transient Thermal Analysis Setup	78
3.3.6.3	Thermal Stress Analysis Setup	84
3.3.7	Result and Validation (Steady State, Transient Response and Thermal Stress)	89
3.3.8	Discussion	89
4.	LOAD ANALYSIS	90
4.1	Introduction	90
4.2	Assumption	91
4.3	Heat Flux Calculation	92
4.3.1	Load Cycle	93
4.3.2	Heat Flux Calculations	95
4.3.2.1	Normal Passenger Car Physical Data	95
4.3.2.2	Braking Force	98
4.3.2.2.1	Braking Force from Road Surface Friction	99
4.3.2.2.2	Braking Force from Brake Pad Friction	103
4.3.2.2.3	Braking Power of Passenger Vehicle	108
4.3.2.2.4	Heat Flux	109
4.4	Conventional Heat Transfer As A Boundary Condition	113
4.4.1	Conventional Heat Transfer Coefficient on Inboard and Outboard Surfaces	115
4.4.2	Conventional Heat Transfer Coefficient on Outer Ring Surface	117
4.4.3	Conventional Heat Transfer Coefficient on Inner Ring (Outer)	119
4.4.4	Conventional Heat Transfer Coefficient on Inner Ring (Inner Upper)	122
4.4.5	Conventional Heat Transfer Coefficient on Inner Ring (Inner Bottom)	125
4.4.6	Conventional Heat Transfer Coefficient on Inner Vane Passage	128
4.4.7	Conventional Heat Transfer Coefficient of Curved Vane Disc Brake	133
5.	RESULT AND DISCUSSION	137
5.1	Introduction	137
5.2	Steady State Thermal Analysis Results	138
5.3	Steady State Discussion	140
5.4	Transient Thermal Results and Discussions	140
5.5	Transient Thermal Validation	147
5.6	Transient Structural Results and Discussions	151
5.6.1	Deformation	151
5.6.2	Stress	154

5.7	Transient Structural Validation	161
6.	CONCLUSION AND RECOMMENDATIONS	163
6.1	Conclusion	163
6.2	Further Recommendations	165
	REFERENCES	166
	APPENDICES	174

LIST OF FIGURES

FIGURE	TITLE	PAGE
2-1	Early Brake System (Source: Auto Brake 3rd Edition, 2008)	10
2-2	Snubbing rope brake system (Source: PT Indo Bintang Mandiri, 2016)	11
2-3	The wooden block and lever (Source: http://www.dbrake.com)	12
2-4	Weight transfer during braking (Source: http://www.monroe-sea.com/)	15
2-5	Heat dissipation (Source: http://www.myturbodiesel.com/)	16
2-6	Velocity-time diagram for braking (Source: Brake Design & Safety 3rd Edition)	16
2-7	General rules techniques and advice for all drivers and riders (Source: https://www.gov.uk/guidance/the-highway-code)	18
2-8	Heat transfer during braking	19
2-9	Temperature development during series of braking (Source: Brake Technology Handbook, Bert Breuer, Karlheinz H. Bill, 2008)	20
2-10	Brake circuit system of normal vehicle. (Source: https://www.howacarworks.com/)	21
2-11	Cutaway of power booster (Source: http://www.corvette-restoration.com)	22

2-12	Disc brake components. The hub and the disc are formed as one piece (integral) unit (Source: Auto Brake 3rd Edition, 2008)	23
2-13	Floating calliper (Source: Source: Auto Brake 3rd Edition, 2008)	24
2-14	Fixed calliper (Source: Source: Auto Brake 3rd Edition, 2008)	25
2-15	Brake pads (Source: Bosch)	26
2-16	Temperature (°C) distribution	27
2-17	Solid (left) and ventilated (right) disc brake (Source: MaxBrakes)	28
2-18	Type of vanes (Source: Super Street Network & Disc Brake Australia, DBA)	29
2-19	Typical curved vane (Source: CamaroTech)	30
2-20	Convergent and variable vane (Source: RacingBrake & StopTech)	30
2-21	Normal passenger car (Source: Proton)	31
2-22	Integral ventilated disc brake	31
2-23	NGV conversion stages (Source: Supro NGV Gas Malaysia)	33
2-24	NGV main components (Source: Supro NGV Gas Malaysia)	34
2-25	ANSYS thermal analysis package, steady-state thermal and transient thermal. (Source: ANSYS)	40
2-26	Heat flux	42
2-27	Heat conduction through a plane with area A and wall thickness Δx	43
2-28	Force and natural convection (Source: Cengal)	44
2-29	Heat transfer through slab	47
2-30	Cluster brake disc casting (Source: Wolny R and Rygallo A. 2010)	51
2-31	Sand casting or gravity casting	

	(Materials Selection in Mechanical Design, 1999)	52
2-32	Die casting (Materials Selection in Mechanical Design, 1999)	52
3.1	Project Flow Chart	56
3-2	WENZEL LH54	57
3-3	Disc brake ready to measure	58
3-4	Probe joystick.	59
3-5	Measuring the disc brake	59
3-6	Windows software Metrosoft CM	60
3-7	Disc brake dimension	61
3-8	Young Modulus vs. Compressive Strength of Grey Cast Iron. (CES Edupack (2013))	62
3-9	Specific Heat vs Thermal Conductivity of Grey Cast Iron. (CES Edupack (2013))	63
3-10	Disc brake	65
3-11	Single faction of disc brake (12° segments)	65
3-12	Steady State Thermal for straight vane	67
3-13	Steady State Thermal for curved vane	67
3-14	Editing grey cast iron properties	68
3-15	Assigning material to geometry	68
3-16	Importing disc brake from SOLIDWORK	69
3-17	Symmetry Region setting for straight vane	69
3-18	Symmetry Region setting for curved vane	69
3-19	Quadrilateral and triangular meshing option (Source: ANSYS)	70
3-20	Detail of Mesh for straight vane	71
3-21	Initial Temperature setting	72
3-22	Analysis Setting for steady state straight and curved vane	72
3-23	Inboard heat flux (534,024.57 W/m ²)	73
3-24	Outboard heat flux (488,098.45 W/m ²)	74
3-25	Inboard convection heat transfer coefficients (221.75 W/m ² C)	74
3-26	Outboard convection heat transfer coefficients (221.75 W/m ² C)	75
3-27	Outer ring convection heat transfer coefficients (63.05 W/m ² C)	75
3-28	Vane convection heat transfer coefficients (134.67 W/m ² C) (Curved vane 152.18 W/m ² C)	76

3-29	Inner ring (outer) convection heat transfer coefficients ($52.72 \text{ W/m}^2\text{C}$)	76
3-30	Inner ring (inner upper) convection heat transfer coefficients ($51.22 \text{ W/m}^2\text{C}$)	77
3-31	Inner ring (inner bottom) convection heat transfer coefficients ($53.18 \text{ W/m}^2\text{C}$)	77
3-32	Transient Thermal for straight vane	78
3-33	Transient Thermal for curved vane	78
3-34	Details of Mesh for curved vane	79
3-35	Analysis setting for transient thermal	81
3-36	Heat flux for inboard ($534,024.57 \text{ W/m}^2$)	83
3-37	Outboard heat flux ($488,098.45 \text{ W/m}^2$)	83
3-38	Transient Structure for straight vane	84
3-39	Transient Structure for curved vane	85
3-40	Analysis Setting	86
3-41	Frictionless Support for disc brake	87
3-42	Inner hub/hat of disc brake	87
3-43	Imported Body Temperature	88
4-1	Disc brake cutaway (Source: SOLIDWORK)	92
4-2	Load cycle (Source: Huang and Chen, 2006)	93
4-3	Ramped heat flux for 6 seconds (Source: Huang and Chen, 2006)	94
4-4	Dimension of normal passenger car (Source: Proton)	95
4-5	Force reaction on the vehicle (Source: Proton)	99
4-6	Percentage of weight transfer, WT (Source: Proton)	102
4-7	Free body diagram of wheel and disc brake (Source: https://revisionworld.com)	103
4-8	Brake pad area	105
4-9	Disc cutaway	109

4-10	Inboard and outboard disc surface	111
4-11	Inboard and outboard heat flux	112
4-12	Inboard and outboard conventional heat transfer coefficient	115
4-13	Outer ring conventional heat transfer coefficient	117
4-14	Inner ring (outer) conventional heat transfer coefficient	119
4-15	Inner ring (outer)	119
4-16	Inner ring (inner upper) conventional heat transfer coefficient	122
4-17	Inner ring (inner upper)	122
4-18	Inner ring (inner bottom) conventional heat transfer coefficient	125
4-19	Inner ring (inner bottom)	125
4-20	Vane conventional heat transfer coefficient	128
4-21	Air flow inside the inner vane passage	128
4-22	Chords length of inner vane passage	129
4-23	Straight and curved vane	133
4-24	Curvature angle	133
5-1	Steady state thermal of straight vane disc brake	138
5-2	Steady state thermal of curved vane disc brake	139
5-3	Temperature distribution after 6 seconds braking for straight (left) and curved (right) vane disc brake	142
5-4	Temperature distribution after 35 seconds braking for straight (left) and curved (right) vane disc brake	143
5-5	Temperature distribution after 146 seconds braking for straight (left) and curved (right) vane disc brake	143
5-6	Temperature distribution after 175 seconds braking for straight (left) and curved (right) vane disc brake	144
5-7	Temperature distribution after 321 seconds braking for straight (left) and curved (right) vane disc brake	145
5-8	Temperature distribution after 350 seconds braking for straight (left) and curved (right) vane disc brake	145
5-9	Straight vane temperature distribution over time	146
5-10	Curved vane temperature distribution over time	146
5-11	Trend of maximum temperature of curved, straight and pillar vane (Source: Baron <i>et al.</i> 2015)	147

5-12	Trend of maximum and minimum temperature for curved and straight vane	148
5-13	Temperature pattern of Limpert (1999) and ANSYS	151
5-14	Total deformation of straight vane at 338 seconds	152
5-15	Total deformation of curved vane at 336 seconds	152
5-16	Straight vane maximum deformation at 338 seconds	153
5-17	Curved vane maximum deformation at 336 seconds	153
5-18	Total stress of straight vane at 350 seconds	154
5-19	Total stress of curved vane at 350 seconds	154
5-20	1 st loading process for straight vane	155
5-21	2 nd loading process for straight vane	156
5-23	3 rd loading process for straight vane	156
5-24	10 th load cycle for straight vane	157
5-25	Tensile stress for straight vane	158
5-26	1 st loading process for curved vane	158
5-27	2 nd loading process for curved vane	159
5-28	3 rd loading process for curved vane	159
5-29	10 th load cycle for curved vane	160
5-30	Tensile stress for curved vane	161

LIST OF TABLES

TABLE	TITLE	PAGE
2-1	Fuel saving (Source: Petronas)	32
2-2	NGV components weight (Source: CITY NGV (M) SDN BHD)	33
2-3	General procedure of FEA	39
2-4	The corresponding unit for heat measurement	42
3-1	Disc brake dimensions	61
3-2	Grey cast iron properties (Source: CES Edupack 2013)	63
3-3	Number of elements and nodes (Steady State)	71
3-4	The convection heat transfer coefficient	73
3-5	Number of elements and nodes (Transient)	80
3-6	<i>Analysis Setting</i> for transient thermal	80
3-7	Heat flux inboard and outboard	81
3-8	<i>Analysis setting</i> for transient thermal	85
3-9	<i>Analysis setting</i> for transient structure	86
4-1	Car dimension	95
4-2	Weight Data	97
4-3	Disc brake dimensions	134
4-4	Disc brake properties	135
4-5	Simplifies disc brake properties	136

5-1	Temperature comparison	140
5-2	Temperature distribution	141
5-3	Temperature for 10 load cycles	150

LIST OF SYMBOLS

\dot{q}	–	Heat Flux (W/m ²)
\dot{Q}	–	Heat Transferred per Unit Time is (J/s or Watt, W)
Q	–	Thermal Energy (Joule, J)
ΔT	–	Average temperature increase per stop (°C)
\dot{Q}_{cond}	–	Conduction Heat Transfer (kW)
\dot{Q}_{conv}	–	Convection Heat Transfer (kW)
\dot{Q}_{emit}	–	Radiation Heat Transfer (kW)
(Al-MMC)	–	Aluminium Metal Matrix Composite
(CH ₄)	–	Methane
(DBA)	–	Disc Brake Australia
[C]	–	Thermal capacitance matrix
[K]	–	Stiffness Matrix
$\{\dot{T}\}$	–	Vector of nodal rates of temperature increases
$\{F\}$	–	Nodal Forces
$\{T\}$	–	Thermal Condition Containing Temperature
$\{\delta\}$	–	Resultant Nodal Displacement
μ	–	Dynamic Viscosity of air (1.872 x 10 ⁻⁵ kg/m.s)
μ_p	–	Friction coefficient of brake pad and disc surface
μ_R	–	Coefficient of friction of dry tarmac, gritted bitumen
A	–	Area (m ²)
A_{sect}	–	Cross sectional area normal to the direction of heat transfer (m ²).
A_p	–	Pad area (m ²)
A_{bs}	–	Area of both sides (m ²)
A_R	–	Rotor surface area (m ²)

$Area_{in}$	–	Inner radius area of disc brake
$Area_{out}$	–	Outer radius area of disc brake
A_s	–	Surface area of object (m^2)
A_s	–	Surface area through which convection heat transfer occurs (m^2)
BCIRA	–	British Cast Iron Research Association
CAD	–	Computer Aided Design
CFD	–	Computational Fluid Dynamic
CG	–	Centre Gravity (mm)
CGH	–	Centre Gravity Height (mm)
CMM	–	Coordinate Measuring Machine
CNG	–	Compressed Natural Gas
C_p	–	Specific heat capacity, (J/kg.K)
c_R	–	Specific heat grey cast iron (J/kg.°C)
d_h	–	Hydraulic diameter (m)
D_i	–	Inner diameter (m)
D_o	–	Outer diameter (m)
DR	–	Deceleration of normal passenger
E	–	Young's modulus, (Gpa)
ε	–	Emissivity ($0 \leq \varepsilon \leq 1$)
F	–	Force on each pad (N)
F_{BF}	–	Braking force at front tyre
F_{BR}	–	Brake force from pad friction (N)
FEA	–	Finite element analysis
FEM	–	Finite Element Method
FKM	–	Fakulti Kejuruteraan Mekanikal
GW	–	Gross Weight
h	–	Convection Heat Transfer Coefficient, in $W/m^2.K$
h_c	–	Convection heat transfer coefficient of disc brake (W/m^2K)
h_R	–	Heat transfer coefficient of rotor surface (W/m^2K)
IGES	–	Initial Graphics Exchange Specification
k	–	Thermal conductivity, ($W/m^{\circ}C$)
k	–	Thermal Conductivity, watt per meter per Kelvin (W/mK).
k_a	–	Thermal conductivity of air ($W/m.K$)
L	–	Vane length (m)

L	–	Length (mm)
L	–	Wheelbase of the car
LNG	–	Liquefied Natural Gas
m_c	–	Gross mass of vehicle
M_F	–	Moment of equilibrium
m_R	–	Mass of rotor (kg)
N_{disc}	–	Angular velocity of the tyre (rpm)
NGV	–	Natural Gas Vehicle
NU_D	–	Nusselt Number of disc brake
p	–	Pressure (Pa)
P_{ave}	–	Average pad pressure applied on disc surface (MPa)
A_p	–	Brake pad area (m ²)
P_B	–	Braking Power (W)
Pr	–	Prandtl number
$q_{inboard}$	–	Heat flux generated on the inboard surfaces (W/m ²)
$q_{outboard}$	–	Heat flux generated on the outboard surfaces (W/m ²)
r	–	Mean radius (from centre wheel to centre pad) (m)
r_0	–	Outer radius of disc (m)
R_{ave}	–	Radius of average vane ring (m)
r_c	–	Radius of disc centroid/mean radius from centre wheel to centre pad (m)
Re	–	Reynolds number of disc braking surface
R_F	–	Reaction force at front
R_F	–	Force reaction on front tyres
R_R	–	Reaction force at rear
r_t	–	Radius of tyre
r_{tyre}	–	Radius of 185/60R14 tyre (mm)
r_{tyre}	–	Radius of tyre (288.29 mm, Size of tyre :185/60R14)
R_{vi}	–	Radius of vane inner ring (m)
R_{vo}	–	Radius of vane outer ring (m)
S_{ave}	–	Average ring chord length (m)
SG	–	Ductile iron
S_{in}	–	Inner ring chord length (m)
S_{out}	–	Outer ring chord length (m)

S_{total}	–	Total Distance
T	–	Braking torque (Nm)
T	–	Temperature difference between two surfaces separated by distance Δx (K/°C)
T_{∞}	–	Ambient temperature (°C)
T_{∞}	–	Ambient temperature (K/°C)
$T_{braking}$	–	Brake torque
t_C	–	Cooling time cycle (s)
T_s	–	Braking Time
t_S	–	Brake time (6s)
T_s	–	Surface temperature (K/°C)
T_s	–	Surface temperature of object (K/°C)
T_{tyre}	–	Tyre torque
UK	–	United Kingdom
$V_{air-ave}$	–	Average air velocity (m/s)
V_{air-in}	–	Velocity of air flow through the inlet of inner vane passage (m/s)
$V_{air-out}$	–	Velocity of air flow through the outlet of inner vane passage (m/s)
v_R	–	Rotor volume (m ³)
V_{tr}	–	Travel Speed
$V_{vehicle}$	–	Velocity of normal passenger (m/s)
WB	–	Wheelbase (mm)
Weight _R	–	Weight distribution of vehicle at rear axle
WT	–	Weight transfer
WT_{Front}	–	Weight transfer at front tyre
W_{total}	–	Total weight of car
Δh	–	Height of rear axle when rise
ΔW_f	–	Front tyre weight reading on scale during test
Δx	–	Wall Thickness (m)
θ	–	Fraction angle (°)
μ	–	Coefficient of friction
ν_a	–	Kinematic viscosity of air (m ² /s)
ρ	–	Density, (kg/m ³)
ρ_R	–	Rotor density (kg/m ³)
σ	–	Stefan-Boltzman constant (5.670 x 10 ⁻⁸ W/m ² .K ⁴)

ω_{disc}	–	Angular velocity of the disc (rad^{-1})
ω_{tyre}	–	Angular velocity of the tyre (rad^{-1})