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DEVELOPMENT OF A BRAKE DRUM MODEL WITH FINS INCORPORATION FOR HEAT DISSIPATION ENHANCEMENT

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ABSTRACT

Extreme heat within an automobile brake drum could cause brake failure which could as well lead to death of passengers and lost of properties. One of the ways to dissipate heat faster from an automobile brake drum is by incorporating fin on the outer surface of the brake drum as pointed out in many literatures. This work concerns converting 1/10 0f the overall height thickness of the brake drum into fins for effective heat dissipation by both conduction and convection. During the modified brake drum development process, necessary fin design formulae were taken into account. Modeling and simulation analysis were carried out using Solidworks (2013) software, followed by validation using theoretical Finite Element analysis. The minimum temperatures obtained from the simulation analysis were 4935K and 4927K for the existing and the modified brake drum model respectively. While maximum displacements obtained from the simulation analysis were $5142 \times 10^{-5}mm$ and $5102 \times 10^{-5}mm$ for the existing and the modified brake drum model respectively. This implies that the modified brake drum have improved strength and better heat dissipation than the existing model. This is as the result of the circumferential arrangement of the fins on the outer surface of the brake drum.

Key words: Modified Brake Drum Development and Validation

1.0 INTRODUCTION

The brake drum is a critical component that experiences high stresses, and this cause the drum to crack, oversize, extreme wear, out of round drums and also lead to vibration which can lead to reduced brake drum service life and efficiency. The high temperature during braking also causes brake fade, premature wear, brake fluid vaporization, bearing failure and thermal cracks. 0ne of the way to ensure surface cooling on automobile brake drum according to Alin-Marian *et al*. (2015) is by using brake drum with with circumferential ribs (fins). While Carlos Abilio Passos Travaglia and Luiz Carlos Rolim Lopes (2014), did a research work on drum brake. One of their recommendations for future work was the improvement of the brake drum cooling. Rong-Hau *et al.* (1997), have it that heat transfer from a system can be increased by extending the surface area through the addition of fins. While Fred Pulm (1985), also mentioned that one of the several ways to improve brake drum cooling is to change to finned or aluminum brake drum. The concept of this paper came up as the result of the above suggestions and recommendations by the above listed authors. The paper tends to fill the gap by incorporating circumferential fins round the wall of the brake drum in order to improve the heat transfer of the automobile brake drum.

Nash (1998), noted that the ratio should not exceed 1/10. The dimensions of the brake drum from literatures (Anup Kumar and R. Sabarish (2014). Aly *et al.* (2014), Bire and Yogesh (2015) and Venkataramana (2013) shows that the thickness to diameter ratio of the brake drums exceed 1/10. Therefore for this reason; 10% of the wall height thickness would be converted to fins. This is because even after deducting the 10% of the wall thickness; the brake drum wall thickness would still be within the value of 1/10 or approximately 1/10. The fins would be arranged circumferentially round the brake drum as suggested by Alin-Marian et al (2015) and Fred Pulm (1985). This circumferential arrangement of the fins would add more strength to the wall of the brake drum and would also enhance its heat dissipation.

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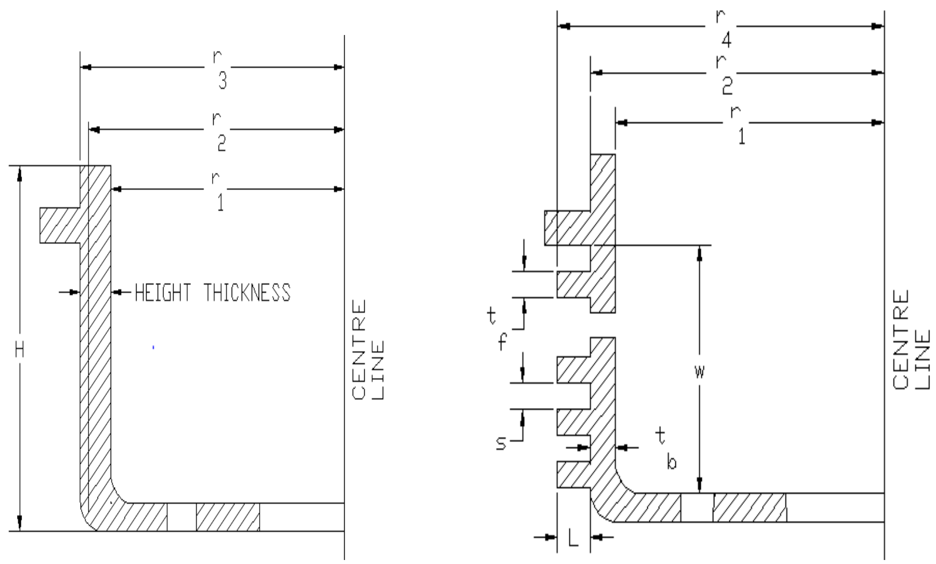
2.0 MATERIALS AND METHOD

A Peugeot 406 D8 brake drum was used as a case study for this analysis. The values of various dimensions of the brake drum were collected from the market by measurement. One-tenth (10%) of the brake drum wall thickness was calculated and converted to annular fins. The various dimensions of the brake drum were taken by measurement using veneer caliper. These dimensions were used as the reference for the modeling of the original brake drum model. Calculations were carried out from the values measured in order to calculate the various fin dimensions for the modeling of the modified brake drum model. For the sake of validation purpose, both Finite Simulation by Solidworks (2013) software and Finite Element Method analytical approach were carried out.

3.0 BRAKE DRUM DEVELOPMENT AND FIN PARAMETERS CALCULATION

Since deducting 10% of the brake drum wall thickness would maintain a ratio approximately 1/10 (0.10), therefore 10% of the brake drum wall thickness would converted to annular fins in order to improve the heat transfer performance of the automobile brake drum.



(a) (b)

Figure 1.0 Brake Drum Sectional View. (a) Existing Model (b) Modified Model

3.1 Determination of Fins Base Radius r2 of the Modify Brake Drum

Since the brake drum thickness is reduced by 10% of its existing thickness ($^1/_{10}\,(r_3 - r_1)$). therefore the outer radius r_2 of the modify brake drum model is given by;

$$r_2 = r_3 - \frac{10}{100}(r_3 - r_1) \qquad 1$$

3.2 Determination of Fin Base Thickness t_b

The fin base thickness t_b (new thickness of the brake drum) is given by;

$$t_b = r_2 - r_1 \qquad 2$$

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3.3 Determination the Fin Thickness t_f

In order to satisfy the condition stated by Antonio (2013) (equation 3.10) and to obtain the optimum fin thickness; the fin thickness t_f is assigned to be 1/3 of the fin base thickness t_b. This is done with the aim of obtaining the optimum value for fun thickness in order to enhance the heat transfer of the modified brake drum model.

$$t_f = \frac{t_b}{3} \qquad 3$$

3.4 Determination of the Fin Spacing

Prabal (2012) noted that if the fin spacing and fin thickness are approximately equal, it will provide optimum spacing to maximize heat transfer. Therefore the fin thickness and the fin spacing are designed to be equal ($s = t_f$).

3.5 Determination of the Number of Fins N

The number of fins round the brake drum is given by Prabal (2012);

$$N = \frac{W}{S + t_f} \qquad 4$$

3.6 Determination of the Outer Radius of the Fins r_4

The volume V_1, of the brake drum deducted from the existing model is given by;

$$V_1 = \pi(r_3^2 - r_2^2)H \qquad 5$$

Where, H = Overall Brake drum height.

The volume of one annular fin V_f is given by;

$$V_f = \pi(r_4^2 - r_2^2)t_f$$

Where t_f = Fin thickness.

The total volume of N fins is given by;

$$V_{Nf} = N\pi(r_4^2 - r_2^2)\, t_f \qquad 6$$

Since the thesis involves converting the volume V_1 of the existing model deducted into extended surface (fins) of equal volume V_{Nf}. Therefore the volume V_1 deducted from the original model is equal to total volume of the fins N V_{Nf}. Therefore,

$$\pi(r_3^2 - r_2^2)H = N\pi(r_4^2 - r_2^2)t_f$$

$$r_4 = \sqrt{\frac{(r_3^2 - r_2^2)H}{Nt_f} + r_2^2} \qquad 7$$

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3.7 Determination of the Length of the Fin L_f

The length of the fin L_f is given by Prabal (2012);

$$L_f = r_4 - r_2 \tag{8}$$

3.8 Determination of the Brake Drum Normalized Radii Ratio R_r

The normalize radii ratio is expressed by Antonio (2013) as;

$$R_r = \frac{r_4}{r_2}, \qquad 1 \le \frac{r_4}{r_2} \le 5 \tag{9}$$

3.9 Determination of the Heat Transfer Coefficient h For the Brake Drum Models

It was noted in Nurulhuda (2005) that the heat transfer coefficient of a brake drum can be calculated by;

$$h == 0.1\left(\frac{k_a}{d_4}\right)Re^{2/3} \tag{10}$$

Where; d_4= Outer Brake Drum Diameter (m); k_a= Thermal Conductivity of Air (W/m.K)

Re = Reynolds Number, ρ = Density of Air (kg/m^3); V = Velocity of Air (m/s),

μ = Dynamic Viscosity of Air (kg/m.s)

The ambient temperature of the air around the brake drum is assumed to be at 20^{0}C. The below properties of the air at 20^{0}C were obtained from thermodynamics table.
$\rho = 1.204Kg/m^3$, $\mu = 1.825 \times 10^{-5}kg/m.s$, $k_a = 0.02514W/m.K$

3.10 Determination of Fin Parameter m

Yunus (2008), noted that the fin parameter m of a annular fin of rectangular cross section is given by;

$$m = \sqrt{\frac{2h}{kt_f}} \tag{11}$$

3.11 Determination of the Fin Effectiveness ε_f

Yunus (2008), noted that fins effectiveness is the ratio of the heat transfer from the finned surface to heat transfer from the same surface if there are no fins on the surface. Yunus (2008), also noted that the fin effectiveness is calculated by;

$$\varepsilon_f = \sqrt{\frac{kP}{hA_c}} \tag{12}$$

Where; k = Thermal Conductivity of the Fin Material (Gray Cast Iron) (W/m.K)

P = Perimeter of the Fin (m); A_c = Cross Sectional Area of the Fin (m^2)

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3.12 Determination of the Fin Efficiency $\boldsymbol{\eta_f}$

Fins are likely not designed to be so long that their temperature approaches the surrounding temperature at the tip (Yunus 2008).

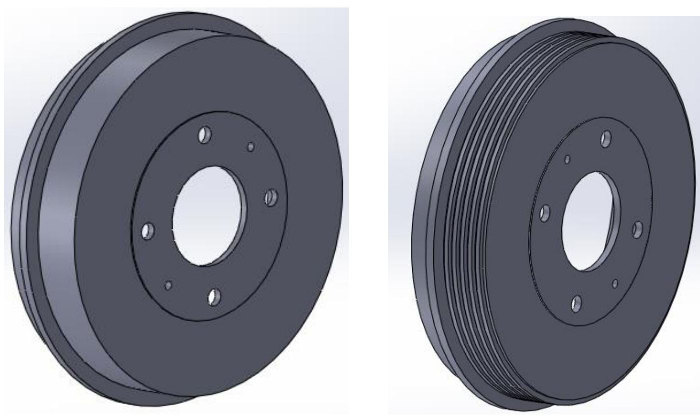
Yunus (2008), relates fins effectiveness and fin efficiency as;

$$\boldsymbol{\eta_f} = \frac{A_b}{A_f}\varepsilon_f \qquad 13$$

Where A_f= Total Surface Area of the Fin; A_f= Base Area of the Fin

4.0 BRAKE DRUM MODELING AND SIMULATION

The first step in this analysis was to prepare a solid model of the existing and the modified brake drum model. The models were developed with the help of data measured and the fins parameters calculated above. The modeling was carried using Solidworks (2013) software.



(a) (b)

Figure 2.0 (a) Existing Brake Drum Model (b) Modified Brake Drum Model

4.1 Boundary Conditions

It was shown in Andrzeji (2010), that at the ambient temperature of 20°C; the average brake drum temperature is 379°C. The exterior and the interior temperature of the brake drum models are assigned to be 20℃ and 379℃ respectively in order to investigate the two models at the same condition. The models were subjected to equal pressure of 1500N/m^2 in order to investigate which model would have the minimum displacement. A fine mapped mesh of triangular element with 0.004m element size was used for both the existing and the modified brake drum model. After setting these conditions, the Finite Element computational simulation was carried out.

5.0 Validation of Simulation Results

With the use of the finite element method and assuming a linear variation of temperature, the resulting stiffness matrix is given by Roland *et al.* (2004) as;

$$[K] = \frac{2\pi k}{l}\frac{(r_i + r_j)}{2}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} + 2\pi r_o h \begin{Bmatrix} 0 & 0 \\ 0 & 1 \end{Bmatrix} \qquad 14$$

$$Q^e = hT_\infty 2\pi r_o \begin{bmatrix} 0 \\ 1 \end{bmatrix} \qquad 15$$

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It was also noted in David (2004), that the Finite Element Equation with conduction and convection are expressed as

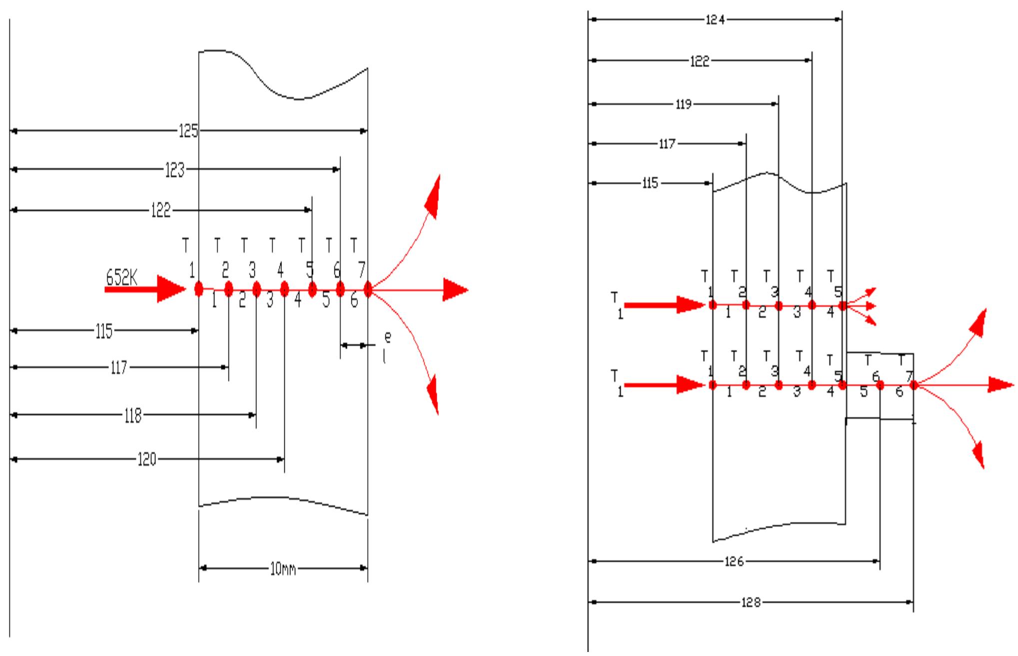
$$([K_T^e] + [K_C^e])[T] = [Q^e] + [q^e] \qquad 16a$$

$$\left(\frac{2\pi k}{l}\frac{(r_i + r_j)}{2}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} + 2\pi r_o h \begin{Bmatrix} 0 & 0 \\ 0 & 1 \end{Bmatrix}\right)\begin{bmatrix} T_i \\ T_j \end{bmatrix} = \begin{bmatrix} Q_i^e & q_i^e \\ Q_j^e & q_j^e \end{bmatrix} \qquad 16b$$

Where, e = Element. i, j = Nodes. l = Length.(m), Q^e = Thermal load (W/m^3)

q = Vector of nodal heat flow (W/m^3), T_∞= The ambient temperature (K)

5.1 Determination of Temperature Distribution at the Main Wall of the Brake Drum Models



(a) (b)

T_1, T_2, T_3, T_4, T_5, T_6 = Nodal Elements, 1, 2, 3, 4, 5 = Elements

Figure 3.0 Nodal Temperature Distributions. (a) Existing Model (b) Modified Model

To calculate the Thermal Load Vector and Element Conduction Matrix for each Element; equation 15 and 16b were used. The matrixes were assembled and simplified by applying Gauss Elimination Method.

To calculate the Thermal Load Vector and Element Conduction Matrix for each Element for the adjacent wall of the brake drum models; the wall was divided into seven nodal points (7,8,9,10,11,12,13) and equation (15) and (16b) were used. The matrixes were assembled and simplified by applying Gauss Elimination Method.

5.2 Determination of the Displacement at the Walls of the Brake Drum

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Since the brake drum is fixed at the closed end and free to deflect at the opened end; therefore the brake drum can be treated as a cantilever beam with an internal force applied to the inside inner surface of the brake drum as shown in Figure 4.0. This was done in order to simplify the complexity of the models.

$$\frac{t}{r_1} << 1 \quad or \quad \frac{r_1}{t} > 1, \quad \frac{r_1}{t} > 1 \qquad 17$$

$$\sigma_c = \frac{pd_1}{2t}, \quad \sigma_a = \frac{pd_1}{4t,}, \qquad \sigma_r = p \qquad 18$$

Where $t =$ Thickness of the cylinder (m); $d_1 =$ Inner diameter of the cylinder (m)

$\sigma_c =$ Circumferential stress (N/m^2); $\sigma_a =$ Axial stress (N/m^2); $\sigma_r =$ Radial stress (N/m^2)

From equation 3.21

$$F = Pd_1 \qquad 19$$

From beam formula Ansi (2005); the deflection/displacement of a cantilever beam with a point load ‘P’ at a distance ‘a’ from the opened end and ‘b’ from the fixed end can be obtained by;

$$\delta_n = \frac{pd_1 b^2}{6EI}(3l - 3x - b) \qquad (x < a) \qquad 20$$

$$\delta_n = \frac{pd_1 (L - x)^2}{6EI}(3b - l - x) \qquad (x > a) \qquad 21$$

Where $\delta_n =$ Nodal deflection/displacement at distance x from the opened end (m)

$F =$ Force (N), $b =$ Distance between the fixed end and F (m)

$x =$ Distance from opened end toward fixe end (m), $l =$ Distance from fixed to free end (m)

$E =$ Modulus of elasticity of brake drum material (N/m^2)

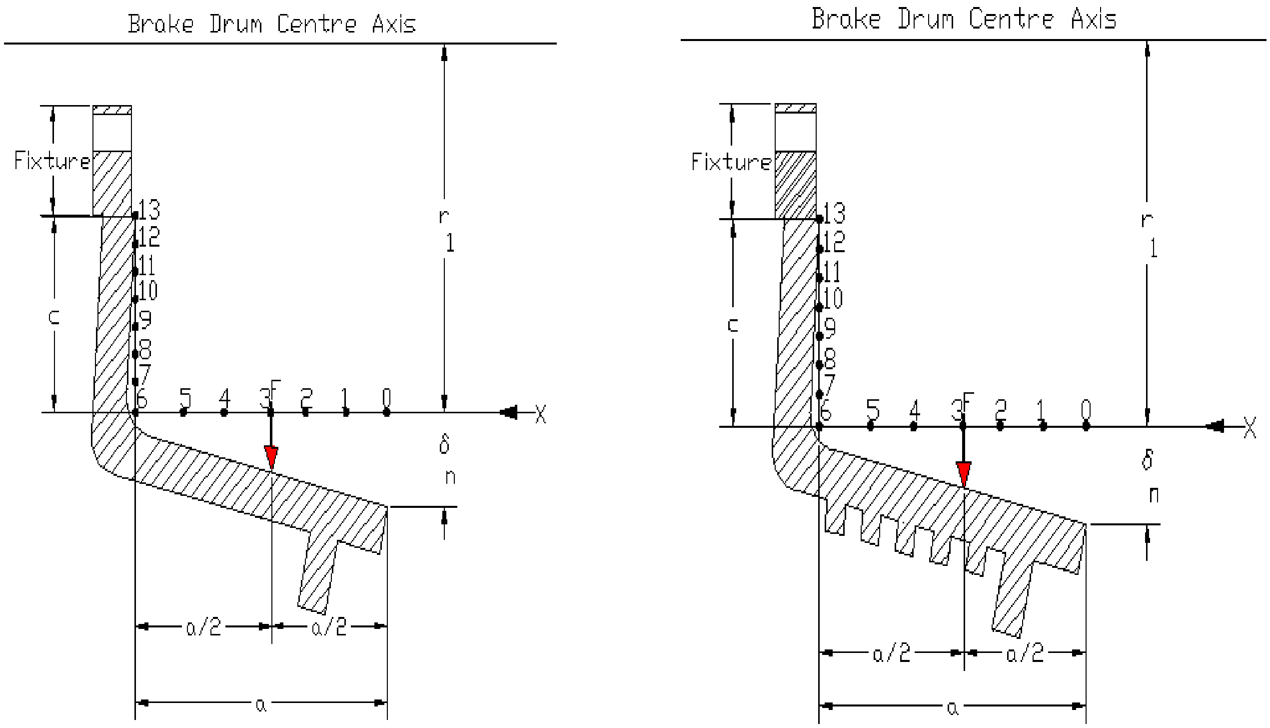
$I =$ Moment if inertia the brake drum subjected to deflection/displacement (kg/m^2)

To determine the displacement at the wall of the brake drum; the walls of the brake drum is divided into thirteen elements with thirteen nodal points as shown in the figure (4.0). Equation (20) is used to calculate the nodal displacement from node 1 to node 3. Recall,

$b = c + \frac{a}{2}$; $l = c + 2a$

$x =$ Linear distance from node 1 to node 13

Since $(x > a)$ from node 4 to 13, Therefore equation (21) is used to calculate the nodal displacement from node 4 to 13



(a) **(b)**

Figure 4.0 Displacement Analysis (a) Existing Model (b) Modified Model

6.0 RESULTS AND DISCUSSION

The value of the normalized ratio calculated from equation (9) is 1.032. According to Antonio (2013), the normalize radii ratio should be within the range of equation 9 ($1 \leq \frac{r_4}{r_2} \leq 5$). Since the value of the normalize ratio (1.032) is within the stated range (equation 9); therefore the value of the fin thickness, fin length and fin radii developed are justified. The value of the fin effectiveness ε_f calculated from equation (12) is 7. This shows that the rate of heat transfer from the fins increases by a factor of 7 as a result of adding fins on the surface of the modified brake drum. Yunus (2008), noted that if;

$\varepsilon_f = 1$ Implies that the addition of fins to the surface does not affect heat transfer at all

$\varepsilon_f < 1$ Implies that the fin actually acts as insulation,

$\varepsilon_f > 1$ Implies that fins are enhancing heat transfer from the surface, as they should

The use of fins cannot be justified unless ε_f is sufficiently larger than 1 (Yunus 2008). This shows that the fins developed on the surface of the modified brake drum are justified. The value of the fin efficiency $\boldsymbol{\eta_f}$ calculated from equation (13) is 108%. The efficiency of most fins used in practice are above 90 percent (Yunus 2008). This shows that the fins developed on the surface of the modified brake drum are satisfied.

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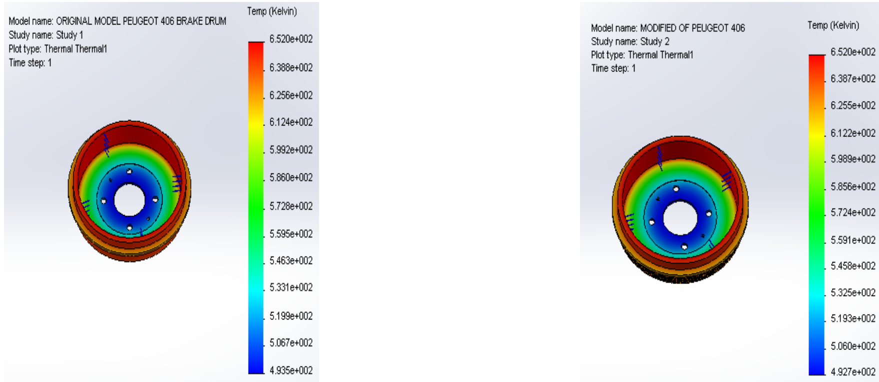
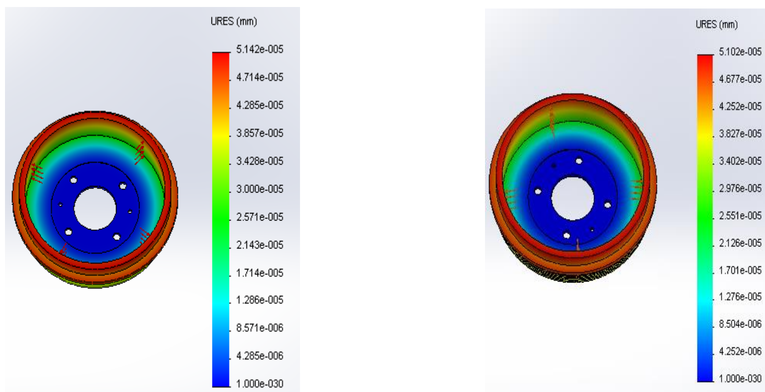


(a) (b)

Figure 5.0 Thermal Analysis Results (a) Existing Model (b) Modified Model



(a) (b)

Figure 6.0 Displacement Analysis Results (a) Existing Model (b) Modified Model

The graphs (figure 7.0) show the temperature variation from inner surface to the outer surface of the brake drum models. The initial point of intersection of the graphs shows that the models were investigated at the same initial temperature while the lowest temperature signifies the temperature at the outer surface of the brake drum after the computational analysis. The temperature of both model declined from their initial (maximum) temperature to their minimum temperature as also justified by their computational (simulation) result and the theoretical calculations. But the existing model shows a lower rate of decreasing in temperature than the modified model. This shows that the rate of heat dissipation from the modified model is higher than that of the existing model. Therefore some amounts of heat energy tend to remain inside the inner wall of the existing brake drum model as the result of the low heat transfer. This retained heat is the major causes of the thermal problems of the brake drum system earlier stated in this thesis.

The displacement graphs (figure 8.0) show the prediction of the displacements of the brake drum walls as result of the pressure acting on the inner wall of the brake drums. The maximum points on these graphs indicates the maximum displacement at the opened end of the brake drum while lowest displacement signifies the lowest displacement at the fixed end of the brake drum models.

The modified brake drum model shows minimum displacement than the original model. This is due to circumferential or annular arrangement of the fins on the outer surface of the brake drum.

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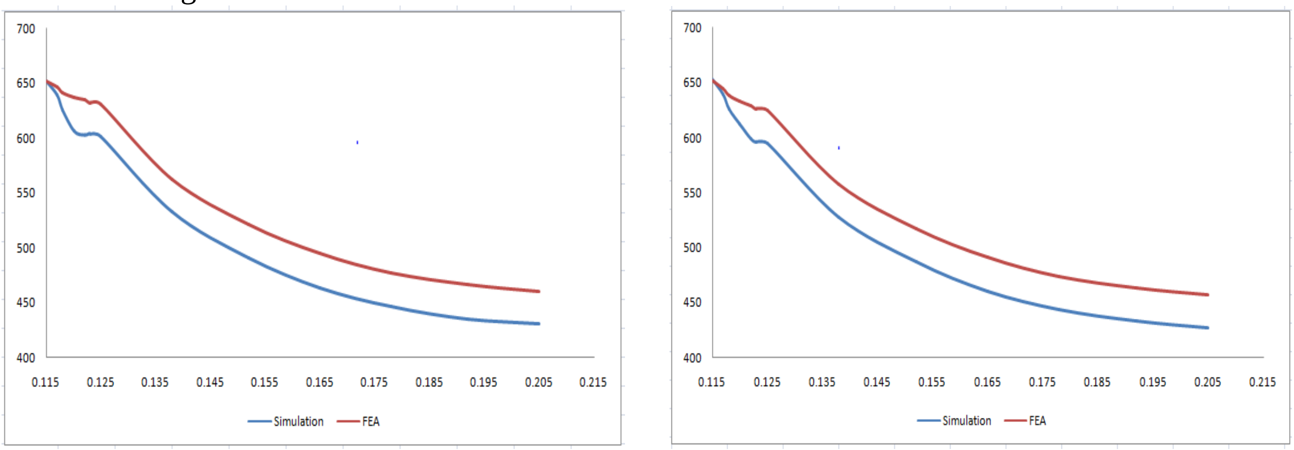
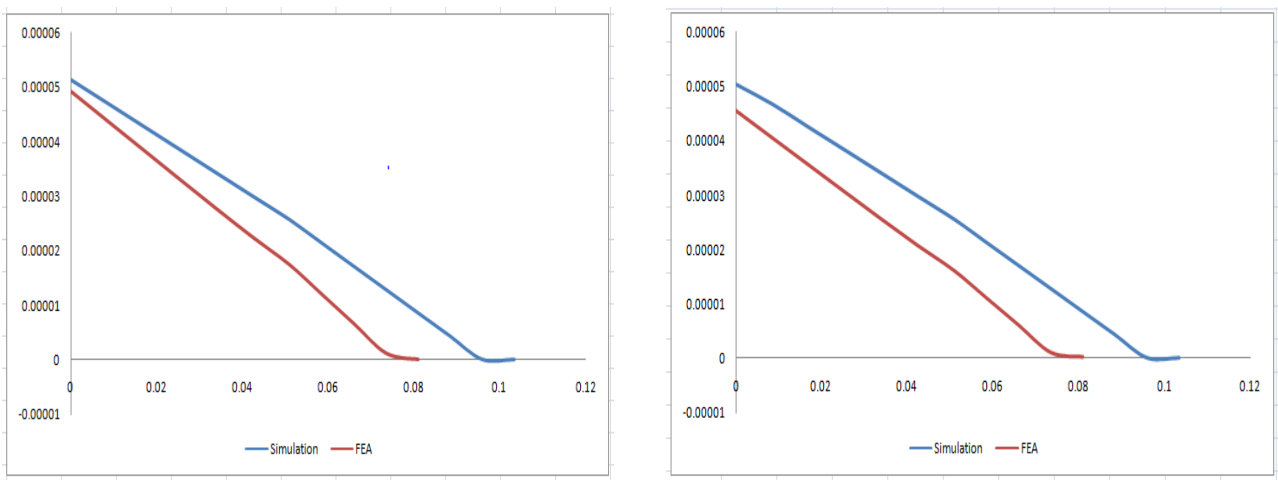
This indicates that the fins have added more strength circumferentially on the braking surface of the brake drum. This has also increased the circumferential resistance of the brake drum to the action of the brake shoe force. This makes the brake drum to be more rigid and more resistance to the action of the force acting on this surface.



(a) (b)

Figure 7.0 Brake Drum Temperature Distributions (a) Existing Model (b) Modified Model



(a) (b)

Figure 8.0 Brake Drum Displacement (a) Existing Model (b) Modified Brake Drum Model

7.0 CONCLUSIONS AND RECOMMEDATIONS

7.1 Conclusions

This work presents the improvement of automobile brake drum heat transfer dissipation using fins. The results obtained from the computational analysis and the theoretical calculation shows that the modified brake drum model have an improved heat dissipation and lower displacement. The lower displacement and temperature shown by the modified brake drum model indicates that the model is stronger and rigid with better heat dissipation than existing brake drum model. The lower temperature of the modified model shows that more heat is transferred and dissipated from the inner to the outer surface of the brake drum while the high temperature of the existing model indicates that some heat are retained in the inside brake drum lower rate of heat dissipation. This retained heat energy in the

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existing brake drum model is the major causes of thermal problems of the brake drum earlier stated in chapter one of this project. The use of fins on the modified brake drum brake drum enormously increased the heat dissipation and the structural strength without a change in mass of brake drum of the existing model. It can also be deduced that more improvement could be achieved such as;

i. Improved coefficient of friction between the brake drum and the brake shoe
ii. Low wear rate of the brake drum and the brake shoes
iii. Long service life of the braking system
iv. Less contamination of the brake fluids
v. Less thermal problems of the braking system

It can finally be concluded that a method of improving the heat transfer dissipation of an automobile brake drum has been developed without a change in mass and without compromising the existing properties and requirements of the automobile brake drum while the reduction in size of the back plate can leads to its low cost of its production and little reduction in weight of the vehicle. This method of brake drum modification can assist Automotive Engineers to design a more effective and improved brake drums models.

7.2 Recommendations

This work has provided a method for improving the strength and heat dissipation of the automobile brake drum without the change in its original mass and without compromising the properties and requirement of the brake drum.

For the future, this thesis can be further be extended by:

i. Further simulation analysis should be carried out in order to discover other advantages that can be obtained from implementing this brake drum modification.
ii. Physical validation of the models should be carried out and compared.
iii. Similar work should be carry out using fins of different cross sectional area such as square, triangular and semi-circular cross sectional area; in order to verify the one would be more efficient.
iv. Similar investigation can be replicated with bimetallic materials thereby using a better heat conduction material for the fins and a material of higher strength for the other part of the brake drum.

Finally, since these thermal problems has many negative implications to the braking system and has leads to lost of many lives and properties on our roads. It is therefore call on automotive designers to always take critical measure in the design of the automobile brake drum.

References

[1]. Alin-Marian Puncioiu, Ioan Vedinas, Marian Truta (2015). Overheating Analysis of the Special Vehicles Braking Systems. Review of the Air Force Academy. No 1 (28) 2015.

[2]. ANSI AF&PA (2005). Beam Design Formulas with Shear and Moment Diagram. American Forest & Paper Association Inc. 2005 Edition. Figure 14.

[3]. Antonio Acosta-Iborra and Antonio Campo (2013). Aproximate Analytic Analysis Of Annular Fins With Uniform Thickness By Way Of The Mean Value Theorem For Integration That Avoids Modified Bessel Functions. Latin American and Caribbean Journal of Engineering Education, Vol. 7, No. 1, 2013. © LACCEI, ISSN 1935-0295.

[4]. Anup Kumar and R. Sabarish (2014). Structural and Thermal Analysis of Brake DrumMiddle-East Journal of Scientific Research 20 (6): 715-719, 2014.

[5]. Carlos Abilio Passos Travaglia and Luiz Carlos Rolim Lopes (2014). Friction Material, Temperature distribution,thermal and mechanical contact stress analysis. Scientific Research.

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Published Online December 2014 in SciRes. http://www.scirp.org/journal/eng, http://dx.doi.org/10.4236/eng.2014.613092

[6]. Fred Puhn (1985). Brake Handbook. 2rd edition.HP Books Pp 10, 19. 29, 139.

[7]. Nurulhuda Binti Khalid (2005). Thermal Stress Analysis on Brake Drum. Faculty of Mechanical Engineering. Kolej Universiti Teknikal Kebansaan Malaysia.

[8]. Prabal Talukdar (2012) Associate Professor. Department O\of Mechanical Engineering, IIT Delhi. E-mail: prabal@mech.iitd.ac.in. Heat Conduction through Fins

[9]. Rong-Hau Yeh, Shun_Pin Liaw, and Ming Chang (1998). Optimum Spacing of Longitudinal Convective Fins Arrays. Journal of Marine Science and Technology. Vol. 5, No,1, pp47-53.

[10]. Venkataramana p, (2013), Design of a Brake Drum Using Finite Element Method. International Journal of Mechanical Engineering and Robotics Research, Vol 2, No 2, April 2013,

[11]. William A. Nash and Merle C. Potter(1998), Stregnth of Materials. 5th Edition. McGraw-Hill. Schaum's Outline series. Pp 64.

[12]. Yunus A, Cengel (2008). Introduction to Thermodynamics and Heat Transfer. 2rd Edition. McGraw-Hill Company. Pp 435, 437, 438.