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Development of Software Using Matlab for Design Optimization of Brake for Minibike

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***Abstract**: Mini bikes are normally preferred by for their light weight. Hence attention needs to be focused on weight while configuring each and every key element like brake, gear box,engine, clutchs etc. Design optimization of brake for one such mini brake has been taken up in this work. To start with, mathematical model of the brake has been established so as to bring out the relation between key parameters of the design and the same has been used in the later stage so as to formulate the optimization strategy. Configuring the brake by choosing restraining value of width of brake lining in place of choosing restraining value of size of brake drum yielded to reduction of volume and hence weight. Optimized design lead to increased area of lining which in turn will reduce dissipation of energy per unit area. Accordingly it has bagged additional merits like reduction in operating temperature and wear. Further a general purpose software has been developed using MATLAB for design optimization of brake. For accomplishing this, formulation has been transformed in form of a code in MATLAB. Programme has been written with interactive mode of operation which means upon executing the programme it prompts the user to enter the value of inputs and subsequently it generates the outputs.*
***Keywords:** Optimization, Mathematical modelling, Brake lining, MATLAB, etc .*

I. Introduction

Light weight vehicles like mini bikes need to be configured while giving utmost attention to key elements like brake, clutch, gears, etc in optimal manner. Mathematical modeling of the intended subsystem needs to be established before making an attempt for optimization. Relation between various design parameters need to be understood so as to carry out optimization effectively. Primary objective of the optimization would be reduction of volume and hence weight. Design optimization of brake meant for one such mini bike is considered in this project. One such typical brake of a mini bike is shown in Fig. 1.

Fig. 1. Typical brake of a mini bike

To begin with efforts have been put up to understand the state of art for design optimization procedure that needs to be applied for the planned requirement.

Each and every system has been studied and developed so as to meet safety. In place of having air bag, apt suspension systems, good handling and safe surrounding, there is one another critical system in the vehicle which is nothing but brake systems. Without proper brake system, vehicle will put a passenger in risk.

Therefore, it is must for all vehicles to have suitable brake system. In this work carbon ceramic matrix disc brake material used for estimating normal force, shear force and piston force. The typical disc brake has been modeled in ANSYS and thermal analysis and modal analysis were done and the deflection, heat flux, temperature of disc brake are calculated. This is essential to know how disc brake works more effectively, which can assist to reduce the hazard that may happen any time [1]. The objective of this paper is to optimize the design of brake drum by reverse engineering approach. Optimization is carried out by altering the material of the brake drum, under various braking time and operational situations. Brake drum is optimized and evaluated different stresses, displacement values, increase in temperature on various braking instances and heat transfer rate. Optimized results thus obtained are compared for aluminium and controlled expansion material alloys. It completes that the controlled expansion alloys can be a right candidate material for the brake drum installations of light commercial vehicles and it also enhances the braking performance [2]. Disc brake consists of a cast iron disc attached to the wheel hub with bolt and a fixed housing called caliper. The caliper is attached to some fixed part of the vehicle like the axle casing or the stub axle as it is cast in two different parts out of which each part consists of a piston. Between each piston and the disc there exists a friction pad held in place by retaining pins, spring plates. The passages are so attached to another one for bleeding. Each cylinder consists of rubber sealing ring between the cylinder and piston. Due to the usage of brakes on the disc brake rotor, heat generates due to friction and this temperature so produced has to be dissipated across the disc rotor cross section. The objective of this paper is to study the temperature and also structural characteristics of the solid disc brake during short and emergency braking with four dissimilar materials. The temperature distribution depends on different factors such as friction, material and speed. The effect of the angular velocity and the contact pressure creates the temperature rise of disc brake. The finite element analysis for two-dimensional model is considered due to the heat flux ratio uniformly distributed in circumferential direction. Currently the disc brakes are made up of cast iron and cast steel. With the value at the hand the best suitable material for the brake drum can be determined with maximum life span. The detailed drawings of all subsystems are provided [3]. An automobile brake disc or rotor is a device for retarding the motion of a wheel while it runs at a certain speed. Mostly used brake rotor material is cast iron which spends much fuel due to its high specific gravity. The objective of this paper is to develop the material selection methodology and choose the best material for the application of brake disc system highlighting on the substitution of this cast iron by any other lighter material. Two methods are discussed for the selection of materials. Material performance requirements were studied and alternative solutions are evolved among cast iron, aluminium alloy, titanium alloy, ceramics and composites. Mechanical properties including compressive strength, friction coefficient, wear resistance, thermal conductivity and specific gravity as well as cost, are used as the chief parameters in the material selection stages. The analysis yielded to aluminium metal matrix composite as the most correct material for brake disc system [4]. Brake lining material is an improper conductor of heat; most of the heat passes into the disc during braking. Under simple use, brake disc may reach high temperatures. The coefficient of friction between the disc and lining is condensed excessively at these high temperatures, so that extra pedal pressure is required. So as to reduce the brake fade operation the design of disc should be in such a way that the heat generated during braking should be easily carried away to the atmosphere so that brake fade operation will not occur. Also optimization of weight can decrease the manufacturing cost along with the sluggishness effect of the disc [5]. In this analysis, a new wedge disc brake performance is evaluated using brake dynamometer and Taguchi method. The Taguchi method is frequently used in the industry for optimizing the product and the process conditions. Taguchi orthogonal design method is used to increase better understanding about the factors that effect of wedge brake enactment using L9 orthogonal array. Three control factors were reflected as applied pressure, vehicle speed and wedge angle inclination, each at three levels is chosen. It can be concluded that Taguchi method is trustworthy and decrease the time and experimental costs. In addition, the results shown that the applied pressure and wedge angle are the most noteworthy parameters for evaluation of the wedge disc brake [6].

As can be seen, optimization techniques are not so effective and practical implementation of the same would be tedious. Under these circumstances great need exists for design optimization of brake with following merits.

- Reduction of volume and hence weight
- Increased area of lining
- Reduction in dissipation of energy per unit area

II. Design Inputs

- Coefficient of friction for brake = 0.4
- Size of drum = 200 mm
- Allowable stress = 100 MPa
- Maximum pressure rating of brake = 0.23 MPa
- Torque = 40000 N-mm

III. Design Constraints

- Size of drum $\leq$ 200 mm
- Width of brake lining $\leq$ 25 mm
- Wrap angle < 290^0
- Factor of safety (FOS) $\geq$ 1.5

IV. Mathematical Modeling

Design parameters are shown in Fig. 2.

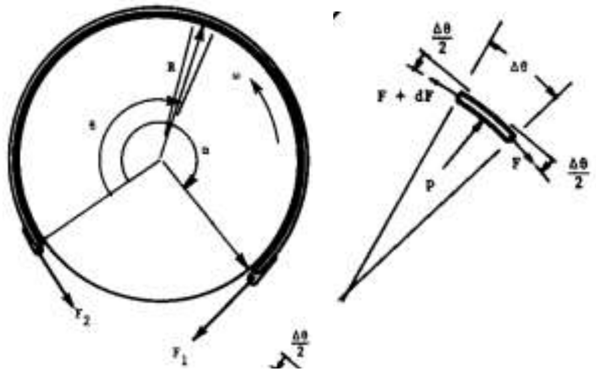

Fig. 2. Design parameters

Where

ω: Angular velocity

α: Wrap angle

r: Outer radius of brake drum

F_1, F_2: Forces acting on either side of brake band

Taking equilibrium of forces acting on parallel and orthogonal directions to that of tangent to a small element of brake at its center yields to

$$(F+dF)\cos\left(\frac{d\theta}{2}\right)-F\cos\left(\frac{d\theta}{2}\right)-\mu pwrd\theta=0 \qquad (1)$$

$$(F+dF)\sin\left(\frac{d\theta}{2}\right)+F\sin\left(\frac{d\theta}{2}\right)-pwrd\theta=0 \qquad (2)$$

Where

μ: Coefficient of friction for brake

p: Pressure acting on lining

w: Width of brake lining

$$As\ \mathrm{d}\theta \to 0,\ \sin\left(\frac{d\theta}{2}\right)\to\frac{d\theta}{2}\ \text{and}\ \cos\left(\frac{d\theta}{2}\right)\to 1$$

And

$$d\mathrm{F}\left(\frac{d\theta}{2}\right)\text{becomes negligible compared to}\ \mathrm{Fd}\theta$$

With all above

Equation (1) reduces to

$$\mathrm{dF} = \mu.\mathrm{p.w.r.d}\,\theta \qquad (3)$$

Further equation (2) reduces to

$$\mathrm{F = p.w.r} \qquad (4)$$

Substituting equation (4) in equation (3) and integrating gives

$$\int\frac{1}{F}dF=\mu\int d\theta$$

$$\left[\ln F\right]_{F_2}^{F}=\left[\mu\theta\right]_0^{\theta}$$

$$\ln F - \ln F_2 = \mu.\theta \tag{5}$$

$$\ln \frac{F}{F_2} = \mu\theta$$

$$\frac{F}{F_2} = e^{\mu\theta} \tag{6}$$

Which represents tangential force in the brake as a function of position along the brake

$$\text{When } \theta \rightarrow \alpha \text{ Then } F \rightarrow F_1$$

With which equation (6) becomes

$$\frac{F_1}{F_2} = e^{\mu\alpha} \tag{7}$$

Equation (7) conveys that when θ approaches α force attains its maximum value i.e. F_1
Considering this, equation (4) can be rewritten as

$$F_1 = p_{max}.w.r \tag{8}$$

Equation 8 highlights the disadvantage of the brake that wear of the lining is more at high pressure side of the brake. Due to this the lining should be swapped when it is worn out at only one side, or it has to be swapped near around mid of its life or brake should have more lining materials with different friction coefficients so as to avoid replacement of lining very often.
Further relation between torque applied by the brake and force can be expressed as

$$T = (F_1-F_2)\ r \tag{9}$$

Substituting equations (7) and (8) in(9) yields

$$T = p_{max}.\ w.r^2(1-e^{-\mu\alpha}) \tag{10}$$

Equation (10) relates maximum constraining torque of the brake with its dimensions and its maximum pressure (Compressive)

V. Existing Design

Width of brake lining for the existing design has been calculated from equation (10) as follows

$$w = \frac{T}{p_{max} r^2 \left(1-e^{-\mu\alpha}\right)} \tag{11}$$

From this expression w = 20 mm
Area of brake lining can be expressed as

$$A = \alpha.r.w \tag{12}$$

From this expression A = 10142 mm^2
Factor of safety can be expressed as

$$FOS = \frac{\text{Allowable stress}}{\text{Working stress}} \tag{13}$$

From this expression working stress = 66.67 MPa
Working stress can also be expressed as

$$\text{Working stress} = \frac{\text{Force}}{\text{Area of link}} = \frac{F}{\left(\frac{\pi}{4} d_1^2\right)} \tag{14}$$

From equation (4)
F =460.8 N

d_1: Size of link

Substitution of necessary inputs gives d_1= 3 mm

VI. Design Optimization

Width of brake lining for the existing design is 20 mm as calculated using equation (11). However its restraining value imposed by space constraints is 25 mm. It is decided to explore the advantage of utilizing the

width of lining to the fullest extent permitted so as to optimize the existing design. Accordingly size of drum has been reworked taking the restraining value of width of lining i.e. 25 mm as follows.
Equation (10) can be rearranged as

$$r = \sqrt{\frac{T}{p_{max}\, w\left(1 - e^{-\mu\alpha}\right)}} \qquad (15)$$

From this expression r = 90 mm
From which size of drum (D) = 2 x r = 180 mm
From equation (12)
Area of brake lining, A = 11328 mm^2
From equation (14)
Size of link d_1 = 3.1 mm

VII. Results And Discussion

Parameters for optimized design are compared with that of existing one in table 1.

Table 1. Summary of design parameters

Sl. No.	Parameter	Existing design	Optimized design
1.	Size of drum	200 mm	180 mm
2.	Width of lining	20 mm	25 mm
3.	Area of lining	10142 mm^2	11328 mm^2
4.	Size of link	3 mm	3.1 mm
5.	Torque	40000 N-mm	
6.	Pressure	0.23 MPa	

- Both the configurations meets the design constraints
- But for the same torque and pressure capability of brake lining optimized design yields to lesser drum size which contributes a lot to both volume and weight.
- Further brake having higher lining area dissipates less energy per unit area which imparts two high order merits to the design which are: Lower operating temperature and less wear of lining

VIII. Development Of Software In Matlab

General purpose software has been developed using MATLAB for design optimization of brake. For accomplishing this formulation stated in section (5) has been transformed in to some form of a code in MATLAB and the screen shot of associated m-file is shown in Fig. 3.

```
clear
% Input section
T=input('Enter the value of torque in N-m');
p=input('Enter the value of pressure in MPa');
w=input('Enter the limiting value of width of lining in mm');
sigma=input('Enter the value of allowable stress in MPa');
mu=0.4;                                  % Coefficient of friction
alpha=290;                               % Wrap angle in degrees
FOS=1.5;                                 % Factor of safety
% Calculation
alpha_rad=alpha*pi/180;  % Wrap angle conversion from degrees to radians
r=(T/((p*1e6)*(w/1000)*(1-exp(-1*mu*alpha_rad))))^0.5; % Radius of drum
D=(r*2)*1000;                            % Size of drum in mm
A=(alpha_rad*w/1000*r)*1e6;              % Area of lining in mm^2
F=p*1e6*w/1000*r;                        % Force
d1=(2*((F*FOS)/(pi*sigma*1e6))^0.5)*1000;  % Size of link in mm
fprintf('Size of the brake drum is %4.1f mm \n', D)
fprintf('Area of brake lining is %4.1f mm^2 \n', A)
fprintf('Size of the link is %4.1f mm \n', d1)
```

Fig. 3. Screen shot of associated m-file

Programme has been written with interactive mode of operation which means upon executing the programme it prompts the user to enter the value of inputs as shown in Fig. 4.

```
Command Window
>> clut
Enter the value of torque in N-m40
Enter the value of pressure in MPa0.23
Enter the limiting value of width of lining in mm25
fx Enter the value of allowable stress in MPa100
```

Fig. 4. Inputs needed to execute the code

Subsequently programme will generate the outputs as shown in Fig. 5.

```
Command Window
>> clut
Enter the value of torque in N-m40
Enter the value of pressure in MPa0.23
Enter the limiting value of width of lining in mm25
Enter the value of allowable stress in MPa100
Size of the brake drum is 179.1 mm
Area of brake lining is 11328.3 mm^2
Size of the link is  3.1 mm
fx >>
```

Fig. 5. Outputs generated by the code

IX. Conclusions

Reconfiguring the design of brake for mini bike by choosing the restraining value of lining width rather than choosing restraining value of size of drum yielded to reduction in volume and weight and hence resulted in optimizing the design. It also reduced the operating temperature and wear.

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