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Stress Analysis of Automobile Brake Drum

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***Abstract* — Hydraulic brakes are widely used in automobile because they are easy to operate, maintain and repair than the mechanical brakes and air brakes. This paper describes the design of wheel cylinder diameter used in front disc brake and rear drum brake and stress analysis of brake drum in rear drum brake for hydraulic brake system of Hilux Surf. In the design calculation, clearly illustrates the contact force, the braking torque, friction head losses through the brake line, stopping distances with the various vehicle speeds and the braking efficiency of vehicle moving down the hill. In this case, slope ratio 1:5 is used for the minimum slope condition and vehicle moving on dry asphalt road. The purpose of this analysis is to know the stress behaviour of brake drum which is made of grey cast iron.**

Indexed Terms -- **Automobile, grey cast iron, hydraulic, rear drum**

I. INTRODUCTION

The ability of the braking system to bring a vehicle to safe controlled stop is absolutely essential in preventing accidental vehicle damage and personal injury. Brakes absorb the total energy of moving masses by help of friction forces. Brake systems may be mechanically, pneumatically, or hydraulically operated. The hydraulic brake is noted for small actuating time, simple design, small overall dimension, small mass, low cost of procurement and maintenance. Among the major components of hydraulic brake are master cylinder, wheel cylinder, brake shoes and their mechanism, brake lines, brake pedal and brake fluid. The braking system of a vehicle is undeniably important, especially in slowing down or stopping the rotation of a wheel by pressing brake pads and brake shoes against rotating wheel disc and drum. Disc brakes are used on the front wheels and drum brakes are used on the rear wheels of most vehicles. A disc brake consists of a cast iron disc bolted to the wheel hub and a stationary housing called caliper. The caliper is connected to some stationary part of the vehicle like the axle casing or the stub axle as is cast in two parts each part containing a piston. The self-energization of the drum brake is one of the most advantages of the drum brake rather than disc is which help in reducing the required actuating force and it's relatively lesser cost. The necessary friction is obtained by passing a stationary shoe against the rotating member [1].

Most brake systems with front disc and rear drum have larger diameter pistons than the master cylinder piston and a power booster to increase the input force or pedal force. When the brake pedal is depressed, the linkage forces the push rod, primary piston and secondary piston in the dual type master cylinder. The primary piston force is directly transferred to rear drum brake and the secondary piston force is also transferred to front disc brake [2].

In today's growing automotive market the competition for better performance vehicle is growing enormously. The racing fans involved will surely know the importance of a good brake system not only for safety but also for staying competitive. The disc brake is a device for slowing or stopping the rotation of a wheel. A brake disc usually made of cast iron or ceramic composites includes carbon, Kevlar and silica, is connected to the wheel and the axle, to stop the wheel.

A friction material in the form of brake pads is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc. This friction causes the disc and attached wheel to slow or stop. Generally, the methodologies like regenerative braking and friction braking system are used in a vehicle. A friction brake generates frictional forces as two or more surfaces rub against each other, to reduce movement. Based on the design configurations, vehicle friction brakes can be grouped into drum and disc brakes. If brake disc are in solid body the heat transfer rate is low [3]. Time taken for cooling the disc is low. If brake disc are in solid body, the area of contact between disc and pads are more. In disc brake system a ventilated disc is widely used in automobile braking system for improved cooling during braking in which the area of contact between disc and pads remains same [4].

II. DESIGN CALCULATIONS

The change in potential energy of vehicle can be calculated by

$$E_p = mgh \quad (1)$$

The change in kinetic energy of vehicle can be calculated by

$$E_k = \frac{1}{2} mv^2 \quad (2)$$

If the rotating body is stopped after applying the brake on the inclined plane, both potential and kinetic energy must be absorbed by the brake.

$$E = E_p + E_k \quad (3)$$

The tangential braking force of wheel can be calculated by

$$F_t = \mu R_n \quad (4)$$

In the braking stage, 60% of tangential braking force or retarding force occurs in front wheels and 40% of total braking force also occurs in rear wheels because this model vehicle is front engine rear wheel drive vehicle. The engine transmission and most other heavy parts are located toward the front of the vehicle. The stopping distance of vehicle in down-hill position increases with increasing vehicle speed. In this design, the vehicle is moving down with the minimum speed of 50 km/hr. In braking performance, the stopping distance can be calculated by

$$S = \frac{v^2}{2a} \quad (5)$$

The efficient braking of vehicle in down-hill position is one of the principal factors of safe operation. The brake efficiency is based on deceleration and can be calculated by

$$\eta = \frac{a}{g} \times 100\% \quad (6)$$

The friction head losses in hydraulic pipe line system are calculated by using experimental data. The brake fluid which is used in hydraulic pipe line can be made from glycol-based, department of transportation (DOT3), society of automotive engineers (SAE 1703), minimum operating temperature (-54°C) and maximum operating temperature (185°C).

$$h_f = \frac{64}{R} \times \frac{L}{d_p} \times \frac{v_f^2}{2g} \quad (7)$$

where, h_f = friction head losses (m)
R = reynolds number
L = pipe length (m)
v_f = flow velocity of brake fluid (m/s)
d_p = inner diameter of brake pipe (m)

The wheel cylinder assembly is simple in construction; it consists of cast iron housing, two aluminium pistons, two-rubber cup expander, two push rods and two rubber dust boots. The purpose of wheel cylinder is to transmit the master cylinder pressure to the brake shoe and force them outward against the drum. In the wheel cylinder, the hydraulic pressure applied between the two piston cups forces the piston out, thus, the brake shoe actuating pins force the brake shoes into contact the brake drum.

A. Contact Force and Braking Torque Design for Front Wheel Disc Brake:

When the driver's foot force is applied on the brake pedal, the friction force occurs between brake pads and shoes against disc rotor and drum. Therefore, tangential braking force or retarding force and torque occur between the tyre and road. Initially, we need to find contact force and torque for each wheel in the front axle.

Friction force is dependent upon normal force which is based on brake line pressure applied onto top of the wheel cylinder. Therefore, friction force for both side of rotor can be calculated by

$$\text{Tangential Braking Force} = \frac{\text{Tetarding Force}}{2} \quad (8)$$

Friction force is dependent upon normal force which is based on brake line pressure applied onto top of the wheel cylinder piston. Therefore, friction force for both side of rotor can be calculated by

$$F_{friction} = \mu_1 F_{normal} \quad (9)$$

For a disc brake system, there is a pair of brake pads, thus the total brake torque is

$$T_r = 2\mu_1 F_{normal} \times \text{Effective Radius} \quad (10)$$

We can get the normal force or wheel cylinder piston force from the equilibrium condition of braking torque. Normal force acting on disc rotor is directly from the force of wheel cylinder piston in contact with the braking fluid.

$$F_{normal} = \frac{\text{Tangential Braking Force} \times R}{2\mu_1 \times \text{Effective Radius}} \quad (11)$$

$$F_{normal} = \text{Wheel Cylinder Force} \quad (12)$$

B. Contact Force and Braking Torque Design for Rear Wheel Drum Brake”

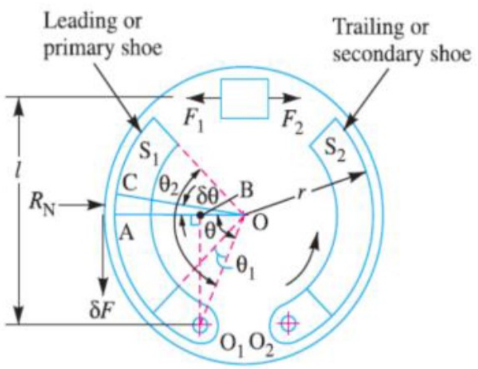

Fig.1 Forces on the Internal Expending Brake Shoes

In internal expending drum brake, torque of wheel tyre and torque of drum are equal. There are two shoes in this drum type, thus the torque for one shoe is equal to half of the torque of drum. It is assumed that the pressure distribution on the shoe is nearly uniform and the normal pressure acting on the shoe can be calculated by

$$P_1 = \frac{T_1}{\mu_2 b r^2 \cos\theta_1 \cos\theta_2} \quad (13)$$

where, P_1= normal pressure acting on shoe
μ_2= coefficient of friction between drum and shoe
b = width of shoe
r = radius of shoe
θ_1= 25°
θ_2= 125°

For the leading shoe, taking moment about O_1,

$F_1 \times l = M_N - M_F$(14)

where, F_1 = force for leading shoe (N)
M_N = total moment of normal force (N-m)
M_F = total moment of friction force (N-m)

For the trailing shoe, taking moment about O_2,

$F_2 \times l = M_N + M_F$(15)

where, F_2= force for trailing shoe (N)

C. Wheel Cylinder Diameter Design for Disc and Drum Brake:

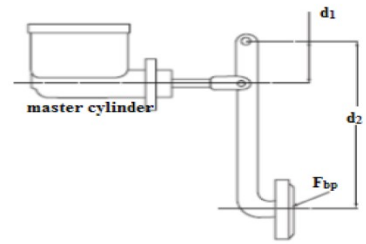

Fig.2 Brake Pedal and Master Cylinder

The force that can be exerted on the brake pedal varies due to the strength and size of the driver. Normal driver’s foot force is taken as 500N in the braking stage. When the driver presses the brake pedal, the foot force is transferred through the pedal linkage to the pistons in the master cylinder. Moving the pistons generates hydraulic pressure. This pressure is then transmitted through the brake line to the wheel cylinder.

Wheel cylinder diameter can be calculated by

$$d_{wc1} = \sqrt{\frac{4A_{mc}F_{wc1}}{\pi F_{mc}}} \quad (16)$$

$$d_{wc2} = \sqrt{\frac{4A_{mc}F_{wc2}}{\pi F_{mc}}} \quad (17)$$

where, A_{mc} = area of master cylinder (m^2)
d_{wc1}= wheel cylinder diameter of front wheel (m)
d_{wc2} = wheel cylinder diameter of rear wheel (m)

III. STRESS ANALYSIS

The drum material is gray cast iron (GFC) ISO standard with good thermo physical characteristics and the brake shoe has an isotropic elastic behaviour. The purpose of this analysis is to predict stress distribution occur in the drum when the vehicle is subjected to stop under the driving condition. Stress induced in the drum brake due to brake pressure is compressive stress.The expression for the yield strength on the drum can be estimated based on Von Mises and Tresca.

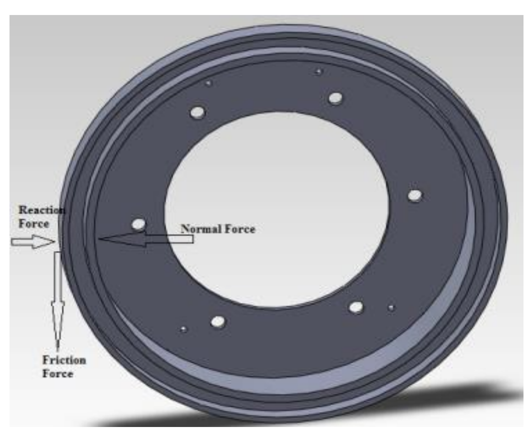

Fig.3 Forces Acting on Drum Brake

Shear stress due to the rotation of drum and principle stress occur in the drum can be calculated by

$$\tau_{xy} = \frac{TR_d}{J} \qquad (18)$$

where, τ_{xy} = shear stress of drum (N/m²)
T = torque of drum (Nm)
R_d = inner radius of drum (m)
J = polar moment of inertia(m⁴)

$$\sigma_{1,2} = \frac{1}{2}(\sigma_x + \sigma_y) \pm \frac{1}{2}\sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2} \qquad (19)$$

For Von Mises criteria,

$$\bar{\sigma} = \frac{1}{\sqrt{2}}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{\frac{1}{2}} (20)$$

where, σ_x = axial stress (N/m²)
σ_y = hoop stress (N/m²)
$\bar{\sigma}$= yield strength (N/m²)

For Tresca criteria,

$$\bar{\sigma} = \sigma_{max} - \sigma_{min} \qquad (21)$$

IV. RESULTS AND DISCUSSIONS

Tangential braking force between tyre and wheel can be calculated from equation (4). The depressing force for disc brake and the expending force for drum brake can be calculated as equation (11), (14) and (15). The braking torque for disc brake can be obtained from the relation of normal force acting on the rotor and the effective radius of brake pad. Braking torque for drum brake is the same as the torque of wheel.

TABLE I
RESULT DATA OF CONTACT FORCE AND BRAKING TORQUE FOR DISC AND DRUM BRAKE

No.	Design Parameters	Value	Unit
1	Normal reaction force	232	kN
2	Tangential braking force	15.6	kN
3	Torque for rear wheel	1.2	kN-m
4	Total energy	462	kN-m
5	Tangential force for front one wheel	4.7	kN
6	Tangential force for rear one wheel	3.1	kN
7	Torque for front wheel	1.8	kN-m
8	Tangential force for front axle wheels	9.4	kN
9	Tangential force for rear axle wheels	6.2	kN

TABLE II

RESULT DATA FOR THE DESIGN OF WHEEL CYLINDER

No.	Design Parameters	Value	Unit
1	Wheel cylinder force for disc brake	17.6	kN
2	Torque for one shoe of brum brake	0.6	kN-m
3	Normal Pressure	1.959	MPa
4	Wheel cylinder force for drum brake	8.5	kN
5	Wheel cylinder diameter of front wheel	50	mm
6	Wheel cylinder diameter of rear wheel	32	mm

TABLE III

CALCULATION RESULTSIN STATIC CONDITION

Type	Yield Strength (MPa)	
	Von Mises criterion	Tresca criterion
Brake Drum	0.6	0.59

In commercial brake drum, aluminium alloy, steel and gray cast iron are used. But gray cast iron brake drums are used only in this model. The yield strength of gray cast iron is 250 MPa.

The simulation result showed that the stress distribution of the scale varies from 0.04 MPa to 8.8 MPa and this result based on Von Mises criteria. The calculation result of yield strength in Von Mises criteria is 0.6 MPa and those in Tresca criteria is 0.59 MPa. The results of yield strength occur in the minimum range.

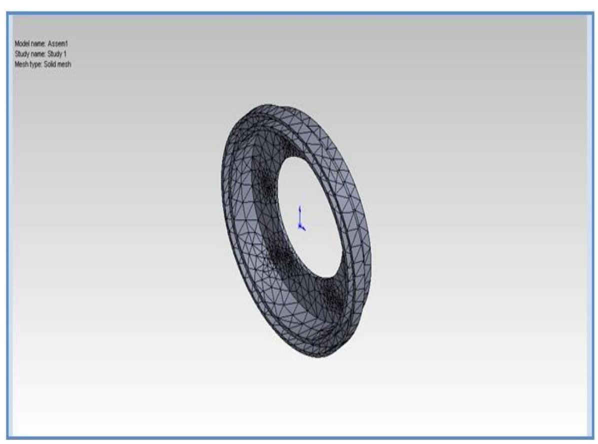

Fig.4 Mesh Plot of Brake Drum

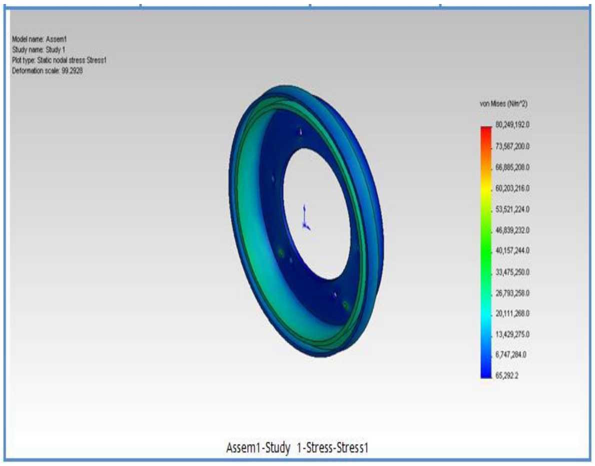

Fig.5 Stress Distribution of Brake Drum

V. CONCLUSIONS

Friction head losses through the brake line are so small that it can be neglected in design calculation. This means that if there is no leakage in thebrake line, the pressure at the wheel cylinder will be the same as the pressure from the master cylinder. It can be concluded that the smaller diameter of wheel cylinder gives the less force required drum brake due to the 40% of weight transfer effect in braking condition and good condition of brake efficiency in down-hill position. The static analysis is developed to study the yield criteria of grey cast iron brake drum. According to the yield strength of using material, result obtained from the stress distribution of brake drum is satisfied in the analysis of static condition. It is assumed that the pressure distribution on the drum is nearly uniform and the force acting on the drum mainly depends on wheel cylinder piston pressure and torque of drum.

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