ISSN (O): 2393-8609

International Journal of Aerospace and Mechanical Engineering

Volume 3 – No.4, August 2016

Peripheral Disc Brake System and its Comparison with Conventional Disc Brake System for use in Motorcycle Front Wheel

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ABSTRACT

This paper aims at comparing conventional disc brake with lesser used peripheral disc brake for motorcycles. Various parameters of both systems are analyzed and advantages and disadvantages of using peripheral disc brakes over conventional disc brakes have been discussed.

Keywords

Motorcycle brakes, disc brakes, peripheral brakes, comparison

1. INTRODUCTION

Peripheral disc brakes use a large diameter disc mounted near the rim of the wheel unlike the conventional disc brakes which employ a disc mounted near the center. Peripheral disc brakes have had limited usage in motorcycles. They have been used on custom made motorcycles. Stealth Brake System from Wilwood®, ZTL® brakes from Buell Motorcycle Company® and brakes used by Erik Buell Racing LLC® are some examples of peripheral disc brakes [1, 2].

These brakes use inside-out piston caliper. This means that unlike in conventional disc brakes, where caliper clamps the radially outer edge of the disc, the caliper clamps the ring shaped disc from the radially inner edge [2].

Fig 1: Peripheral disc brake set-up on EBR 1190SX

2. LOAD PATH COMPARISION

Stopping of vehicle due to braking occurs due to frictional force acting on the contact patch on tire by the road surface in direction opposite to that of vehicle's motion. This happens as the rotational motion of the wheel (and therefore, tire) is slowed down or locked using a braking system. The wheel is now slower than before or no longer able to rotate and the momentum of the vehicle continues to push the wheel forward in slowed down or locked state. As a result, the tire surface in contact with the road experiences frictional force exerted by the road in opposite direction.

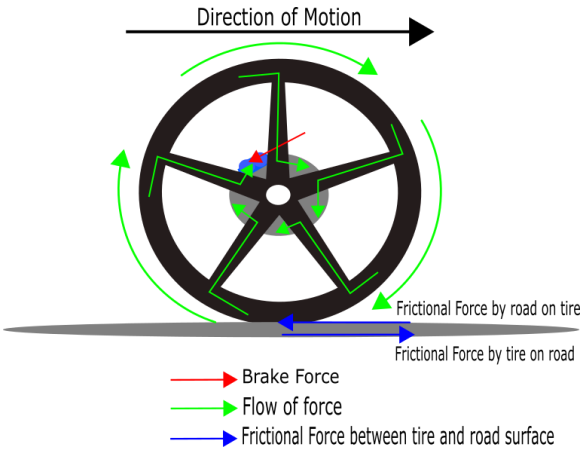

Fig 2: Schematic showing load path for conventional disc brake set-up

The frictional force which acts on the tire during braking travels through the rim of the wheel. In a conventional disc brake set up, the force is transferred from the rim or periphery of the wheel to the hub via spokes of the wheel. The force then travels from hub to disc via fasteners connecting disc and hub. The disc reacts to the force as it is fixed by braking action of the caliper.This reaction force is due to friction between brake pads and disc and is called brake force [3].

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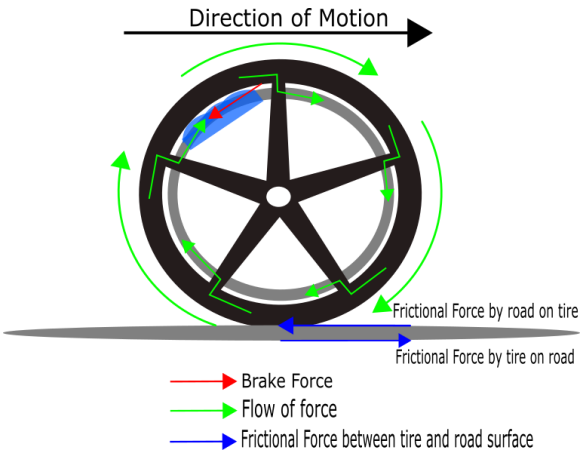

Fig 3: Schematic showing load path for peripheral disc brake set-up

The peripheral disc brake on the other hand has disc mounted near to the rim of the wheel, at greater radial distance than conventional disc brakes. As a result, force is almost instantaneously transferred from the rim to the disc and passes through the spokes for no or very less distance. This means that the spokes can be made considerably lighter since they no longer have to carry braking load.

3. BRAKE FORCE

When brakes are applied, the wheel reaches rotational equilibrium. The frictional force acting on the contact patch of tire tends to rotate the tire in forward direction and this moment is reacted by brake force. In conventional disc brake, the disc radius is smaller than that of Peripheral disc brake and therefore higher force is required cancel the moment of same magnitude than that of peripheral disc brakes.

Let us assume that both the systems experience equal frictional force. If F_{fr} is the frictional force, R is the distance of center of wheel from contact patch, F_{BC} is the force of braking for conventional disc brake, F_{BP} is the force of braking for peripheral disc brake, r1and r2 is the effective distance of application of braking force from center of the wheel in conventional and peripheral disc brake respectively, then for rotational equilibrium, we have:

$$F_{fr} \times R = F_{BC} \times r1$$

$$F_{fr} \times R = F_{BP} \times r2$$

$$\therefore F_{BC} \times r1 = F_{BP} \times r2$$

$$\because r1 < r2, \therefore F_{BC} > F_{BP}$$

Therefore, for the same conditions and end effect, peripheral disc brake force is lesser than their conventional counterparts.

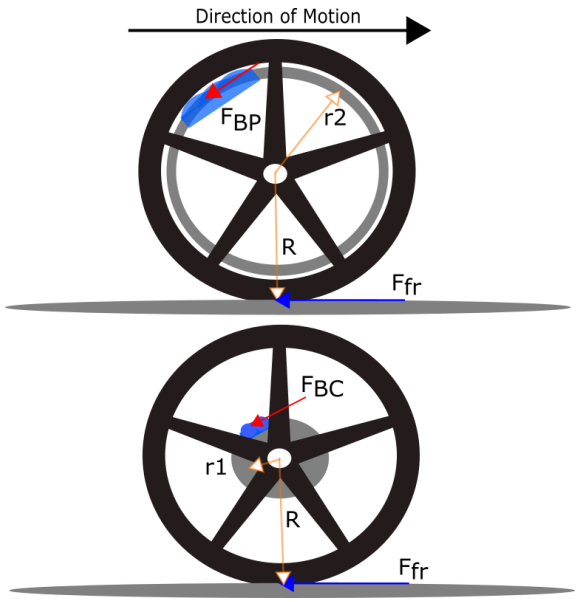

Fig 4: Schematic showing brake force, brake force effective radii and contact patch distance from center in peripheral (above) and conventional (below) disc brake systems

This means that peripheral disc brake can function with same output using lesser normal reactionbetween piston and disc. This means lesser human effort or pressure in hydraulic lines is required for same effect as that of conventional disc brake. If normal reaction is not reduced, the disc can take higher braking loads. Due to this reason, a single peripheral disc at front for high performance motorcycles can be used instead of conventional disc brake system which requires dual discs. This results in significant reduction of unsprung mass.

4. SPOKE ANALYSIS IN IDEAL CONDITIONS

Spokes act like beams during braking. Spokes are free to rotate about the wheel center. Therefore, the center of the wheel acts like a hinge support for the spokes. Brake force acts on the spoke where the disc or carrier (in floating disc brakes) is fastened to the hub or spoke through bolts. Frictional force on tire's contact patch by road surface acts on the end of spokes which is merging with the rim and free to rotate. This force is distributed among different wheel spokes. The force on the free end of the spoke beinganalyzed is taken 1000N for simplicity of calculation and it is assumed both the systems are subjected to identical loads and the lateral forces and weight of the wheel and the vehicle is neglected for sake of comparison.

Bolt circle diameter of the Peripheral set up is taken 386mm [4] and bolt circle diameter of the conventional disc brake taken is 140mm [5]. Spoke length is taken to be 215mm which is slightly lesser than half of 17 inches, 17 inches being the diameter of wheel rim. C is the center of the wheel and A is the point where spoke joins the rim. B is the point where disc is bolted to the spoke or hub. Beam analysis is done for equilibrium conditions. Forces acting at A, B and C are F_A, F_B and F_C respectively. Then, F_A=1000N as taken above.

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4.1 For conventional set-up

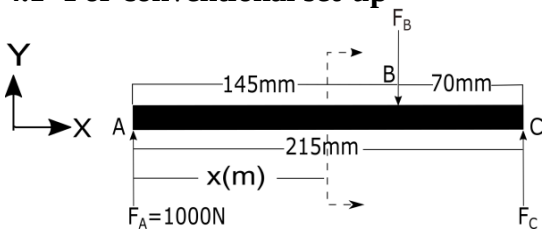

Fig 5: Schematic showing forces on spoke of conventional disc brake set-up

$$\sum M_Z = 0$$

$$\therefore [1000 \times (215 \times 10^{-3}) - F_B \times (70 \times 10^{-3})]Nm = 0$$

$$\Rightarrow [F_B \times 0.07]Nm = 215Nm$$

$$\Rightarrow F_B = 215Nm \div 0.07m$$

$$\Rightarrow F_B = 3071.42N$$

$$\sum F_Y = 0$$

$$\therefore F_A - F_B + F_C = 0$$

$$\Rightarrow F_C = F_B - F_A$$

$$\Rightarrow F_C = [3071.42 - 1000]N = 2071.42N$$

4.1.1 Shear force, SF:

From A to B:

$$SF = 1000N$$

From B to C:

$$SF = (1000 - 3071.42)N = -2071.42N$$

$$\therefore SF_{maximum} = 2071.42N\ (in - Y\ direction)$$

4.1.2 Bending moment, BM:

From A to B:

$$BM = [1000x]Nm\ where\ 0 \le x \le .145m$$

From B to C:

$$BM = [1000x - 3071.42(x - 0.145)]Nm$$

$$where\ 0.145m \le x \le 0.215m$$

$$\therefore BM_{x=0} = 0\ ,\ BM_{x=0.145m} = 145Nm \text{ and } BM_{x=0.215m} = 0$$

$$\therefore BM_{maximum} = 145Nm$$

4.2 For peripheral set-up

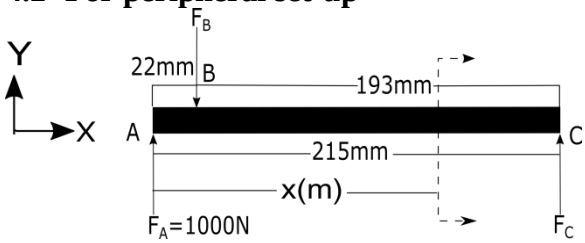

Fig 6: Schematic showing forces on spoke of peripheral disc brake set-up

$$\sum M_Z = 0$$

$$\therefore [1000 \times (215 \times 10^{-3}) - F_B \times (193 \times 10^{-3})]Nm = 0$$

$$\Rightarrow [F_B \times 0.193]Nm = 215Nm$$

$$\Rightarrow F_B = 215Nm \div 0.193m$$

$$\Rightarrow F_B = 1113.98N$$

$$\sum F_Y = 0$$

$$\therefore F_A - F_B + F_C = 0$$

$$\Rightarrow F_C = F_B - F_A$$

$$\Rightarrow F_C = [1113.98 - 1000]N = 113.98N$$

4.2.1 Shear force, SF*:*

From A to B:

$$SF = 1000N$$

From B to C:

$$SF = (1000 - 1113.98)N = -113.98N$$

$$\therefore SF_{maximum} = 1000N$$

4.2.2 Bending moment, BM:

From A to B:

$$BM = [1000x]Nm\ where\ 0 \le x \le .022m$$

From B to C:

$$BM = [1000x - 1113.98(x - .022)]Nm$$

$$where\ 0.022m \le x \le 0.215m$$

$$\therefore BM_{x=0} = 0\ ,\ BM_{x=0.022m} = 22Nm \text{ and } BM_{x=0.215m} = 0$$

$$\therefore BM_{maximum} = 22\text{Nm}$$

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Table 1: Shear forces, bending moments and radial bearing thrust corresponding to a force of 1000N on both set-ups

	Conventional Disc Brake	Peripheral Disc Brake
Maximum Shear Force(N)	2071.42	1000
Maximum Bending Moment(Nm)	145	22
Radial thrust at bearing due to braking(N)	2071.42	1113.98

Therefore, shear force and bending moment experienced by the spokes of the wheel in the peripheral disc brake is significantly lesser than that of conventional disc brakes for equal frictional force. Also, wheel bearing experiences lesser radial thrust due to braking in this system. This allows for very light spokes.

5. STRESS AND EXPANSION DUE TO HEAT

Disc brakes heat up as the kinetic energy of the vehicle is dissipated as heat energy in the environment. Due to this heating, conventional disc brakes experience expansion on the face where the brake pads come in contact with the disc. This expansion induces tensional stress in the central part of the disc which is relatively cooler. The heat and stress generated therebyis not harmful where braking load is less, such as in commuter motorcycles and rear wheels but can cause severe damage in performance vehicles. It can cause heat cracks or disc warping. To overcome this, performance motorcycles use floating or semi-floating discs, which employ two different pieces of metal to make up the brake assembly. One piece is bolted to the hub which is called carrier and the other piece comes in contact with the brake pads which is the disc. This allows for free or unconstrained radial expansion of disc due to heating, hence inducing no stress in central part [3, 6and 7].

Expansion due to heat is a major drawback in peripheral disc brakes. This is because peripheral discs have no central part and are bolted to the wheel at very less distance from disc's face which comes in contact with the brake pads and heats up. This problem can be solved by bolting the disc with the wheel indirectly with the help of slotted spacers as patented by Buell Motorcycle Company [2].

6. ROTATIONAL INERTIA OF WHEEL

The rotational inertia of peripheral disc brake system is more than conventional disc brake system due to shifting of mass radially outwards. This means a higher torque is required to achieve same rotational acceleration of the wheel employing a peripheral disc brake system as compared to conventional disc brake system.

7. CONCLUSION

It can be seen that peripheral disc brakes need lesser brake force for same end effect, induce lesser bending and shear stress in wheel spokes and lesser radial thrust at the wheel bearing. All these factors allow for a very light weight motorcycle front wheel. Lighter weight means more efficiency, reduced unsprung mass and a higher power to weight ratio. Radial expansion due to heat can also be taken care of. The only drawback is the increase in rotational inertia of the wheel which is very small since the wheel spokes also become lighter. This increased rotational inertia is a very small price to pay when compared to the benefits. Use of a single disc instead of two not only means reduction in weight but also makes system simpler and more reliable by removing components such as brake line and brake caliper corresponding to the removed disc.

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