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Effective Braking in a Two-wheeler

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Abstract—*The braking system in a two-wheeler plays a critical role in safety of the rider. The normal reaction on the wheel and coefficient of friction between tyre and road surface determines the braking force. The normal reaction on the rear wheels changes with vehicle loading condition. So the braking force required to achieve minimum stopping distance depends on pillion load. In conventional braking system brake force distribution is fixed and does not vary with load. One of the methods to vary the brake force is by varying the effective disc radius based on pillion load. Varying the brake force results in increased deceleration thereby reducing the stopping distance. Wheel lockup is avoided. By varying the effective radius based on pillion load optimum deceleration is achieved and stopping distance is reduced. Braking forces are brought closer to optimum. Braking efficiency is increased and stability of vehicle is maintained.*

Keywords*: effective radius, minimum stopping distance, wheel lock, pillion load.*

1. INTRODUCTION

Accidents involving two wheelers are increasing rapidly. Braking and stability plays a critical role in safety of two wheelers. A two wheeler capable of doing high speeds requires increased stopping power. Increased braking force does not always translate into reduced stopping distance. During hard braking, the wheels of two wheeler may tend to lock. It may skid losing its stability. In order to prevent accidents in two wheelers braking must be effective. Wheel lock must be avoided. Braking force is directly proportional to the normal reaction and the coefficient of friction between tyre and ground. As the pillion load on the vehicle changes the normal reaction also changes. Therefore the load on the vehicle influences the braking force. In design of brakes for two wheelers it must be noted that front wheels must lock before the rear wheels so that the vehicle remains stable. If the rear wheel tends to lock it may lead to loss of direction control. The brake force distribution is set accordingly. But this condition may vary depending on various factors and one fixed force distribution cannot cater to varying braking requirements. In this paper one way to maintain optimum braking force is discussed. The disc radius is directly proportional to braking force generated. So by varying the effective disc radius varying braking force can be generated depending on the requirement and optimum braking force can be maintained. This allows better tyre road friction utilisation. Braking efficiency can be improved.

2. WHEEL DISC RADIUS

Disc radius has got a direct effect on braking force. Greater the wheel disc radius more the braking force being developed. This is because the braking force is nothing but a force that opposes the rotation of the wheel. Since this force is caused by the friction acting between wheel disc and the brake pads at a point near its outer perimeter, the greater the radius of the wheel disc greater will be opposing torque available to decelerate the vehicle. This direct relation between the change in wheel disc radius and the braking force is given by the formula

$$F_x = (p_l - p_o)\, A_{wc}\, BF\, \eta_c\, (r/R),\ N$$

Where, A_{wc} is area of wheel cylinder cm^2

BF is Brake factor

η_c is efficiency of Wheel cylinder

r is radius of brake disc mm

R is radius of Tire mm

p_l is the brake line pressure N/cm^2

($p_l = F_l\, \eta_p\, l_p / A_{mc}$, N/cm^2)

p_o is the push out pressure, minimum pressure required to bring the pad into contact with disc N/cm^2

The wheel disc radius r is directly proportional to the braking force F_x which proves the theory.

The specifications of the vehicle are as follows

Wheel Base L	1.38m
Wheel Radius R	600 mm
Brake Disc radius r	120 mm
Area of master cylinder A_{mc}	804.2477 mm^2
lever ratio n	4.142
Efficiency of master cylinder η_{mc}	0.8
Efficiency of wheel cylinder η_{wc}	0.98
Minimum Pressure required to push the piston Po	0.05 N/cm^2
Area of wheel cylinder	226.9800 mm^2
Slip Angle	3 deg

3. DECELERATION

It is defined as the rate at which the velocity of the vehicle changes.

$a = F_x / W$ (g units)

where,

F_x is the total Braking force acting on vehicle in N

W is the weight of the vehicle in N

A Matlab program was created to determine deceleration using the values above. The program was run and the deceleration versus the time graph was plotted using the output values of deceleration at any instant. It was considered that the vehicle moves in constant velocity for 3 seconds and after the third second the brake was applied and the graph was plotted.

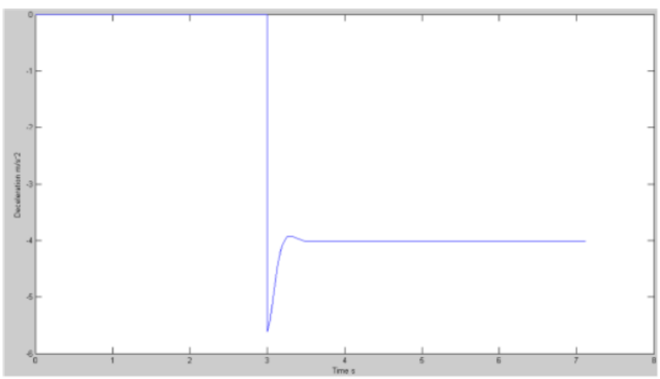

Fig. 1: Deceleration vs Time

Deceleration was calculated for various brake disc values. It can be seen that higher deceleration is obtained as brake disc radius is increased.

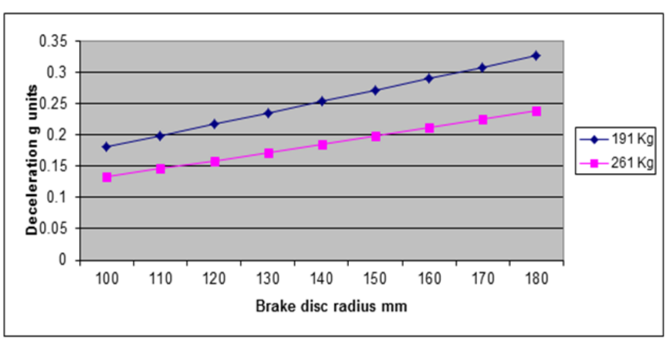

Fig. 2: Deceleration vs Brake disc radius

4. YAW RATE ANALYSIS

The movement of the vehicle about the vertical axis of the vehicle due to various factors such as wind, slip, wheel lock etc. is called Yaw.

The dynamic equation for Yaw rate,

$\varepsilon = (L/I)\{\psi F_{xf} \sin \alpha_v - (1-\psi)F_{xr} \sin\alpha_v + \psi F_{yf} \cos\alpha_v - (1-\psi) F_{yr} \cos\alpha_v \}$

Where

F_{xf} -Braking force on front axle in x dirction N

F_{xr} -Braking force on rear axle in x direction N

F_{yf} - tire side force on front axle N

F_{yr} -tire side force on rear axle N

I -Mass moment of Inertia kgm^2

L -Wheel base m

α_v -Slip angle deg

ε -Angular acceleration **$1/s^2$**

ψ -static rear axle load divided by weight of the vehicle

From the above analysis it is seen that.

1) If the rear brakes lockup when the front wheels still rolling $F_{yr} = 0$; **ε** will be positive resulting in unstable vehicle.

2) If the front brakes are locked with the rear wheel rolling $F_{yf} = 0$; **ε** will be negative leaving the vehicle stable.

Therefore brakes must be designed such that front wheel locks before rear wheel so that stability is maintained.

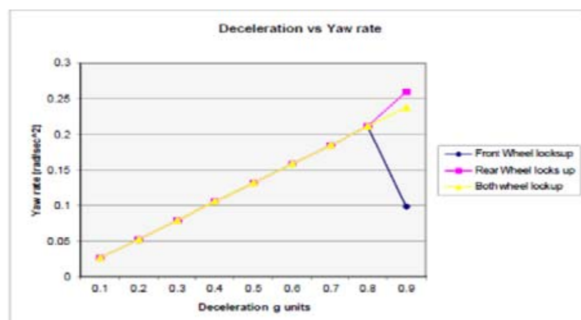

Fig. 3: Deceleration vs Yaw rate

5. AXLE REACTION

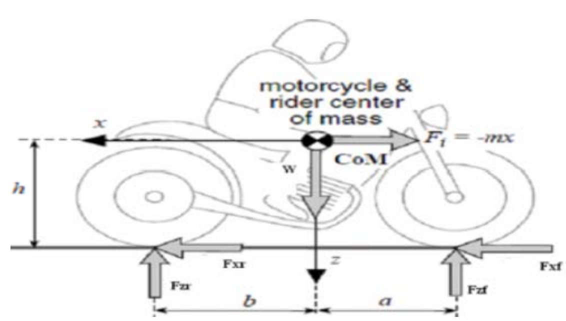

Fig. 4: Axle Reaction

There are two types of loads that can act on the wheels of a motorcycle.

1. Static axle load

The static axle load distribution is defined as the static rear axle load to total weight of the vehicle.

$\Psi = F_{zr}/W$

Where,

F_{zr} is static rear axle load N,

W is weight of the vehicle in N

Static axle load is also given by the formula

$1 - \Psi = F_{zf}/W$

Where F_{zf} is the static front axle load N

2. Dynamic axle load

Inertial forces come into play during braking. There is a transfer of weight to the front axle and a loss of weight in the rear axle. This is given by the formula

$F_{zf},dyn = (1 - \Psi + \chi_a)W$, N

Where,

a = F_x total/W = deceleration in g units

χ = centre of gravity height (h) divided by wheel base (L)

Similarly moment balance about the front tire to ground contact point yields dynamic rear axle normal force

F_{zr} ,dyn = $(\Psi - \chi_a)$ W, N

This phenomenon can be explained by plotting the graph between change in reactions on each wheel with respect to time. After 3 seconds when the brakes are applied the graph shows that the reactions in front wheel increases with respect to time and the reactions in rear wheel decreases with time respectively.

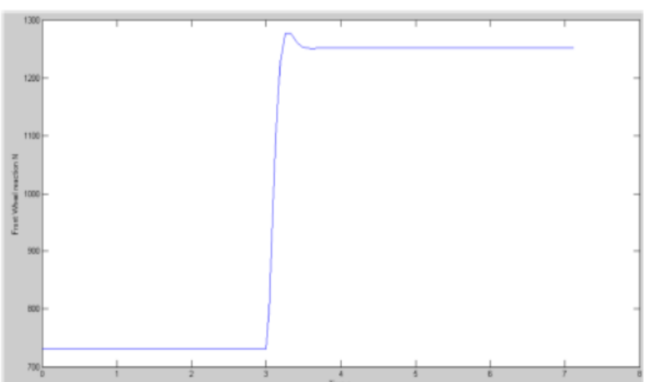

Fig. 5: Front wheel reaction vs. Time

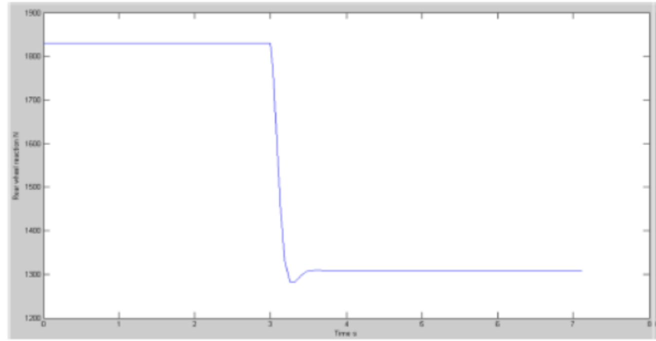

Fig. 6: Rear wheel reaction vs. Time

The figure shows the variation of axle reaction with respect to brake disc radius. Front axle reaction increases whereas rear axle reaction decreases showing load transfer effect. The corresponding disc radius to provide the braking force is plotted.

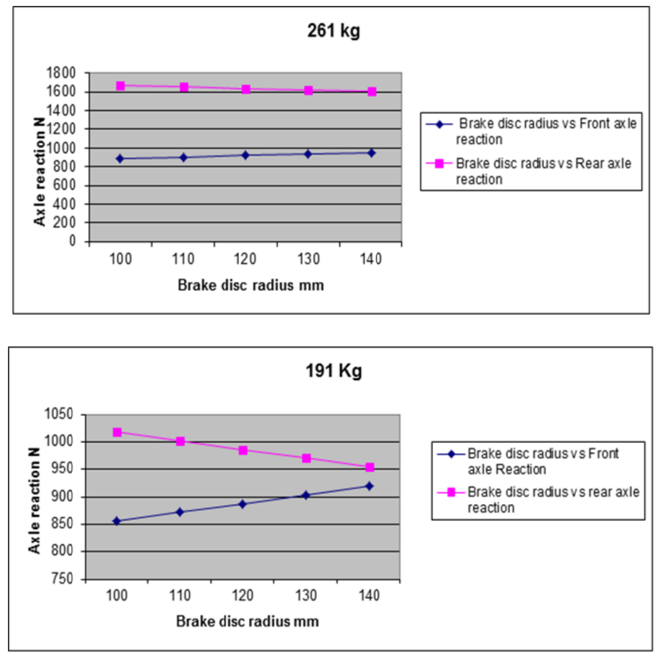

Fig. 7,8: Brake disc radius vs. Axle Reaction

6. EFFECTIVE RADIUS

Variation in axle load requires varied braking forces. For effective braking optimum braking should be provided. I.e. braking force not exceeding the point of wheel lock are calculated. It is seen that the optimum braking in a vehicle is directly related to the load on the vehicle apart from friction co efficient. With the increase in load the most effective radius value tends to increase and result in the highest deceleration value.

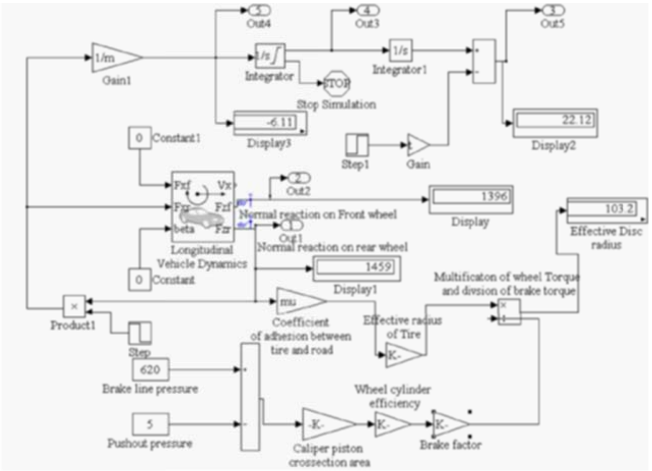

Fig. 9: Matlab Program to calculate Effective Disc Radius

The figure shown above is a MAT lab program to calculate the effective radius for the rear brake at a given load of the 2 wheeler. The tabulations are as follows.

Mass Kg	Effective Radius mm
191	67.73
211	74.83
231	81.92
251	89.01
271	96.1
291	103.2

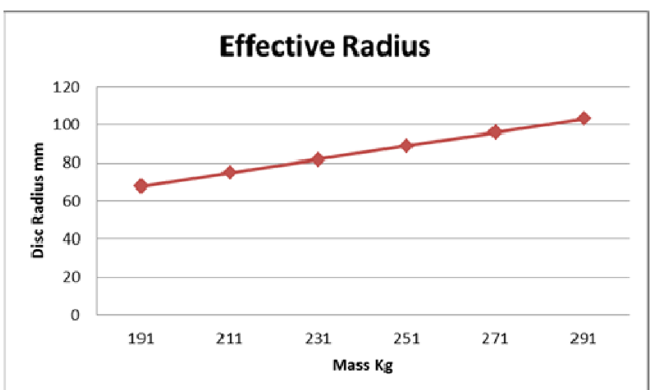

Fig. 10: Effective radius

7. CONCLUSION

A new method for obtaining optimum deceleration and reducing stopping distance by varying the effective disc radius is proposed. Disc radius has got direct effect on braking force. So it is used to obtain varying braking force. Increased braking efficiency is obtained by better tyre road friction utilisation. Wheel lock is prevented thereby maintaining stability of vehicle during braking.

8. ACKNOWLEDGEMENTS

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