The Optimum way to Brake your Motorcycle

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Motorcycle braking seems easy. Everyone assumes that application of both the front and rear brakes simultaneously will bring the motorcycle to a halt in the quickest and safest way, but there is more to braking mechanics than meets the eye.

There are a number of factors which come into play while braking, such as:

- Friction coefficient of the road surface to the motorcycle tyre.
- The dynamic change in the weight of the front and rear of the motorcycle.
- The speed with which the motorcycle is travelling.
- Type of application of brake force

The friction coefficient of the road surface to the motorcycle is a key factor and varies with respect to road surface conditions. The coefficient of friction, μ plays an important role in keeping traction between the wheel and the road surface. It goes as low as 0.1 when the road is covered with ice to as high as 0.7 on a good, dry asphalt road. Higher the friction coefficient better is the braking available.

The weight distribution changes during a braking event and therefore plays a significant role during braking. The dynamic weight change during braking is also related to the friction coefficient and rate of deceleration. With a higher friction coefficient majority of the weight shifts to the front of the motorcycle, in turn changing the C.G (centre of gravity). The C.G. shifts towards the front during braking but, with a lower friction coefficient the change in weight is not much, keeping the C.G almost in the same position. Therefore braking is a function of friction coefficient, dynamic change in the C.G of the system and the brake force.

A typical panic braking situation requires use of both front and rear brakes up to the point of wheel lock to achieve shortest braking distance. It is achieved through the use of Threshold and Cadence Braking.

Threshold braking [1] or limit braking is a driving technique most commonly used in motor racing but also practiced in road vehicles to slow a vehicle at the optimum rates using the brake. The technique involves the driver controlling the brake pedal (or lever) pressure to maximise the braking force developed by the tires. The optimal amount of braking force is developed at the point when the wheel just begins to slip.

Cadence Braking [2] or stutter braking is an advanced driving technique that involves pumping the brake pedal and is used to allow a vehicle to both steer and brake on a slippery surface. It is used to affect an emergency stop where traction is limited to reduce the effect of skidding from road wheels locking up under braking. This can be a particular problem when different tires have different traction such as patchy ice for example. Its use in an emergency requires a presence of mind that the situation itself might preclude.

Cadence braking is supposed to maximise the time for the driver to steer around the obstacle ahead as it allows him to steer while slowing. It needs to be learned and practiced.

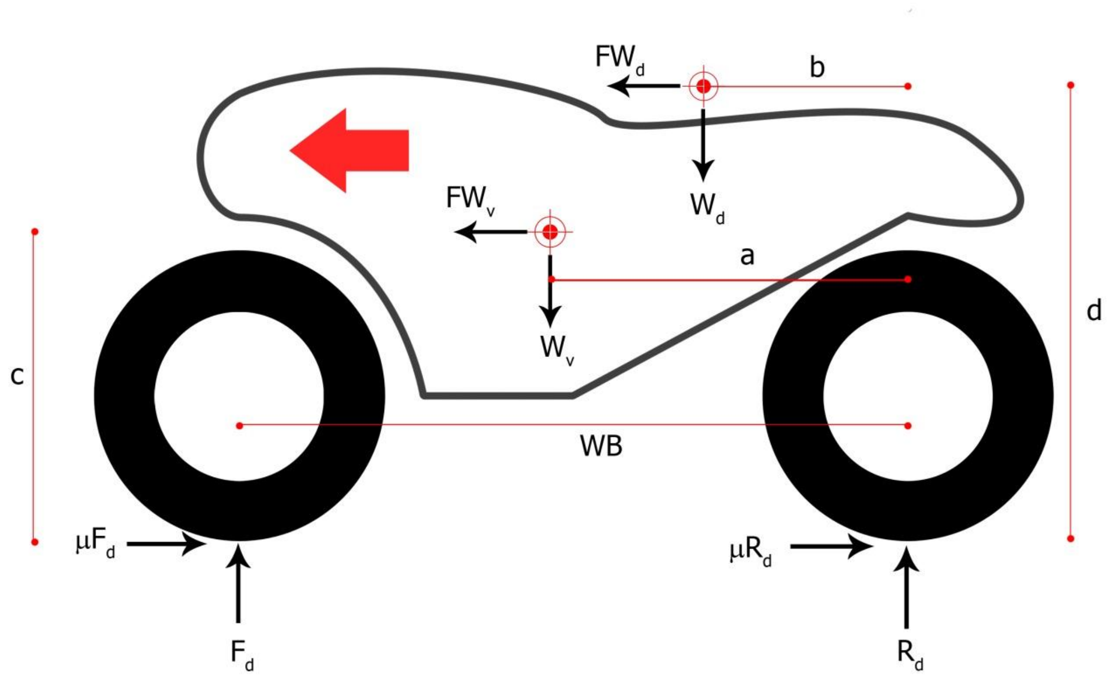
Modelling a braking event:

A typical motorcycle braking event is analysed in this section to determine the parameters required to improve braking. A standard motorcycle is considered as the base for the calculations. The calculations are performed with computer software and results displayed below.

The following scenario was considered as the basis for the calculations.

A motorcycle of weight $\mathbf{W_v}$ is riding along a flat plane at some velocity. The driver of weight $\mathbf{W_d}$ is riding the motorcycle. $\mathbf{W_p}$ is the weight of passenger. The centre of gravity (c.g.) of the rider is at coordinates **(b, d)** with the bottom of rear wheel as origin. The c.g. of the motorcycle is at coordinates **(a, c)**. The c.g. of the passenger is at **(e, f)**. The wheelbase of the motorcycle is **WB**. The coefficient of friction between the tires and the road is represented by **μ** and can range from 0.1 to 0.7. A line diagram of the forces involve is shown in the figure.

$\mathbf{F_d}$ and $\mathbf{R_d}$ are the load reactions on the front and rear wheel respectively. $\mathbf{FW_v}$, $\mathbf{FW_d}$, and $\mathbf{FW_p}$ are the inertial deceleration forces acting on the vehicle, driver, and the passenger respectively.



Schematic 1

Condition 1 :

Weight Transfer Analysis for Driver only condition

$W_v := 100\ kgf \quad W_d := 75\ kgf \quad W_p := 75\ kgf \quad WB := 1220\ mm \quad a := 488\ mm$

$b := 300\ mm \quad c := 600\ mm \quad d := 900\ mm \quad \mu := 0.1 \quad e := 1000\ mm \quad f := -100\ mm$

$Fd := 1\ kgf \quad FW_v := 1\ kgf \quad FW_d := 1\ kgf \quad Rd := 1\ kgf \quad FW_p := 1\ kgf$

Resolving forces and moments

$Fd \cdot WB = FW_v \cdot c + FW_d \cdot d + W_v \cdot a + W_d \cdot b$ Resolving Moments about the rear wheel

$Fd + Rd = W_v + W_d$ Resolving Vertical Loads

$\mu \cdot Fd + \mu \cdot Rd = FW_v + FW_d$ Resolving Horizontal Loads

$$FW_v = \frac{W_v}{W_d} \cdot FW_d$$

$$R_{es} := \text{Find}(Fd, Rd, FW_v, FW_d) = \begin{bmatrix} 68.893 \\ 106.107 \\ 10 \\ 7.5 \end{bmatrix} kgf$$

$R_{es_0} = 68.893\ kgf \quad R_{es_1} = 106.107\ kgf \quad R_{es_2} = 10\ kgf \quad R_{es_3} = 7.5\ kgf$

$$Ratio_{fr2bk} := \frac{R_{es_0}}{R_{es_1}} \cdot 100 = 64.929$$

Fig 1: Weight transfer analysis for the motorcycle during friction coefficient of 0.1

The analysis gives us some important data. From our assumptions we can see that the maximum brake force at the front should not exceed 68.89 kg. This means that if the front brake exerts a force greater than 68.89 kg the wheel will lock. As seen from the figure above the transfer in weight of the motorcycle is not much since the friction coefficient is very low. Majority of the weight is at the rear and thus, in this scenario the rear brakes are more effective in stopping the motorcycle.

But with lower friction coefficient could also lead to a faster wheel lock up. As we all would have experienced the wheel lock up on a sand patch with the slightest application of brake. This is because the reaction in the wheels is reduced due to the surface conditions.

It can also be observed that the retardation forces FW_v and FW_d are very small in magnitude. This is because the weight of the vehicle and driver have less of an effect due to the low coefficient of friction.

Condition 2 :

Weight Transfer Analysis for Driver only condition

$W_v := 100\ kgf$ $\quad W_d := 75\ kgf$ $\quad W_p := 75\ kgf$ $\quad WB := 1220\ mm$ $\quad a := 488\ mm$

$b := 300\ mm$ $\quad c := 600\ mm$ $\quad d := 900\ mm$ $\quad \mu := 0.7$ $\quad e := 1000\ mm$ $\quad f := -100\ mm$

$Fd := 1\ kgf$ $\quad FW_v := 1\ kgf$ $\quad FW_d := 1\ kgf$ $\quad Rd := 1\ kgf$ $\quad FW_p := 1\ kgf$

Resolving forces and moments

Constraints Values

$$Fd \cdot WB = FW_v \cdot c + FW_d \cdot d + W_v \cdot a + W_d \cdot b$$ Resolving Moments about the rear wheel

$$Fd + Rd = W_v + W_d$$ Resolving Vertical Loads

$$\mu \cdot Fd + \mu \cdot Rd = FW_v + FW_d$$ Resolving Horizontal Loads

$$FW_v = \frac{W_v}{W_d} \cdot FW_d$$

Solver

$$R_{es} := \text{Find}(Fd, Rd, FW_v, FW_d) = \begin{bmatrix} 131.598 \\ 43.402 \\ 70 \\ 52.5 \end{bmatrix} kgf$$

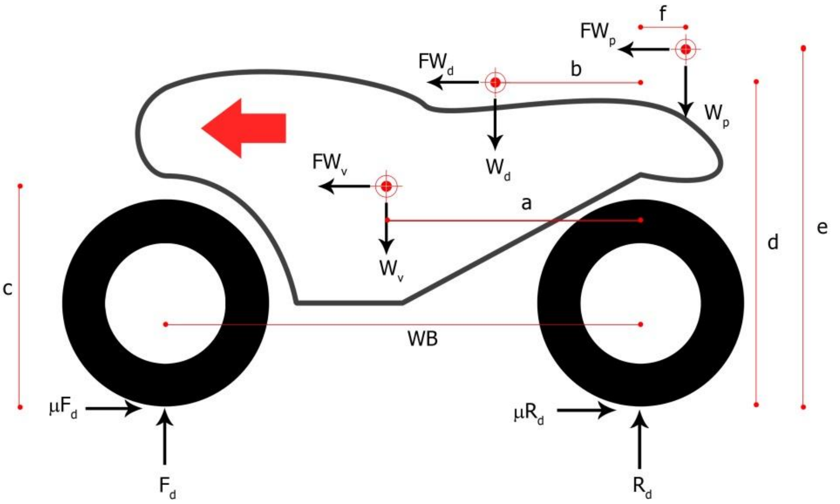
$R_{es_0} = 131.598\ kgf$ $\quad R_{es_1} = 43.402\ kgf$ $\quad R_{es_2} = 70\ kgf$ $\quad R_{es_3} = 52.5\ kgf$

$$Ratio_{fr2bk} := \frac{R_{es_0}}{R_{es_1}} \cdot 100 = 303.211$$

Fig 2: Weight transfer analysis of the motorcycle (driver) during coefficient of friction 0.7

The analysis indicates that a rear braking force of 43 kg or above will lock the rear wheel and result in lateral slip. In this scenario the rear brake should be applied for a short period of time and then gradually released. The front brake will be the major contributor for braking with higher brake force available to be applied.

In this condition majority of the weight is transferred to the front of the motorcycle during braking. This also causes the centre of gravity to shift to the front. Therefore the front brakes becomes of higher importance for faster and effective braking. But continued aggressive application of the front brake force may cause the front wheel to lock up result in directional instability and loss of balance which may lead to a crash.



Schematic 2

Condition 3 :

Weight Transfer Analysis for Driver + Passenger Condition

$W_v := 100\ kgf \quad W_d := 75\ kgf \quad W_p := 75\ kgf \quad WB := 1220\ mm \quad a := 488\ mm$

$b := 300\ mm \quad c := 600\ mm \quad d := 900\ mm \quad \mu := 0.1 \quad e := 1000\ mm \quad f := -100\ mm$

$Fd := 1\ kgf \quad FW_v := 1\ kgf \quad FW_d := 1\ kgf \quad Rd := 1\ kgf \quad FW_p := 1\ kgf$

Constraints/values

$$Fd \cdot WB = FW_v \cdot c + FW_d \cdot d + FW_p \cdot e + W_v \cdot a + W_d \cdot b + W_p \cdot f$$
$$\mu \cdot Fd + \mu \cdot Rd = FW_v + FW_d + FW_p$$
$$Fd + Rd = W_v + W_d + W_p$$
$$FW_v = \frac{W_v}{W_d} \cdot FW_d$$
$$FW_v = \frac{W_v}{W_p} \cdot FW_p$$

Solver

$$R_{es} := \text{Find}(Fd, Rd, FW_v, FW_d, FW_p) = \begin{bmatrix} 68.893 \\ 181.107 \\ 10 \\ 7.5 \\ 7.5 \end{bmatrix} kgf$$

$R_{es_0} = 68.893\ kgf \quad R_{es_1} = 181.107\ kgf \quad R_{es_2} = 10\ kgf \quad R_{es_3} = 7.5\ kgf$

$R_{es_4} = 7.5\ kgf$

$$Ratio_{fr2bk} := \frac{R_{es_0}}{R_{es_1}} \cdot 100 = 38.04$$

Fig 3: Weight transfer analysis of the motorcycle (driver+ passenger) with friction coefficient 0.1

This condition is similar to the 1st one where there is no significant change in weight transfer because of the low coefficient. The weight at the front wheel is identical to Condition 1 and the weight on the rear wheel has increased significantly due to presence of the passenger. Hence the front brake must be used sparingly with the majority of braking force being provided by the rear brake.

Condition 4 :

Weight Transfer Analysis for Driver + Passenger Condition

$W_v := 100\ kgf \quad W_d := 75\ kgf \quad W_p := 75\ kgf \quad WB := 1220\ mm \quad a := 488\ mm$

$b := 300\ mm \quad c := 600\ mm \quad d := 900\ mm \quad \mu := 0.7 \quad e := 1000\ mm \quad f := -100\ mm$

$Fd := 1\ kgf \quad FW_v := 1\ kgf \quad FW_d := 1\ kgf \quad Rd := 1\ kgf \quad FW_p := 1\ kgf$

$$Fd \cdot WB = FW_v \cdot c + FW_d \cdot d + FW_p \cdot e + W_v \cdot a + W_d \cdot b + W_p \cdot f$$

$$\mu \cdot Fd + \mu \cdot Rd = FW_v + FW_d + FW_p$$

$$Fd + Rd = W_v + W_d + W_p$$

$$FW_v = \frac{W_v}{W_d} \cdot FW_d$$

$$FW_v = \frac{W_v}{W_p} \cdot FW_p$$

$$R_{es} := \text{Find}(Fd, Rd, FW_v, FW_d, FW_p) = \begin{bmatrix} 168.484 \\ 81.516 \\ 70 \\ 52.5 \\ 52.5 \end{bmatrix} kgf$$

$R_{es_0} = 168.484\ kgf \quad R_{es_1} = 81.516\ kgf \quad R_{es_2} = 70\ kgf \quad R_{es_3} = 52.5\ kgf$

$R_{es_4} = 52.5\ kgf$

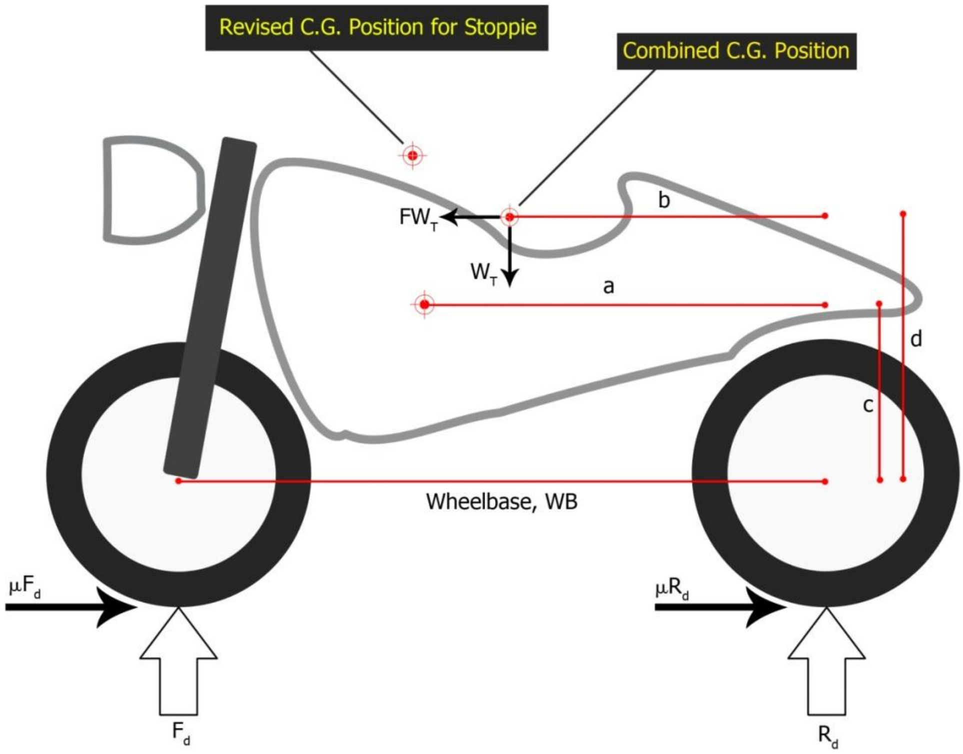
$$Ratio_{fr2bk} := \frac{R_{es_0}}{R_{es_1}} \cdot 100 = 206.687$$

Fig 4: Weight transfer anaylsis of the motorcycle (driver+passenger) with high coefficient of frcition of 0.7

This condition is similar to condition 2 but a lesser percentage of weight has been shifted to the front of the motorcycle due to the presence of the passenger. This situation warrants the use of both the front and rear brakes to a moderate extent with the majority brake force still being provided by the front brake.

Myths about the motorcycle front brake

There are multitudes of myths surrounding motorcycle braking and of the most prominent is the myth that aggressive use of the front brake can lead to the rear of the motorcycle tipping over called a stoppie. Stoppie's are motorcycle stunts that are incredibly hard to perform and require a lot of skill. They involve balancing the motorcycle on the front wheel while the rear wheel is airborne. We now look at the mathematics behind stoppies to discern their potential lethality.



Schematic 3

The above schematic illustrates a typical motorcycle. The centre of gravity (C.G.) of the motorcycle is located at co-ordinates (a, c) and the location of the C.G. with respect to both the Motorcycle and the Rider is at (b, d). W_T is the combined weight of the motorcycle and rider acting at (b, d) downwards. F_d and R_d are the reactions at the front and rear wheels due to the weights acting on them. μ is the coefficient of friction between the tyre and the road. WB is the wheelbase of the motorcycle.

The mathematical analysis shown below takes into account the shift of weight from the rear to the front as the bike decelerates. The premise for this is that for the rear wheel to lift off the ground the reaction at the rear R_d i.e. the weight on the rear wheel should be 0. To simulate a stoppie, R_d is driven to 0. This is done by manipulating the values of the combined C.G. This is deemed correct because most riders lean forward and raise their centre of mass to allow for more weight transfer to the front.

Stoppie Calculations

Weight Transfer Analysis for Driver only condition

$W_v := 112.8\ kgf$ $W_T := 200\ kgf$ $WB := 1232\ mm$ $a := 555\ mm$ $c := 487\ mm$

$b := 496\ mm$ $d := 754\ mm$ $\mu := 0.7$ $F_d := 1\ kgf$ $FW_T := 1\ kgf$ $R_d := 1\ kgf$

Resolving forces and moments

$R_d \cdot WB + FW_T \cdot d = W_T \cdot (WB - b)$ Resolving Moments about the front wheel

$F_d + R_d = W_T$ Resolving Vertical Loads

$\mu \cdot F_d + \mu \cdot R_d = FW_T$ Resolving Horizontal Loads

Solver

$$R_{es} := \mathrm{Find}(F_d, R_d, FW_T) = \begin{bmatrix} 166.201 \\ 33.799 \\ 140 \end{bmatrix} kgf$$

$R_{es_0} = 166.201\ kgf$ $\mu \cdot R_{es_0} = 116.341\ kgf$

Fig 5

The analysis shows us that at a friction of μ = 0.7, the weight on the rear wheel is about 34 kgf. Also the weight on the front wheel multiplied by μ gives us the braking force at the front. We now drive the weight on the rear wheel to 0 kgf. This can only be done by shifting the C.G. of the system forwards and upwards.

Stoppie Calculations

Weight Transfer Analysis for Driver only condition

$W_v := 112.8\ kgf$ $W_T := 200\ kgf$ $WB := 1232\ mm$ $a := 555\ mm$ $c := 487\ mm$

$b := 602.5\ mm$ $d := 899\ mm$ $\mu := 0.7$ $F_d := 1\ kgf$ $FW_T := 1\ kgf$ $R_d := 1\ kgf$

Resolving forces and moments

$R_d \cdot WB + FW_T \cdot d = W_T \cdot (WB - b)$ Resolving Moments about the front wheel

$F_d + R_d = W_T$ Resolving Vertical Loads

$\mu \cdot F_d + \mu \cdot R_d = FW_T$ Resolving Horizontal Loads

Solver

$$R_{es} := \mathrm{Find}(F_d, R_d, FW_T) = \begin{bmatrix} 199.968 \\ 0.032 \\ 140 \end{bmatrix} kgf$$

$R_{es_0} = 199.968\ kgf$ $\mu \cdot R_{es_0} = 139.977\ kgf$

Figure 6

We can see that the weight on the rear wheel is approximately 0. The braking force at the front has understandably increased because of the shift of weight from the rear to the front. Thus we can conclude that aggressive usage of the front brake will not lead to a stoppie situation unless the C.G. of the system is shifted forward by a considerable amount.

Conclusion

i. With high coefficient of friction

When the coefficient of friction between tyre and road is high (0.7-0.8), we can observe in situations of driver only and, driver and pillion that the reaction force at the front is very high. This means that majority of the weight is present at the front and hence the most effective braking will be provided by the front brake.

We have also learnt that aggressive usage of the front brake will not lead to a potentially fatal stoppie situation without shift in the C.G. The major drawback of aggressive usage of the front brake is the wheel lock up which will lead to loss of stability and control.

ii. With low coefficient of friction

Low coefficients of friction (0.1 – 0.2) are observed on road surfaces of sleet and ice. This means that the traction available is minimal and predicting motorcycle behaviour is almost impossible. The model shows us that due to lack of friction much of the weight is at the rear of the motorcycle. This makes the use of the rear brake more effective on such surfaces as shown in figures (1) and (3).

References

[1] http://en.wikipedia.org/wiki/Threshold_braking

[2] http://en.wikipedia.org/wiki/Cadence_braking

On optimal motorcycle braking

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