Variable Brake System Using Optimum Pedal Force

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Abstract: In this research work, a variable braking force is applied to a motor cycle rear wheel to control the maximum braking force which is developed between the tyre and the ground, for reducing the stopping distance of the motor cycle. In this system, the effective pedal force is varied by moving the position of the worm shaft along the vertical, based on the load on the motor cycle. Hence the maximum braking force developed is controlled based on load on the motor cycle. A typical motor cycle is selected to accommodate the variable braking force system. The center of gravity which is measured by adopting a suitable method is required to design the braking system of the motor cycle. An optimum brake disc radius is determined based on the pillion load and vehicle geometry of the typical Motor cycle, keeping rider weight and hydraulic brake line pressure constant.

Moreover, the effective pedal force is determined for various loads which are acting on the pillion of the motorcycle. The brake system that is present needs to be modified to implement the variable braking force system. A worm and wheel arrangement is introduced in order to implement this system. It is found suitable for automatically adjusting the pedal force based on the pillion load on the motor cycle. For automating the variable braking force system, a load cell which is fitted under the motor cycle pillion seat is used to measure the pillion load. Based on the pillion load, the microcontroller sends a signal to stepper motor to vary the position of the worm shaft in order to change pedal force when the motorcycle is in static condition.

An experimental work reveals that the stopping distance of the motor cycle gets reduced if the brake system is set to an optimum pedal force which is calculated for the motorcycle when it is in unladen and in loaded conditions. It is determined that optimum pedal force is 22 kg for a particular motor cycle with a rider of 50 kg alone but with no additional load on the Motorcycle. It is also determined that optimum pedal force is 33 kg for the same motorcycle geometry with a rider of 50 kg and a pillion load of 70 kg.

It is also revealed that the optimum braking forces are only a function of the particular vehicle geometry and weight data, i.e. horizontal and vertical Location of centre of gravity, wheel base, vehicle deceleration.

1. Introduction

Stopping safely is one of the most important functions of the braking system in a motor cycle. Many electronic control systems have been developed for improving the safety of vehicle driving. For example, the anti lock braking system (ABS) was developed for improving the vehicle’s steer ability and stability by preventing the wheel lock under critical circumstance such as slippery road condition during braking. So far various control strategies for the anti lock braking system (ABS) have been proposed by adopting proportional solenoid valve. However, it is generally known that the proportional solenoid valve may produce unwanted fluctuation of the braking pressure during the anti lock braking system (ABS) operation and the braking force distribution under variable load is hard using the above said device. In a practical environment, the contrivance is unwelcome due to its complex design. Hence it is desirable to introduce an alternative actuation mechanism to overcome these drawbacks. Failure of the brake system will almost invariably result in property damage, personal injury, or even death. Consequently, a great deal of consideration has been given to improving the brake system. The problem of skidding reveals the on overwhelming weakness of all motor vehicle braking systems, namely, their strong dependence on the coefficient of adhesion between the tyre and the road and normal load on the wheel on which brake is applied. If for any reason the 2 tyre momentarily loses its adhesion to the road while the brakes are applied, the friction of the brakes against the drums or rotors locks the wheel solidly and the tire begins skidding across the road. In this condition, the braking force of that wheel depends on the sliding friction between the tyre and the road, which is much less than the static friction and normal load on the wheel. Under wet or icy conditions, the sliding friction is reduced even further, resulting in significantly longer stopping distances. Inspection of the axle loads reveals that
the rear axle load is reduced more than that associated with front axle (increased) at higher decelerations due to load transfer effect and the initial axle loads. Braking force is produced due to the frictional force between the tyre and the road surface and must be concentrated onto the front wheel for driving stability. However, in many motor cycles the braking force needs to be appropriately distributed between the front and the rear wheels if the load in the rear wheels is added due to extra load at pillion of the motor cycle. By doing this, the vehicle stability can be significantly increased.

1. EXISTING SYSTEM:
The existing system in the market to prevent the wheel lock of vehicles:
- ABS
- EBD

Anti -Lock Braking System (ABS):
An antilock braking system (ABS) is a safety system on motor vehicles which prevents the wheels from locking while braking. The Antilock Braking System is designed to maintain vehicle control, directional stability, and optimum deceleration under severe braking conditions on most road surfaces. It operates effectively by monitoring the rotational speed of each wheel and controlling the brake line pressure to each wheel during braking. This prevents the wheels from locking up. In general, wheel locks at 100% wheel slip. It is normal to have 15-20% wheel slip which is indicated in Figure 2.5 for effective traction (maximum coefficient of friction value). ABS does no work on snow and loose gravel because there is no peak. Encoders detect excessive wheel slippage and not lock-up. The sensors - one at each wheel, send a variable voltage signal to the control unit, which monitors these signals, compares them to its program information, and determines whether a wheel is about to lock up. When a wheel is about to lock up, the control unit sends the hydraulic unit to reduce hydraulic pressure at that wheel’s brake caliper that helps preserve vehicle stability and steering control as in emergency braking condition. Pressure modulation is handled by electrically-operated solenoid valves.

Electronic Brake Force Distribution (EBD):
An application of anti- lock braking system (ABS) technology, EBD controls rear-wheel braking based on detection of loss of traction at the front and the rear wheels when the brakes are applied. By the controlling distribution of braking force to the front and the rear wheels according to the passenger and payload, EBD minimizes differences in braking performance whether the vehicle load is light or heavy as LTE is greater with laden vehicle. Brake force distribution is now performed under electrical control of the skid control electronic control unit (ECU). The skid control ECU precisely controls the braking force in accordance with the vehicle’s driving conditions. Generally, when the brakes are applied the load transfer effect reduces the load on the rear wheels. When the skid control ECU senses this condition (based on speed sensor output), it signals the brake actuator to regulate rear brake force so that the vehicle will remain under control during the stop. The amount of applied force to the rear wheels varies based on the amount of deceleration. The amount of brake force that is applied to the rear wheels also varies based on whether or not the vehicle is carrying a load. When the brakes are applied while the vehicle is cornering, the load applied to the inner wheels decreases while the load applied to the outer wheel increases. When the skid control ECU senses this condition (based on speed sensor output), it signals the brake actuator to regulate brake force between the left and right wheels to prevent skid. Figure 2.8 shows the vehicle response due to EBD. It proportions brake force between left and right because if any difference in the magnitude of the braking force between the left and the right wheels may lead the vehicle being subjected to yawing moment which affects the stability of the vehicle.
3. OBJECTIVE OF OUR PROJECT:

- The main downside of ABS is it activates only when the wheel tends to lock but our system prevents premature lock.
- To improve the safety of the two-wheeler.
- To reduce the stopping distance of the two-wheeler.
- To improve stability of the two-wheeler by preventing rear wheel skidding.
- To achieve the above task at smaller cost.
- To remove the dependability of the whole braking force on the engine ECU.

4. System Setup:

- Load cell
- Micro controller
- Stepper motor

The main function of the entire system is to automate the braking force control based on the load on the two-wheeler. In this work, a simple system is proposed to automate this work.

Load cell:
The basic function of a load cell is to measure the pillion load and send appropriate signals to the controller unit based on various pillion loads on the two-wheeler. The load cell is exactly placed rigidly under the load position of the motorcycle seat.

Micro-controller:
Micro-controller unit is used to control the stepper motor rotation for the various loads measured by the load cell. It is programmed in such a way that the stepper motor gives precise rotation for the various signals of the load cell. The worm shaft moves 1.5mm for a single rotation of the stepper motor shaft. Hence the stepper motor rotation is calculated for the various pillion loads.

Logic Sequence generates programmed logic sequence required for the operation of a stepper motor. It is a finite sequential logic circuit which generates the particular logic sequence. The logic sequence is treated as a truth table, and is implemented with the help of flip-flops and logic gates. The signals output by the logic sequence generate low-level signals which are too weak to energize stepper motor windings. Power drivers are power switch circuits which ensure a fast rise of current through the phase windings which are to be turned on at a particular step in the logic sequence. Consequently, switching power amplifiers have to be used to raise the voltage, current, and power levels of the logic sequence sufficiently high to drive the rated currents through stepper motor circuits. Current suppression circuits needed fast decay of current through the winding when it is turned off.

Function of logic sequence:
The stepper driver logic consists of buffer, opto-coupler, pre-driver and driver.

- A buffer amplifier (sometimes simply called a buffer) is one that provides electrical impedance transformation from one circuit to another. A current buffer amplifier is used to transfer a current from a first circuit, having a low output impedance level, to a second circuit with a high input impedance.
level. The interposed buffer amplifier prevents the second circuit from loading the first circuit unacceptably and interfering with its desired operation. It is the first stage of stepper driver logic unit.

- It consists of opto-emitter and Phototransistor. An opto coupler is essential to prevent the computer from hazardous conditions like voltage transients, back electro motive force (EMF), and high voltage spikes. Normally when direct current (DC) is passed to a coil it will get electro magnetized. If the DC source is withdrawn from the coil it will not get demagnetized immediately. If it is not demagnetized, back EMF is produced which can create kick back current (Current flow due to the back EMF) to the subsequent devices or associated circuitries. To avoid these problems, a device is required which can isolate electrically and couple by other means.

- CL 100 power transistor is used as pre-driver. It is used to boost the current. It is an NPN transistor. When 24Volts supply is given from the opto coupler as an input to the base it starts conducting the output.

- TIP 122 power transistor is used. A 24Volt supply is given to it through 47ohms resistor to its base. The logic 0 output from CL 100 is given to the base of TIP122. It is an NPN transistor and so output is low. When the TIP 122 transistor has high input signal in its base, collector to emitter the resistance is relatively low. So it produces a low output signal. When the output signal is low the coil is energized. Now the motor can move forward or reverse as per the pattern given in the software routine. A reverse biased diode is connected in parallel with the coil. When the coil is demagnetizing it produces high back EMF which can destroy TIP122 which is in the cut off state. This can be avoided by this diode.

Stepper motor:
Stepper motors uses a magnetic field to rotate a rotor. Stepping can be done in full step, half step or other fractional step increments. Voltage is applied to the poles around the rotor. The voltage changes the polarity of each pole, and the resulting magnetic interaction between the poles and the rotor causes the rotor to move. Stepper motors provide precise positioning and ease of use, especially in low acceleration or static load applications. Important performance specifications to consider when searching for stepper motors include shaft speed, terminal voltage, current per phase, continuous output power, and static or holding torque. Shaft speed is the no load rotational speed of output shaft at rated terminal voltage. The terminal voltage is the design DC motor voltage. The current per phase is the maximum rated current or winding for a stepper motor. The continuous output power is the mechanical power provided by the motor output. Static or holding torque is the maximum torque a motor can develop to hold its rotor in a stationary position. Motor types for stepper motors can be permanent magnet, variable reluctance, or hybrid. Permanent magnet (PM) motors use a permanent magnet on the rotor. Step angles range from 1.5 to 30 degrees. Permanent magnet motors are the most common and versatile stepper motors. This includes both unipolar (bifilar) and bipolar types. both unipolar (bifilar) and bipolar types. Variable reluctance (VR) motors have a free-moving rotor; no residual torque is produced due to the lack of a permanent magnet. The rotor is composed of a soft iron metal. The rotor is also composed of its own very prominent poles, tending to stick out more than a rotor found on the PM version. The range of step angles is 7.5 to 30 degrees and a single power source is required (like a bifilar PM motor). This is the least expensive stepper motor. Hybrid motors consist of a heavily toothed PM rotor and toothed stators, plus prominent rotor poles like a VR rotor. They are capable of very fine step angles range 0.5 to 15 degrees and have a high-speed capability (less chance of a stall). There is a higher available torque than in PM or VR stepper motors.

Design:
Working:
As the rider and the pillion sits on the bike the load cell will determine their weight and sends signal to the electronic micro controller. The microcontroller will process the signal and determines the direction and amount of current to be sent to the stepper motor windings. Due to the electromagnetic induction, the current in stator windings causes the rotor to rotate. The rotor rotates a wheel which slides on the worm shaft.

If the current in the windings is in clockwise direction the rotor also rotates in clockwise direction. Thus the wheel moves on the worm shaft and length of shaft is increased. Thus pedal force is reduced. If the current in the windings is in anti-clockwise direction the rotor also rotates in anti-clockwise direction. Thus the wheel moves on the worm shaft and length of shaft is decreased. Thus pedal force is increased.

CALCULATION:

\[ W \] - Total weight of vehicle and riders

\[ L \] - Wheel base

\[ L_f \] - Distance of CG from front axle

\[ L_r \] - Distance of CG from rear axle

\[ H \] - Height of CG from ground

\[ a \] - Deceleration

\[ \mu \] - Co-efficient of friction between ground and tyre

\[ R \] - Radius of tyre

\[ r \] - Radius of disc

\[ \mu_1 \] - Co-efficient of friction between disc and pads

\[ r_1 \] - radius of piston

\[ r_2 \] - radius of master cylinder bore

\[ m \] - Mechanical advantage (or) pedal ratio

\[ L = 1.33 \text{ m} \]
\[ a = 0.45 \text{ m/s}^2 \]
\[ \mu = 0.45 \]
\[ R = 0.3159 \text{ m} \]
\[ R = 0.110 \text{ m} \]
\[ \mu_1 = 0.35 \]
\[ r_1 = 0.0172 \text{ m} \]
\[ r_2 = 0.01 \text{ m} \]

\[ m = 5.6 \]

IN CASE OF RIDER ALONE:

At static condition:

At front:
\[ R_F = w \times L_r / L \]
\[ = 191 \times 0.4943 / 1.330 \]
\[ = 71 \text{ kg} \]

At rear:
\[ R_R = w \times L_f / L \]
\[ = 191 \times 0.835 / 1.330 \]
\[ = 120 \text{ Kg} \]

At dynamic condition:

At front:
\[ R_{F, \text{ dyn}} = (w \times L_r + w \times a \times H) / L \]
\[ = (191 \times 0.4943 + 191 \times 0.45 \times 0.6221) / 1.33 \]
\[ = 119.44 \text{ kg} \]

At rear:
\[ R_{R, \text{ dyn}} = (w \times L_f - w \times a \times H) / L \]
\[ = (191 \times 0.835 - 191 \times 0.45 \times 0.6221) / 1.33 \]
\[ = 79.71 \text{ kg} \]

Frictional force:

At front:
\[ B_F = R_F \times g \times \mu \]
\[ = 119.44 \times 9.81 \times 0.45 \]
\[ = 527.26 \text{ N} \]

At rear:
\[ B_r = R_R \times g \times \mu \]
\[ = 79.71 \times 9.81 \times 0.45 \]
\[ = 351.87 \text{ N} \]

Condition:
Frictional force is equal to braking force

Braking torque:

At rear:
\[ B_T = B_r \times R \]
\[ = 351.87 \times 0.3159 \]
\[ = 111.15 \text{ Nm} \]

Force on the disc:
\[ F_D = B_T / r \]
\[ = 111.15 / 0.110 \]
\[ = 1010.53 \text{ N} \]

Pressure on the brake line:
\[ \text{Pressure} = F_D / (\pi \times r^2) \]
\[ = 2245.63 / (\pi \times 0.00392025) \]
\[ = 2.4 \text{ N/mm}^2 \]

Force on master cylinder:
\[ F_c = P_c \times \text{area of cylinder} \]
\[ = 2.4 \times (\pi \times 0.01) \]
\[ = 760 \text{ N} \]

Pedal force:
\[ P_F = F_c / m \]
\[ = 760 / 5.6 \]
\[ = 135.71 \text{ N or 13.83 kg} \]

IN CASE OF BOTH RIDER AND PILLION:

At static condition:
At front:
\[ R_F = wL_r/L = 261 \times 0.3796/1.330 \]
= 74.5 kg

At rear:
\[ R_R = wL_f/L = 261 \times 0.9503/1.330 \]
= 186.5 Kg

**At dynamic condition:**

At front:
\[ R_{F,\text{dyn}} = (wL_r + w\alpha H)/L = (261 \times 0.3796 + 261 \times 0.45 \times 0.6621)/1.33 \]
= 129.44 kg

At rear:
\[ R_{R,\text{dyn}} = (wL_f - w\alpha H)/L = (261 \times 0.9503 - 261 \times 0.45 \times 0.6621)/1.33 \]
= 131.54 kg

**Frictional force:**

At front:
\[ B_f = R_F \times g \times \mu = 129.44 \times 9.81 \times 0.45 \]
= 571.41 N

At rear:
\[ B_r = R_R \times g \times \mu = 131.54 \times 9.81 \times 0.45 \]
= 580.72 N

Condition:
Frictional force is equal to braking force

Braking torque:

At front:
\[ B_{T_f} = B_f \times R = 571.41 \times 0.3159 \]
= 180.5 Nm

At rear:
\[ B_{T_r} = B_r \times R = 580.72 \times 0.3159 \]
= 183.44 Nm

Force on the disc:
\[ F_D = B_{T_r}/r = 183.44/0.110 \]
= 1667.72 N

Force on the piston:
\[ F_p = F_D/\mu_1 = 1667.72/0.45 \]
= 3706.04 N

Pressure on the brake line:
\[ \text{Pressure} = \text{Fd/(area of piston)} = 3706.04/(\pi \times 0.0172^2 \times 0.0172) \]
= 4 N/mm²

Force on master cylinder:
\[ F_c = \text{pressure} \times \text{area of cylinder} = 4 \times (\pi \times 0.01 \times 0.01) \]
= 760 N

Pedal force:
\[ P_p = F_c / m = 1256 / 5.6 \]
= 224.28 N or 22.86 kg

Considering vehicle and rider:

Considering vehicle, rider and pillion:
Reference: