Robotic arm for automatic brake testing and control

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Abstract. Brake testing is an important verification test before putting an automobile up for sale. Unfortunately, brake judders which act as hindrance for getting true brake performance results can’t be rectified. Therefore, we have to account for brake judders in our brake test results. Our project is aimed at reducing the effects of brake judder by examining the Disc Thickness Variation dynamically with the heat produced because of friction between brake pads and disc as the brake is applied. This thorough examination is done with the help of a capacitive sensor which continuously feeds disc thickness variation data to our robotic arm which is programmed to change the position of the brake pedal in order to keep a uniform brake force on the disc.

Keywords: Brake Judder, Brake Performance, Disc Thickness Variation, Uniform Brake Force, Capacitive sensor.

1. Introduction

The world of automobiles is ever-expanding. This sector is blooming every day to reduce accidents, accounting for a comfortable journey. Brakes play an essential role in reducing accidents and controlling the speed of a vehicle. There exist different braking systems; Drum brakes and Disc Brakes. The Disc Brakes are the most used ones because the operational time is significantly less [1]. Irrespective of the braking system, every vehicle is subject to several tests before it is eligible for being sold to customers. Brake testing is an important test performed to test and verify the performance of brakes. Various brake testing standards are used worldwide to assure vehicle and pedestrian safety. Performance Brake Testing is performed to get brake characteristics of new bikes. Brakes are needed for travelling on bikes and for safety; hence, knowing the brake characteristics of a motorcycle is very important.

The brake characteristics are nonlinear for most vehicles, which makes the control strategy more challenging. The braking force versus pedal position and the pedal force to pedal travel is typically nonlinear with pedal travel [2]. The combination of these two profiles would result in a system, which is inherently nonlinear in behaviour. This non-linearity in the system characteristics should be accounted for in the development of the control strategy of an automated solution. Conventionally, brake testing is performed by placing the wheels on a pair of rollers and by manual operation, the wheels are rotated on the pair of rollers, and the brakes are applied. By performing the brake testing in
the method, as mentioned earlier, various parameters such as stopping time and stopping distance are measured [3]. Previous works have analysed various brake testing procedures and compared different testing standards that are used for automotive braking [4]. Separate studies have been performed for the performance tests of the drum as well as disc brakes [3].

One of the shortcomings that brake testing faces are brake judders. Brake judder is braking induced, forced vibration occurring in different types of vehicles [5]. Judder is a forced vibration mostly due to geometrical deviations including spatial variations of the coefficient of friction of the brake disc. A judder causes uneven vibrations in a brake pedal, causing issues in a brake test. Judders can be caused due to several effects, mainly disc thickness variation and temperature [5]. Previous works have analysed brake judder data [6,7]. It is difficult to obtain the typical brake characteristics because of the judders that take place due to: Disc Thickness Variation, Severe disc overheating and distortion, Misalignment of the disc and the axis of rotation, Rust or corrosion of the disc, Improper shape and structure of the braking pads itself [5]. Due to the problems mentioned above, brake testing is not done precisely in the laboratory. To overcome these errors, it is necessary to apply a constant braking force irrespective of the judders that are caused. Previous work has found that judder frequency is directly proportional to the revolution speed of the wheel and therefore, also to the velocity of the vehicle. The driver experiences judder as vibrations in the steering wheel, brake pedal and floor. Brake judder primarily affects the comfort but could, when confronting an inexperienced driver for the first time, lead to faulty reactions and reduced driving safety [5]. There exists a very intricate relation between DTV and temperature [7], making the problem further complicated as it involves braking line too. Instead of trying to get into all the details of each part in the system, we have decided to focus on the visible outputs of the system.

Our solution achieves accurate brake test results with the help of a robotic arm. The arm consists of two grippers, a primary and secondary one. The primary gripper is used to grip the pedal, and the secondary gripper is attached to a linear actuator that actuates according to the force variations and the thickness variations which are collected from the force and capacitance sensors. The actuation made by the secondary gripper helps in maintaining a constant force which is the focus of the research.

2. Technical design overview

2.1. The general setup
The robotic arm consists of a primary and a secondary gripper. The primary gripper actuates the pedal to the position required in various standard braking tests. The secondary gripper actuates the pedal to the position required to maintain a constant force. The primary gripper consists of force sensors attached to the gripping part's interior to measure and calculate the displacement corresponding to the varying force.

2.2. Electrical Automation
A PWM signal controls the linear actuator. This PWM signal has a 70% duty cycle to ensure that the actuator system does not overheat. Non-contact displacement sensors detect when the actuator has moved to the desired position and reverse the linear actuator's direction using relay switches. The robotic arm produces a telescopic effect to grip pedals of the various existing pulsar models effectively.

2.3. Data acquisition and feedback
Capacitive sensors measure the disc thickness variation. Three capacitive sensors are placed radially along the disc's portion that comes in contact with the braking pad. With the help of the varying
capacitance, we find the DTV and feed it to the primary system. Since the data sent to the actuator is of the previous rotations, a slip in the brake pad does not affect the system.

3. Description of components and setup

3.1. Telescopic cylinder
The Telescopic Cylinder is the component that houses the telescopic mechanism. This mechanism helps the Robotic Arm to grip pedals of varying lengths. It has a motor at the other end that is responsible for producing the required torque to make the arm apply the desired load. The telescopic cylinder is attached to a Cartesian mechanism as shown in Figure 1, which helps in the robotic arm's positioning so that we can precisely grip the pedal.

3.2. Grippers
There is a set of primary grippers and secondary grippers. The primary set grips the pedal, and the second for small actuation of the gripper. Both the sets have force sensors attached to its interior part that facilitate the detection of force variations due to judders.

![Image](Figure 1. The assembly of components)

3.3. Cartesian Mechanism
The Cartesian Mechanism facilitates the robotic arm's motion in a plane parallel to the typical motion of the pedal. This mechanism ensures that the robotic arm's pivot point and the pedal are aligned perfectly along their axis.

3.4. Force sensors
The force sensors measure the force variation that occurs in the brake pedal due to the brake judders. We get the pedal's displacement from its ideal position during standard brake testing.

3.5. Capacitive sensor
The Capacitive Sensor detects the change in the DTV, Disc Thickness Variation. As the disc rotates, the distance between the grounded plate and the rotating disc varies. This variation causes a variation in the measured capacitance. As a result, we can feed the data acquired to the actuating system to
ensure proper and precise actuation when there is slipping during the brakes' application. The placing of the capacitive sensors is shown in Figure 2.

3.6. Linear actuator
The Linear Actuator actuates the secondary gripper if the force variations are detected. The Linear Actuator moves precisely and fast, adjusting the pedal position dynamically to always apply a constant force on the brake pedal. It does not actuate if there are no force variations present; that is when brake judders do not occur.

4. Working of the system

4.1. Overall system workflow process
The working of the overall system is described in the flowchart in Figure 3. The previous capacitance data is sent to the actuator for the subsequent run of the wheel, to avoid error while control.

4.2. Component level working

4.2.1. Capacitive sensor. Calculates the disc thickness variation (DTV) through the change in capacitance for Nth rotation after applying brakes with the help of the fundamental formula: \( C = \frac{A\varepsilon}{D} \), where \( C \) is the capacitance, \( A \) is the area of cross section of the capacitor, \( \varepsilon \) is the dielectric constant, \( D \) is the distance between the plates, which varies with disc thickness. The brake disc and the end of the sensor make the plates of the capacitor. The DTV would bring in a change in capacitance as the distance changes. The corresponding graphs of DTV in MATLAB is plotted.

4.2.2. Actuation of robotic arm. The Robotic Arm applies the required load on the pedal through the rotation of the AC servo motor. Arc length moved by the arm with respect to the angle rotated is recorded. The pedal force with respect to pedal displacement is recorded.

4.2.3. Force sensor. Calculates the force variations of the corresponding pedal pulsations.
4.2.4. **Linear actuator.** The microcontroller transmits the processed DTV data to the secondary actuator using a delay function of Arduino. A variation in the previous force value causes the secondary actuator to actuate. This system ensures that the actuation occurs at a precise location with minimal error. A PWM signal of a 70% duty cycle is supplied to the actuator to reduce the motor's heating in the actuator. The IR module is fed with the displacement values of the Nth rotation. The Non-Contact displacement sensor senses when the actuator reaches the original position then reverses the direction using a relay.

![Figure 3. The schematic flow chart of the robotic gripper controlled using the microcontroller](image-url)
5. Simulation and results
The simulation was performed in Solidworks Motion Analysis Package. The following graphs were obtained in Solidworks Motion Analysis. Figure 4 shows the force variations that occur on a brake pedal due to brake judder, which has been given as the input to the system. Figure 4 can also be interpreted as the range of the pedal pulsations from its mean position. A force sensor placed at the gripper's interior records these values in the Nth revolution.

The values shown in Figure 5 are fed to the linear actuator, which thereby actuates the secondary gripper in the subsequent revolution. The actuator then applies a constant or programmable force to the pedal, as shown in Figure 6 where the sensor measures a nearly constant force with a minimal range of error.

Figure 4. Plot of force versus time measured by the force sensor caused by a judder
Figure 5. A plot of the pedal displacement versus time caused by a judder

Figure 6. The force on the pedal versus time after control of actuator

6. Conclusion
A Robotic Arm design is successfully made which applies constant and programmable force for Performance Testing of Brake precisely even if brake judder happens. The more challenging control strategy has been accounted for by most vehicles whose typical brake characteristics are nonlinear in nature.

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Appendix
The following Figure 7 gives the DTV versus the angle of the brake [8]. We find a minimal difference in micro-meter between the two runs. Hence, a feedback for a subsequent data is found to have minimal error.

Figure 7. Graph of DTV versus Angle of the break disc

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