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Experimental Investigation of Water Spray and Inclination Angle Influence on Wedge Disc Braking Force

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ABSTRACT:

In this research, a new adaptive wedge disc brake mechanism is designed and constructed in order to investigate the behaviour of the braking force using brake dynamometer. The effect of water spray on the braking force is tested under different wedge inclination angles. The experimental results showed that the braking force generally fluctuates as a function of braking time due to the friction coefficient. The water spray has a significant effect on reducing the braking force between pad/disc compared with dry conditions. Reduction in wedge inclination angle increases the self-amplification action leading to an increase of the braking force.

KEYWORDS:

Adaptive wedge disc brake; Water Spray; Brake force; Wedge inclination angle; Brake dynamometer

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1. Introduction

Brake performance is the most significant topic of ongoing research despite much progress being made especially in the last decade. The vehicle brakes are classified into drum and disc brakes. Drum brakes are cheap, simple, have high brake effectiveness, and more sensitive to the brake fade. Disc brakes are less sensitive to friction coefficient variation, but they are expensive and have lower effectiveness when compared with the drum brake. The main advantage of the disc brakes is their high ability to dissipate the generated heat due to friction. Disc brake is neither self-amplified nor self-debilitated [1]. There were many efforts to extend the conventional disc brake with self-amplification. The self-amplification action can be acquired by using a wedge inclination angle. The models of wedge disc brakes are classified in accordance with the applied force direction as normal or radial [2-6]. There are many experimental studies for improving the performance of the brake systems and the braking process behaviour.

Experimental methods still play significant role for a number of reasons. Firstly, it offers more accurate analysis tools than numerical or theoretical methods. Secondly, diagnosis of the cause of brake problems can often be found by experimental tests. Finally, verification of simulation models can only be achieved through experimental means or comparison with literature. Experimental approaches using brake dynamometers have been widely used [7-10]. There are two designs for the brake dynamometer. The first design is an inertia-type brake dynamometer that has an attached flywheel [11-13]. The second design is a drag-type brake dynamometer that gives the ability to test brake performance at a constant speed [14-18].

Parameters such as normal force temperature, humidity and speed significantly affect the quality of brake systems. The effects of water films and sliding speed on the frictional behaviour of conventional disc brake were investigated by Blau and McLaughlin [19]. Their study investigated the frictional behaviour of commercial truck brake pad materials sliding on gray cast iron brake discs in the presence of water films. They concluded that the effects of water films on reducing friction were mitigated if the contact pressure was increased. El-Tayeb and Liew [20] investigated the effect of water spray on friction and wear behaviour of non-commercial and commercial brake pad materials. Their results showed that a reduction in the friction coefficient to unacceptable levels for brake pads was evident but the values were still within the range of dry sliding friction and not in the range of hydrodynamic friction. The results also indicated that water spray resulted in wear of fresh surface of the brake pad due to continuous washing and removal of the debris from the interface.

This paper presents an experimental investigation of adaptive wedge disc brake using a laboratory drag-type brake dynamometer that is capable of measuring maximum braking force under different operational and environmental conditions. The effect different quantities of water spray on the wedge disc brake behaviour are assessed for several wedge inclination angles.

2. Experimental setup

The brake dynamometer is designed to provide the necessary disc rotation speed, applied pressure and wedge inclination angle. Fig. 1 shows the test rig with different sub-systems namely kinetic energy system, braking system and measurement instrumentation. The kinetic energy system consists of an AC motor of 18.56 kW and rotates the driving shaft at different speeds upto 1500 rpm. This is achieved with the help of a two manual gearboxes. A new wedge disc brake assembly is used to increase the braking force. The measurement facilities include tachometer (rotating speed), pressure gauge (applied pressure), thermocouple (temperature) and load cell (brake force). Four-channel data acquisition system is used to monitor the braking force. The acquired signals are transferred to a computer in digital form for storage and further analysis. Further details on the new wedge disc brake and the experimental work can be found in [9]. Fig. 2 shows the new adaptive wedge disc brake that has the ability to change the wedge angle at any operation conditions.

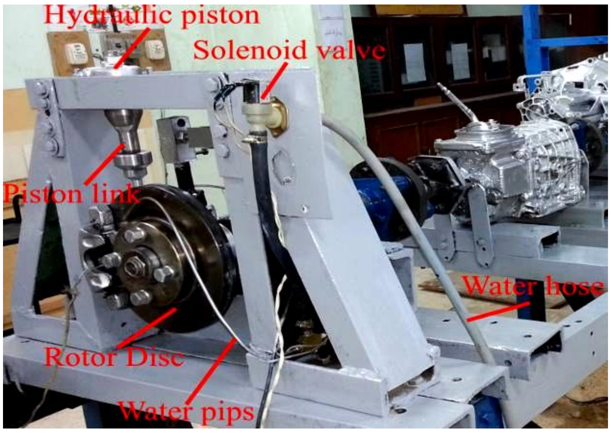

Fig. 1: Main components of wedge disc brake test rig

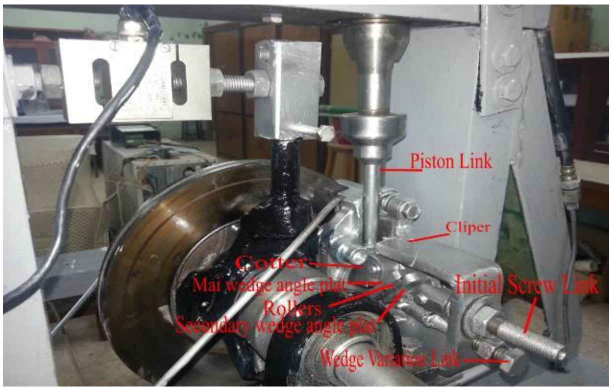

Fig. 2: Components of adaptive wedge disc brake

Fig. 3 shows the main components of the wedge assembly are - calliper, initial screw link, wedge angle variation link, main wedge angle plate, secondary wedge angle plate, rollers and cotter. The wedge assembly is fitted to the calliper. The initial screw link is made of steel and used to regulate the clearance between the pad and disc. It is connected to the main wedge plate to act as a pivot axis. The wedge angle variation link is made of steel and its screw link is used to change the wedge inclination angle. The main wedge angle plate is made of steel. It is connected to both the initial screw link and the wedge screw link to convert the displacement of the wedge screw link to wedge angle. The secondary wedge angle plate is connected to the cotter and contacted to the main wedge angle plate to shift the wedge angle to the cotter. Three rollers were placed between the main and secondary wedge plates to reduce the friction and ensure their easy movements. The cotter is connected to the secondary wedge angle plate through the cotter pin and contacted to the pad back plate in order to transfer the normal force to the brake pad according to wedge angle. The applied force affects the cotter through the piston link and hydraulic piston.

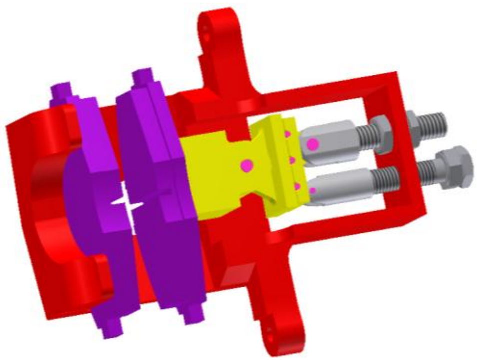

Fig. 3: CAD of adaptive wedge assembly close-up view

Investigation of water spray is carried out at different quantities of water. The time period for water spray is fixed during all tests. The water injection mechanism that is designed and constructed is shown in Fig. 4. It consists of water hose, water mechanical valve, and two nozzles. Water timer unit consists of solenoid valve, timer and two-port electric switch to control the injection time period, the starting and end time of injection. The mechanical water valve is connected to the water hose to control the quantity of water that affects the disc and the pads contact area. The solenoid valve is connected to the timer via the two-port switch and wiring to control the water injection time. The brake force behaviour is investigated at dry conditions and at 80, 160 and 240 mm^3 of water injection. The overall timing of test is 60 seconds and the spray injection began at the 30th second and ended at the 40th second [19].

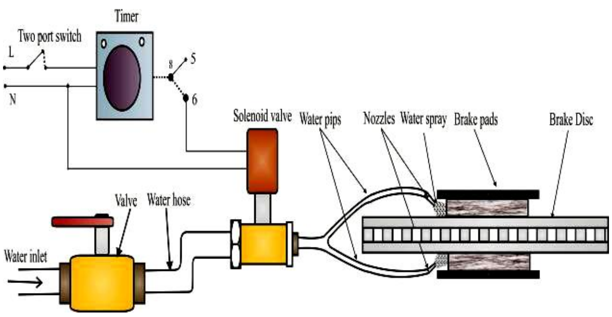

Fig. 4: Schematic of water injection system

3. Results and discussion

The effect of water spray on the brake force is investigated for the adaptive wedge disc brake. The test is carried out at constant applied force 800 N and constant vehicle speed 22.6 km/hr. The wedge angle is adjusted manually between 15˚ to 45˚. All experimental tests are conducted at the same conditions of 60 seconds of braking. During each test, the applied force, brake force, rotational speed and wedge angle are measured and plotted. Figs. 5 and 8 show the effect of water spray on the brake force at wedge inclination angle of 15°, 25°, 35° and 45° respectively. The brake force fluctuates with no trend with the braking time. At dry condition, the brake force varies with the braking time and tends to decrease as the braking time increases due to reduction in the friction coefficient. Water spray causes a decrease in the brake force at the spray time. The brake force reduction at the spray time increases for a raise in the water quantity due to a hydrodynamic effect at high speeds and low-normal forces. For the case of small inclination angle of 15°, the hydrodynamic effect is reduced due to high normal forces generated at low wedge angle. Recovery of brake force occurred within seconds after the water spray is stopped due to frictional heating and lubricant film break-down. Higher the water quantity resulted in longer recovery time. This is in agreement with Blau & Laughlin [19] and El-Tayeb & Liew [20].

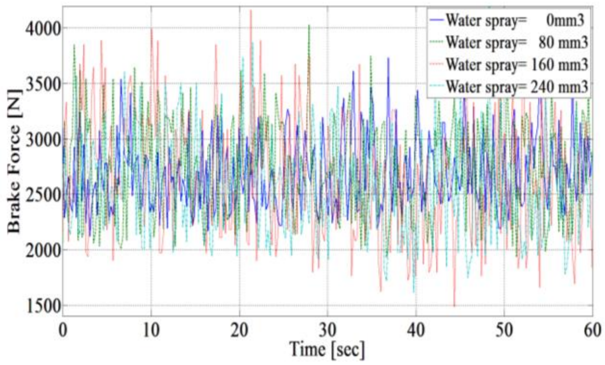

Fig. 5: Brake force vs. Time for 15° inclination angle

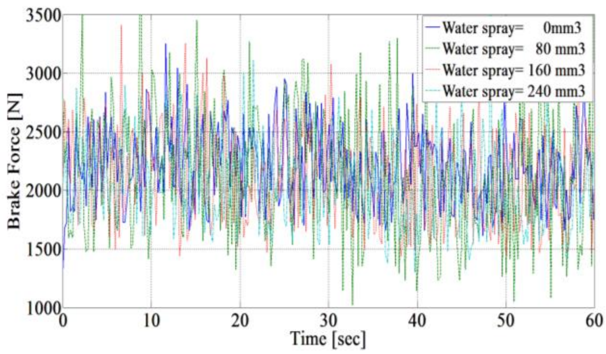

Fig. 6: Brake force vs. Time for 25° inclination angle

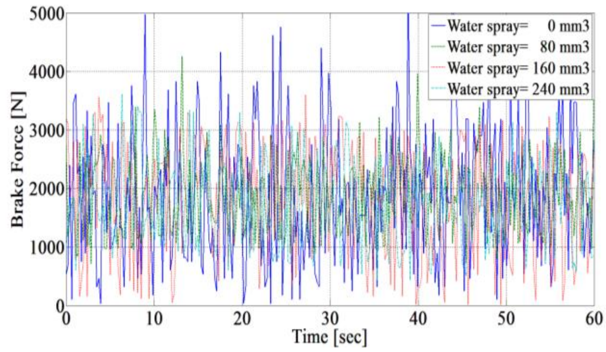

Fig. 7: Brake force vs. Time for 35° inclination angle

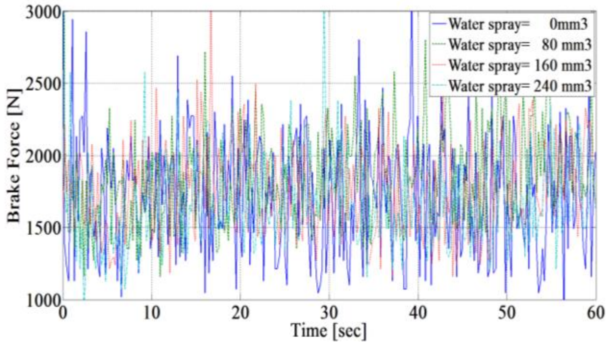

Fig. 8: Brake force vs. Time for 45° inclination angle

The mean brake force for various quantity of water injection is shown in Fig. 9. The increase of water spray quantity decreases the mean brake force by 10.6%, 8.6%, 6% and 4.3% from the dry condition for wedge angles of 45°, 35°, 25° and 15° respectively. As the wedge inclination angle increases, the mean brake force decreases which demonstrates the benefit of adaptive disc brake system.

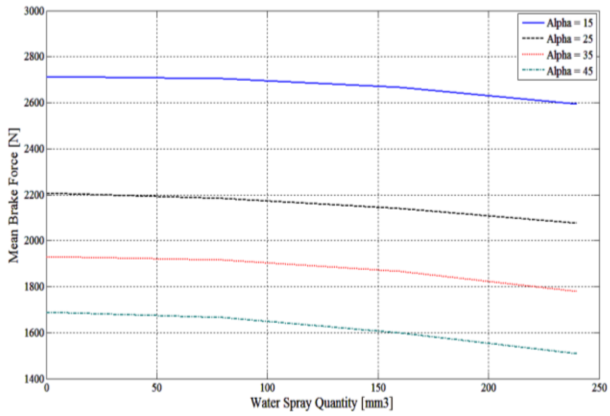

Fig. 9: Effect of water spray on the mean brake force for different wedge inclination angles

4. Conclusion

An experimental investigation of the water spray on the brake performance of a new adaptive wedge disc brake was presented. The tests were carried out at different wedge angle and constant vehicle speed. All experimental tests were conducted in 60 seconds of braking using brake dynamometer. Results indicated that the water spray has a significant effect on reducing the mean brake force. Also, it can be observed that reducing wedge inclination angle increases the self- amplification action leading to increased brake force.

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