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Influence of Water, Oil and Dust on the Performance of Conventional and Wedge Disc Brakes

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ABSTRACT:

In this work, laboratory tests have been carried out to investigate the influence of the presence of water and oil film, as well as the existence of wet dust between the disc and brake pads on the performance characteristics of conventional and wedge disc brakes are examined. The number of brake application and its influence on friction at dry and wet conditions are also investigated. The results indicated that the presence of a water layer between brake pads and disc led to increased friction coefficient and therefore increased the brake shoe factor. The presence of oil film between the friction surfaces lead to obvious reduction in the coefficient of friction. The influence of the presence of wet dust between the friction surfaces has a negligible influence on both conventional and wedge disc brakes.

KEYWORDS:

Wedge disc brake; Braking system; Coefficient of friction; Brake shoe factor; Sliding speed

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1. Introduction

The braking system plays a significant role in vehicle performance on roads, therefore in recent times a lot of theoretical and investigational efforts to enhance and improve the characteristics of the vehicle braking system are carried out. The brake system is an instrument, which is used to absorb the kinetic energy of the vehicle and convert it into heat with the aim to prevent or retard the vehicle motion. Since the deceleration required during an emergency brake stop is much higher than the deceleration during normal operation, the brake power must be much higher than the engine power of the vehicle. The brake force is generated in a friction process between the disc and pads. Coulomb's law [1] postulates that the friction force is varied linearly with normal force. Thus, the coefficient of friction, μ, is defined as the ratio between the friction force and the normal force.

The coefficient of friction is affected by several conditions such as the surface finishing, friction material, temperature, sliding speed, and normal force. This leads to the observation that the friction coefficient varies with the brake time. The sensitivity of the friction coefficient is the continued problem for all brake types especially the drum brake. The brake shoe factor, C^*, is defined as the ratio of the total friction force on the shoe to the applied force. The shoe factor C^* depends on the value of the coefficient of friction. Servirin et al. [2] have presented the variation of the shoe factor with the coefficient of friction variations. There were many efforts to determine accurately the coefficient of friction and its variation depending on the normal force, sliding speed and contact temperature [3]. This leads to the observation that the coefficient of friction is varied with the brake time.

There were many efforts [4-6] to investigate the relation between the sliding speed and the coefficient of friction under extreme loads. Results indicate that the sliding friction increases with the decrease of the sliding velocity and vice-versa. Blau and McLaughlin [4] investigated the effect of water film and sliding speed on the truck brake performances. Their results indicated that the presence of water film between friction surfaces plays a great role of the friction behaviour. The water film between the disc and the brake pads reduces the friction force in comparison with dry case for a constant sliding speed. The decrease of the coefficient of friction with respect to the velocity as the effect of lubricating oxide form at elevated temperatures, and a corresponding decrease of the shear strength of the frictional material with high frictional temperature. The presence of molten material during the braking phase acts as lubricant.

The rate at which a wheel can be slowed depends on several factors including vehicle mass, brake geometry and total braking surface area. It also depends heavily on how quickly the frictional heat is dissipated from the brake components. Roberts et al. [7] presented mechatronic based self-amplification action in wedge disc brake and defined the shoe factor as:

$$C^* = 2\mu \tan\alpha / \left(\tan\alpha - \mu\right) \tag{1}$$

Where α is angle of wedge to the vertical line. They even considered using the operating point when the shoe factor is infinity ($\tan\alpha - \mu = 0$) becomes zero. Dietrich et al. [8] have presented a patent aiming to provide the disc brake with an electromechanical system as well as to apply the self-amplification in the disc brake. They described the shoe factor of the particular disc brake with self-amplification as,

$$C^* = 2\mu/(\tan\alpha - \mu) \tag{2}$$

The difference between the forms of the shoe factor in Eqns. (1) and (2) relates to the applied force direction. Roberts et al. [9] have presented a self amplifying disc brake with two electrical actuators to generate the applied force both in forward and reverse directions. They have modelled the brake and compared the experimental and analytical results. Their results indicated that the power required to brake with self-amplifying disc brake is less than that without self-amplification.

One of the most interesting examples of a disc brake design with self-boosting is the electronic wedge brake [10]. It is based on an electric power controlled friction brake with high self-reinforcement capability. The physical effects involved lead to a significant reduction of energy consumption of the brake actuator compared to “conventional” brake-by-wire systems. The mechatronic wedge brake uses the vehicle’s momentum to support the electric actuator. An auxiliary force derived from the self-reinforcement effect is used to build up the normal force. Therefore, the braking actuator only has to supply a small portion of the required normal force. Furthermore the energy needed to widen the calliper is also taken from the vehicle’s kinetic energy [11]. The number of braking applications had the strongest effect on the friction interface temperature. The maximum temperature at the friction interface does not increase linearly with decreasing contact area ratio. This finding is potentially significant in optimizing the design and formulation of friction materials for stable friction and wear performance.

The aim of the present work is to investigate the effect of the presence of water, dry and wet dust and oil between frictional surfaces on the wedge disc brake performance characteristics. These results are compared with the case of the conventional disc brake

2. Wedge disc brake and test setup

The wedge disc brake modification, as shown in Fig. 1, could amplify the generated brake force at low values of applied force resulting in higher brake shoe factor than the conventional disc brake. The disc brake is provided with a part-lining and a self-energizing electro-mechanical actuator. The self-energizing device has a wedge arrangement designed to press the brake lining against a disc. At least two wedge elements which are movable relative to one another are located on a brake calliper or on an auxiliary frame. These elements are designed to act on the brake lining via a trapezoidal pressure plate. The wedge inclination angle α is about 30°. The wedge and its bearing have the same inclination. The inclination angle α is selected according to the design considerations that generates a high brake force without wedge brake locking (tan α – μ = 0). The movement of the electromechanical actuator is transmitted to the wedge through a spring. This spring is calibrated in relation to the applied force acting upon it and the associated deflection. The displacement can be measured using LVDT to calculate the value of the applied brake force.

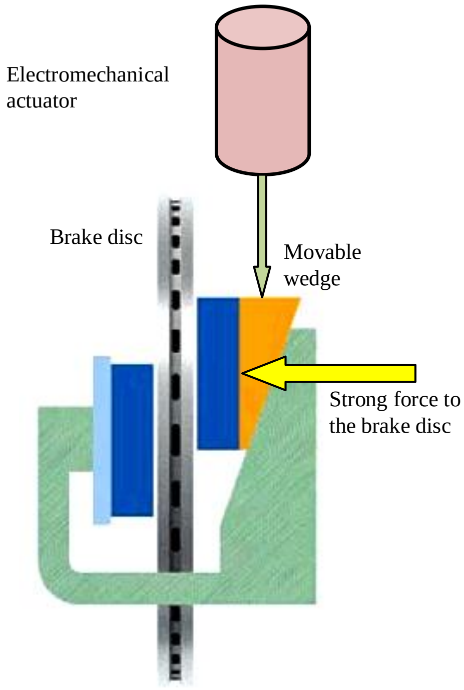

Fig. 1: Sketch of wedge disc brake modification

The main objective of the test rig is to be able to measure the applied force and generate the braking force at different speeds for conventional and wedge disc brakes. In order to meet these prerequisites, a test rig as shown in Figs. 2 and 3 was designed and constructed. An AC electric motor characterised by a constant rotational speed of 1450 rpm with maximum power of 4.47 kW was used. A gear box with different gear ratios was mounted upon the braking system to give different rotational speed at high brake forces. The applied force must have constant values during the test. However, generation of a constant applied force was somewhat difficult. Therefore, a hydraulic jack was used to generate constant applied force. To maintain the pressure during braking process, a control valve was installed directly at the jack outlet. This control valve was kept open during pumping so that the pressure could reach its desired value [11-12].

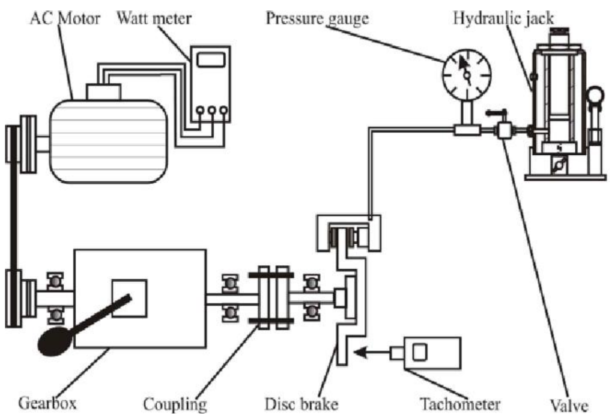

Fig. 2: Schematic of test setup

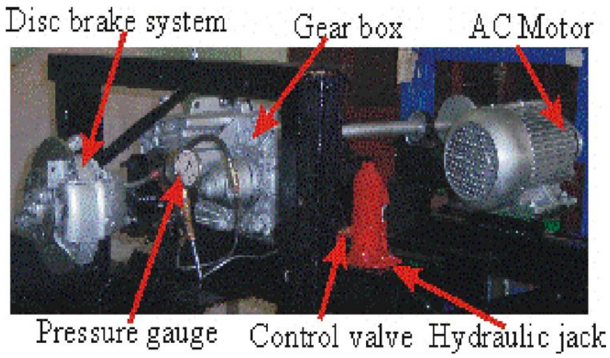

Fig. 3: Photograph of test rig

3. Results and discussions

The applied force was gradually varied from 400 to 1600 N for conventional disc brake. As the values of brake shoe factor for wedge disc brake was about eight times of the conventional one, the applied force was gradually increased from 75 N to 150 N for wedge disc brake. The simulated vehicle speed is maintained about 5.26 km/h. Figs. 4 and 5 show the effect of applied force on μ and C* for conventional and wedge disc brake respectively at dry and wet conditions. For wet conditions, 3 cm^3 of water is injected over both sides of the disc. For an increase in the applied force, there is a decrease in the friction coefficient and hence the brake shoe factor at dry and wet conditions. The water film between the friction surfaces increases the coefficient of friction especially at low values of normal force.

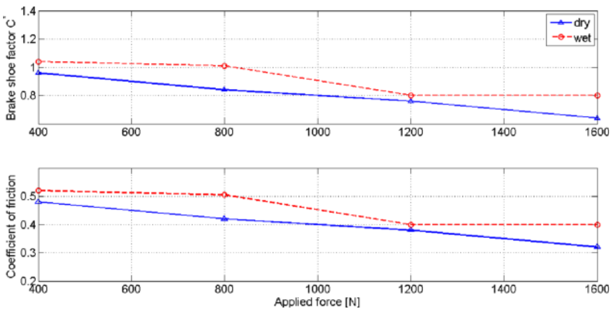

Fig. 4: Effect of normal force on μ and C* for conventional disc brake at dry and wet conditions

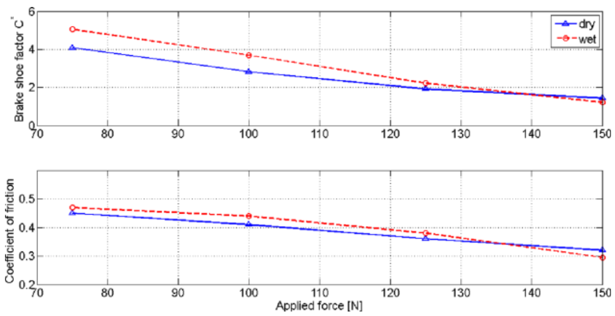

Fig. 5: Effect of normal force on μ and C* for wedge disc brake at dry and wet conditions

By comparing the increases in the coefficient of friction due to water injection, the increase was more for conventional disc brake than wedge disc brake. These results are in disagreement with Blau and McLaughlin [4]. It could be attributed to the diversity of brake pad materials. The injection of water cools the contact area which leads to an increase in the coefficient of friction. The injected water is mixed with abrasion powder and fills the cavities of friction area which leads to an increase in the bedded area thereby increases the coefficient of friction. It is difficult to identify which parameter plays the major role on the coefficient of friction variations [12].

To study the effect of number of brake application, the experiments were conducted as 5 seconds braking and then it is left idle for 120 seconds. The experiment is repeated for many times so that the brake force is measured at 0, 10, 15 and 20 number of brake applications. The simulated vehicle speed was maintained at 5.26 km/h. The applied force is maintained as 400 N and 75 N for conventional and wedge disc brake respectively. Figs. 6 and 7 show the coefficient of friction and shoe factor variations with the number of brake applications for conventional and wedge disc brakes. For wet conditions, the tests were conducted under the same conditions as in the dry state with the exception of injecting 5 cm^3 of water over both contact surface areas of the disc.

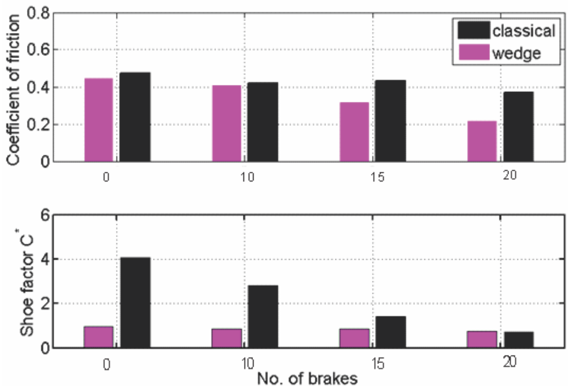

Fig. 6: Effect of number of brake application on μ and C* for conventional and wedge disc brakes at dry conditions

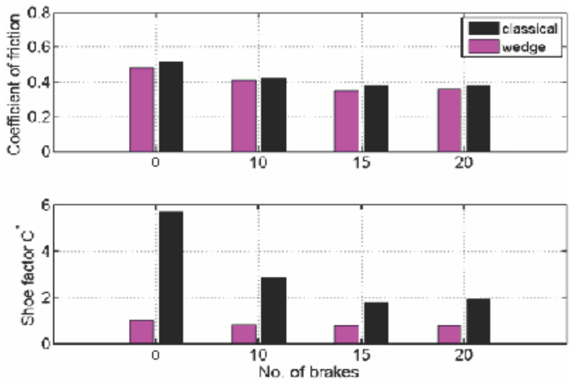

Fig. 7: Effect of number of brake application on μ and C* for conventional and wedge disc brakes at wet conditions

Increase in the number of frequent brake application decreases the coefficient of friction decreases for both brakes at varying degrees at dry and wet conditions. The wedge disc brake performance dependence on μ is highly sensitive than that of conventional disc brake. The reduction of μ for wet conditions was lower rate than at dry conditions. There is little difference in C* variations over the number of brake applications between dry and wet conditions for conventional disc brake when compared to the wedge disc brake. As the number of brake application increases from 0 to 20 times, the brake shoe factor decreases by about 58 % for wedge disc brake at wet conditions.

Figs. 8 and 9 show the effect of the presence of fine dust that ranges from 50 to 200 μm between the friction surfaces of conventional and wedge disc brakes respectively. The presence of dust between friction surfaces leads to some reduction in the coefficient of friction and brake shoe factor for both brakes. This reduction was obvious at low applied forces and negligible at high values of applied force. At low applied force, the presence of dust between friction surfaces acts as rolling balls, which leads to a decrease in the friction coefficient as well as the brake shoe factor. At high values of applied force, the generated pressure increases and crushes the dust. This leads to an increase in the bedded area and thereby contributes to an increase in the coefficient of friction.

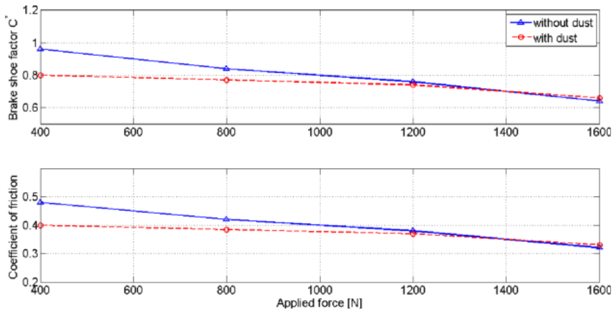

Fig. 8: Effect of presence of wet dust between friction surfaces on μ and C* for conventional disc brake

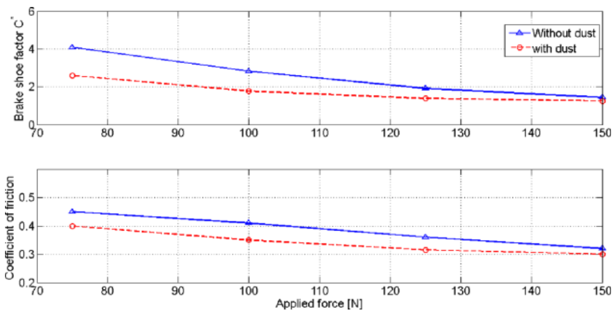

Fig. 9: Effect of presence of wet dust between friction surfaces on μ and C* for wedge disc brake

Figs. 10 and 11 illustrates the effect of injected oil at the friction surfaces on the coefficient of friction and brake shoe factor with conventional and wedge disc brakes respectively. The presence of oil between friction surfaces leads to a reduction in the coefficient of friction for both brakes. This reduction was slightly higher in the case of wedge disc brake as expected.

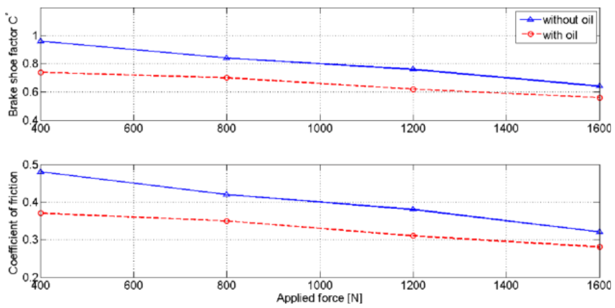

Fig. 10: Effect of presence of oil between friction surfaces on μ and C* for conventional disc brake

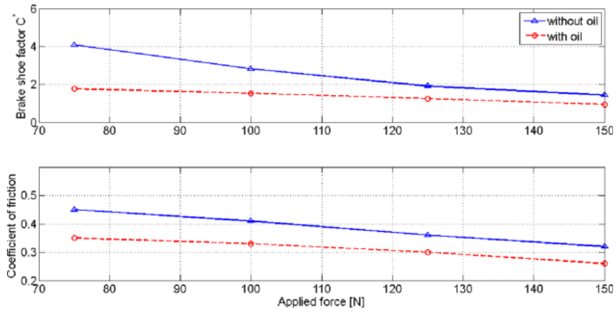

Fig. 11: Effect of presence of oil between friction surfaces on μ and C* for wedge disc brake

4. Conclusions

Laboratory experiments were conducted to study the effect of water film, oil film, and wet dust between brake frictional surfaces on the performances of conventional and wedge disc brakes. A wedge disc brake is designed and constructed by modifying a conventional disc brake. A great amount of applied force could be saved by using wedge disc brake instead of conventional one. High normal force has reduced the coefficient of friction for conventional and wedge disc brakes. Repeated number of brake application has a noticeable effect on the coefficient of friction. Injection of water film between surfaces leads to an increased friction coefficient which further increases the brake shoe factor for both the classical and wedge disc brakes. The presence of wet dust and oil film between brake friction surfaces considerably decreases the coefficient of friction and brake shoe factor at low applied force. This effect reduces slightly by increasing the applied force for conventional and wedge disc brakes.

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