International Journal of Sciences, Engineering & Environmental Technology (IJOSEET), 7(15): 140 – 147, 2022
ISSN 0794-9650

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Development and Prototyping of Automotive Tricycle Brake Wear Rig and Sensor/Monitor

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Abstract

This paper describes the design and development of a model tricycle's brake wear test rig and sensor to indicate the progressive wear of brake lining friction materials with the view to provide additional safety on tricycles. The utilization of automotive tricycles for the movement of people and goods on land has become an important means of transportation in Nigeria. The automotive tricycle has no passenger seat belts and brake wear sensor/monitor that can affect passenger safety. A careful study of some samples of tricycles' worn brake linings shows that wear rates of brake linings often wear most around the centers of the friction materials. Brake wear sensors were fabricated from resistance wire to mimic the wear rate of the friction-lining materials and electrically connected to light-up some lamps when they cut due to wear action between the brake drum and brake lining. Their performance was shown to be comparable to some other factory-made sensors which were found to be cheaper than the imported sensors. Above all, this study developed a locally fabricated electrical circuit system that indicates a progressive loss of materials from the brake lining connected to the sensor. The use of a locally fabricated brake wear sensor in an automotive tricycle will not only provide safety for the occupants but also enhance safety enforcement by road safety regulators.

Keywords: Sensor, Brake, Friction lining, Tricycle.

1. Introduction

Brake safety on an automobile brake system is expected to slow or stop the vehicle when in motion and it must be able to hold the automobile in position when stopped on an inclined surface. The braking system is composed of parts that include; friction pads or linings on each wheel, wheel cylinders, a master cylinder, and a hydraulic control system. There are two types of brake systems used in automobile cars; disc brakes system and drum brake system. The linings of brake pad (used on disc brake system) or brake shoe (used on drum brake system) is expected to ensure that the vehicle is operated in a controlled manner by the friction moment between the quasi-static external surface of the shoe or pad and the internal surfaces of the rolling brake wheel hub or wheel disc.

The increasing use of tricycles in the transportation of people and goods in most Nigerian cities is a development to ease transportation problems of the poor and middle-income earners. However, reports of the numbers of twelve categories of automobiles involved in road traffic crashes in the second quarter of 2020 by the National Bureau of Statistics is 3,325 (STATISTICS, 2020). The report has 139 accidents from tricycle crashes for which 120 of these crashes were identified to have been caused by brake failure. Another study has tricycles accounting for about 6% of injuries from traffic accidents (Onyemaechi, 2020). In most crashes involving tricycles, none of the passengers were wearing helmets nor seat belts (Omoke, Lasebikan, Onyemaechi, & Ajali, 2019). Nigeria loses about 80 billion naira annually to road accidents and of all persons involved in road traffic accidents in Nigeria, 29% were identified to suffer a disability, while 13.5% are unable to return to work after the accident (Atubi, 2012; Juillard, Labinjo, Kobusingye, & Hyder, 2010).

The many accidents of a tricycle on the highway can be related to a disabled brake shoe or pad due to the friction layer becoming too thin to provide braking action. Early detection of brake lining wear is very important. The systems used for this purpose are of different types. Those that use: Hall-effect stroke sensor, anchor pins instrumented with strain gauges, embedded thermocouples, ABS wheel-speed sensors, linear potentiometers, and pressure transducers provide information on brake wear rates (Freund & Skorupski, 2009).

However, wear rate measurement varied considerably when used on vehicles. On tricycles, a similar method will be adopted. A method of wear rate measurement for specific applications such as brakes used in commercial friction materials (Ouyang, Li, & Siegel, 2005) in Equation 1.

$$h = k \, . \, p \, . \, \Omega \, . \, r \, . \, t \qquad \text{Equation 1}$$

Where the wear displacement, k is the specific wear rate coefficient, p is the contact pressure, Ω is the rotational speed, r is the pad mean radius and t is the disc sliding time.

As transportation challenges in Nigeria have grown to the use of tricycles, adequate safety of lives is necessary during vehicle movement. At the moment, brake wear sensors are not installed on tricycles for passenger safety and there are no other means of assessing brake wear rate on tricycles for necessary safety assurance of passengers. However, brake efficiency is an important feature in the research field of active automobile safety (Bera, Bhattacharya, & Samantaray, 2011).

The current problem faced by most tricycle operators in Nigerian is that they do not know the conditions of the friction materials of their brake system until the sensation that the brake pedal is no longer active. This may endanger the lives of occupants in the tricycle. On the other hand, some tricycle owners without a good maintenance plan will allow the friction material to wear out until the backing plate of the pad damage the disk rotor for disc brake types or the backing plate of the brake shoe damage the brake drum of the drum brake types. A deficiency brake system is the most common reason for a motor vehicle to be sighted for a regulatory violation and to be taken out-of-service during a road inspection.

One of the objectives of this project is to assess the wear rates of samples of old and worn brake linings of the automotive tricycle in comparison to new friction lining materials. This is to identify the regions of high brake wear rates on the friction lining to identify locations to install the fabricated sensor. Another objective of this project is to develop and fabricate a brake wear sensor for use in an automotive tricycle to provide accurate measurement of the variation in the thickness of brake friction materials to determine the optimal replacement of the sensor.

Brake wear sensors indicators mostly give warning light when brake wear is severe. Because of this fact, this paper will develop an electrical circuit system to provide a means of monitoring this progressive wear of brake friction materials to show how frequent stops by automobile tricycles could influence the friction materials of its brake wear system of the tricycle, However, installing the sensor and monitor on a live tricycle can be very challenging in terms of frequent fixing the sensor on the wheels of the tricycle. A further objective of this project is to fabricate a test rig that will contain one of the wheels of the tricycle connected to its gearbox which is powered by an electric motor.

2. Materials and Methodology

This study will fabricate a model traction wheel system and brake wear rate monitoring system of an automotive tricycle. To reduce the size of the model, the mechanical power requirement of the conventional internal combustion engine is replaced by a 1.0 kW single-phase electric motor. However, power transmission to the road wheels was achieved through connections to a gearbox, shafts, and brake system assembly as used in the automotive tricycle. All these were mounted on a flat wooden platform surrounded by a rectangular steel frame that will be supported by a rigid angle iron steel structure system on four castor (Sivarao, Rizal, & Kamely, 2009).

A comparison of the thickness of the friction materials of a new brake material to old and worn linings of the tricycle is expected to give an indication of the parts or areas on the linings that mostly wear a lot. These worn samples are randomly collected from the tricycle's auto-mechanics around Ikorodu metropolis. A measurement of the thicknesses of worn brake linings at different locations and comparison with the thickness of new linings enables this study to locate a brake wear sensor at appropriate locations on the lining (Guan XU, 2013). This is possible using a digital vernier caliper.

The brake wear sensor is developed from thin wires made of copper and hardened steel. These are chosen based on their similar adhesive wear coefficients of 0.1 - 0.01 (Bernard J. Hamrock, 1999). The wires from copper and mild steel materials are bent to form two legs with the curved ends embedded in the brake lining. This study will rely on the assumption that the brake friction material exhibits progressive loss of materials as the curved ends of the brake wear sensor wires when in contact with the rotating brake drum. To avoid contact between the two legs, thin insulating coatings are provided by using adhesives and a PVC cylindrical shell with a very small internal diameter to protect the sensor ends from bridging.

The legs are subsequently soldered to an insulated electrical cable for connection to the monitor circuit panel. As the wear rate of the brake friction materials increases due to the running of the test rig for several hours and brake actuation, electrical continuity of the curve section will break the sensor wire into two once lining wear reaches this area. Under normal conditions, electrical indicator lamps connected to the legs via a 12 V battery should go off when this happens. However, an electrical circuit will be fabricated using some relays, lamps, and 12 V batteries used on the tricycle engine for ignition. Wire connections are made in such a way as to light up lamps whenever there is a break in the sensor due to wear of rubbing brake lining and wheel drum. In this way, the performance of wear sensors made from copper and steel wire could be compared to brake wear sensors fabricated in the factory on the same brake lining. Hence, the effectiveness of the fabricated sensors is bench-marked against factory manufactured sensors.

3. Results

3.1. High wear rate identification

In the identification of the regions of high brake linings that produce high wear rates by some automotive tricycle; this study measures the thickness of 34 worn samples of brake lining as shown in Figure 1 (a). The regions on the brake linings where the height of worn brake linings was measured are shown in Figure 1 (b). The purpose of measuring the lining thickness is to compare the variations in the thickness of worn brake lining to new brake lining.

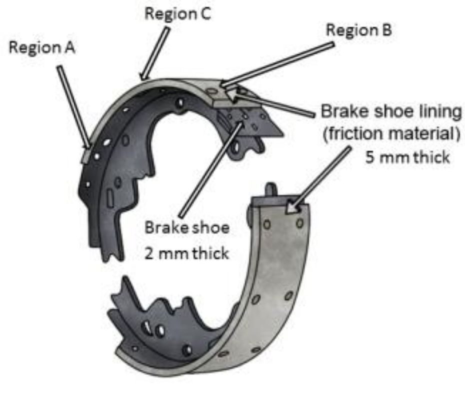


Figure 1 Tricycle brake lining; (a) collected 30 samples, (b) measured height of worn regions

The results of wear rates comparison of worn brake linings to new or unworn brake friction materials based on their height differences are shown in Figure 2. This result indicated that progressive loss of materials on the brake linings of automotive tricycles wear most around region C or the central area of the lining that is comparable to results of similar studies on brake pad (Sivarao et al., 2009); where the high wear rates of the brake friction materials were found to take place around the central region of the brake pad. However, this was attributed to its closeness to the actuating piston (wheel cylinder).

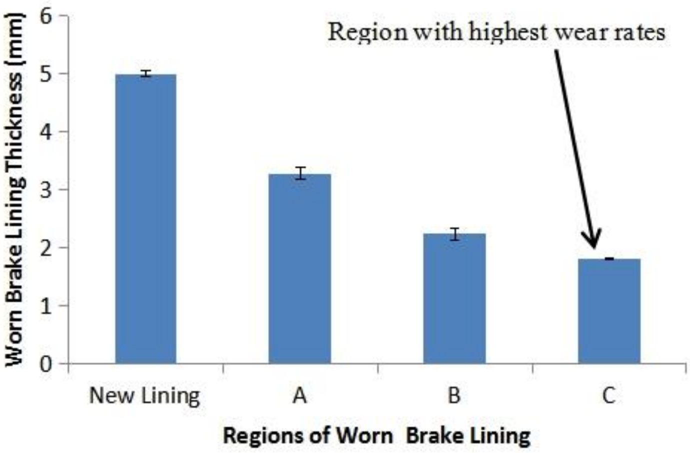
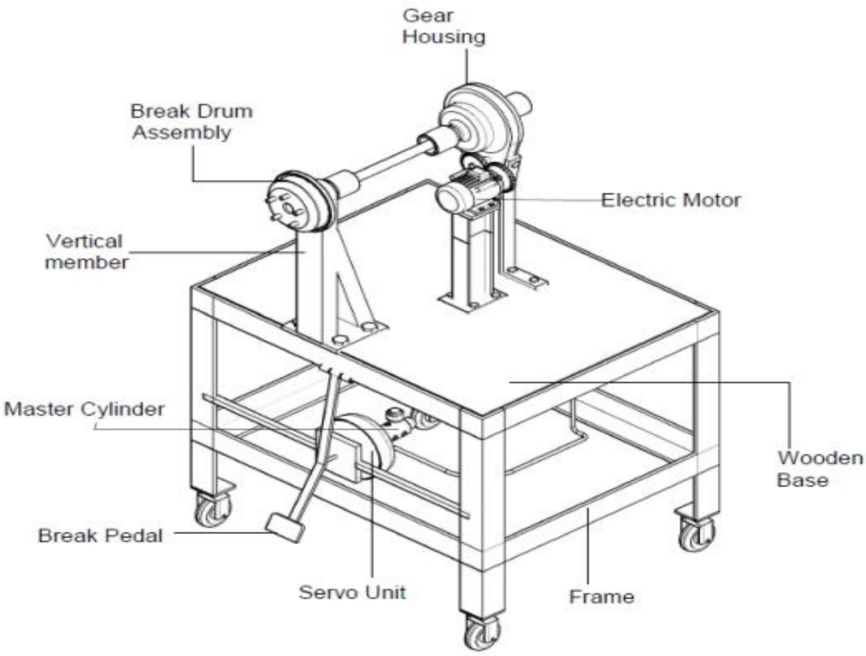


Figure 2 Identification of wear pattern on different regions of the brake lining

The results of a similar study attributed high wear rates in a certain region to abrasive wear mechanisms (Straffelini & Maines, 2013). From the evaluated data sets of automotive tricycle brake friction materials, results shown in Figure 2 indicated that region C of the brake lining is a more suitable spot to embed a wear limit sensor.

3.2. Model automotive tricycle gearbox and wheel test rig

The development of the test rig commenced with the acquisition of the components and a design similar to Sivarao et al. (2009). These components are; drive shaft, electric motor, drum brake component, brake pump, master pump, brake pedal, and electrical circuit panel with a pilot lamp for wear rate indication when different percentages of lining depths are reached. The test rig developed is shown in Figure 4-1 (a). Figure 4-1 (b) shows the fabricated test rig where the electric motor that replaces the engine is first coupled to the differential housing gearbox via a drive shaft and another output shaft from the gearbox coupling the drive wheel. Hence, the fabricated test rig is quite different from the developed test rig.



(a)

(b)

Figure 3 Fabricated automotive tricycles motor, gearbox, and wheel test rig; (a) engineering drawing of the developed rig, and (b) fabricated test rig and associated components

3.3 Wear sensor development and fabrication

Brake wear sensors were fabricated from steel and copper wire materials as shown in Figure 4-2 (a) and (b). These were located in different areas around the centers of the tricycle's brake lining. After running the test rig for twenty-four hours, for appreciable loss of materials from the brake lining to take place, the indicator lamp on the imported brake wear sensors was observed to come on at the same time as the lamps connected to the locally fabricated sensors. The result of this study shows that the wear sensor performance of the fabricated sensor is comparable to the factory manufactured sensor.

(a) (b)

1. Figure 4 Images of brake wear sensors; (a) developed copper and steel wire sensors, and
2. (b) factory manufactured sensors as reference

4. Discussion

At the moment, most brakes on automotive tricycle do not have the mechanical means of sensing brake lining wear unlike those used on cars with disk brakes. When enough of the friction material is worn away, the wear indicator will contact the disc and make a squealing sound where users are alerted by mechanical noise that is produced by a mechanical touch-sensing technique using spring steel when the safety wear limit is reached. Unfortunately, this system alerts only when the car is on the move and secondly, when the car is on move, rarely the alert reaches the driver's ear (Sivarao et al., 2009). This study has developed a brake wear sensor and brake monitor for use in the automotive tricycle. The sensor detects the lining wear safety limit before exceeding the brake shoe lining limit. This development is considered as a prototype and further tribological investigations are needed to validate the sensor behavior of brake lining wear rates when the wheels are on the road. Future work will also consider the use of a digital display system using Light Emitting Diode (LED) circuitry to replace the indicator lamps; as the space occupied by this system can be minimized.

Local manufacture of this sensor is proposed for entrepreneurs who are into manufacturing locally manufacture this brake wear sensor and possibly embed this at the plant level before the asbestos lamination and bounding to the backing plate. This will not only increase the value of the brake lining materials on the tricycle but also provide safety and reduce foreign exchange to import these sensors. At the moment, the price of the imported sensor is in the range of \$10-\$75, the sensor developed in this project is less than \$2. The mass production of the brake wear sensor will not only provide enhanced safety of automotive tricycle on our roads but also boost the employment market.

5. Conclusions

After a careful study of samples of worn brake lining from some tricycles mechanics, this study shows that wear rates of brake linings mounted on automotive tricycles often wear most around the centers of the brake friction materials. Three different sensors were also fabricated and located at different areas around the centers of the brake linings of the fabricated model automotive tricycle system. The sensor's performance was shown to be comparable to some other sensors made in the factory. This fabrication shows that cheaper brake wear sensors can be made locally with comparable performance to imported sensors. This will save the country a lot in terms of foreign exchange.

Also, this study developed a locally fabricated electrical circuit system that can be connected to sensors and embedded into a brake lining at different depths to indicate progressive loss of materials from the brake lining connected to the sensor. This is unlike the mechanical system of detecting brake wear which will only show brake wear when the lining is almost 100% worn out. The result of this study has provided a means of ensuring planned maintenance for the replacement of brake friction material to enhance the safety of the brake system of an automotive tricycle on our roads. This will prevent accidents arising from brake failure by ensuring that drivers of automotive tricycles can quantitatively assess brake lining wear rates of their brake friction materials.

6. Acknowledgements

The authors wish to thank the Tertiary Education Trust Fund (TETFunD), Nigeria, and the management of Lagos State Polytechnic, Ikorodu for their supports.

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