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Wear Measurement of the Vehicle Brake Shoe and Determination Method of the Optimal Position for Inspection

***Abstract**. Wear measurement of a vehicle brake shoe is an effective way to enhance the vehicle safety. The continuous measurement problem of the abrasion loss of a brake shoe is solved by employing an electronic chip with series circuit. The quasi-linear solution is achieved by simulating the constructed model of the resistances distribution. Furthermore, the optimal location for the inspection is formulated by analyzing the brake kinematics. Simulations are performed on the representative conditions and agree to the experiments with an acceptable 0.1 V error.*

***Streszczenie.** Pomiar zużycia szczęk hamulcowych ma istotne znaczenie dla bezpieczeństwa. Problem ciągłego pomiaru zużycia szczęk rozwiązano stosując odpowiedni czujnik. W artykule analizuje się tez optymalne położenie czujnika. (**Pomiar zużycia szczęk hamulcowych i określenie optymalnej pozycji czujnika**)*

Keywords: Vehicle inspection, Brake shoe, Wear, Measurement, Optimal inspection position
Słowa kluczowe: zużycie szczęk hamulcowych, pomiar, diagnostyka

Introduction

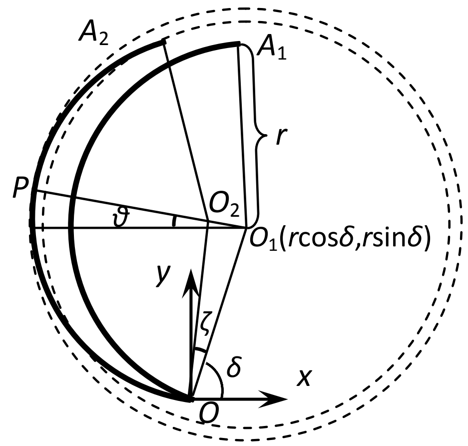
Brake safety of a vehicle is one of the key points in the research field of active automobile safety [1-5]. Brake shoe is normally used to ensure the car is operated in a controlled status by the friction moment between the quasi-static external surface of the shoe and the internal surface of the rolling brake wheel hub. Many typical incidents of vehicles on express way are related to the disabled brake shoe as the friction layer on it is too thin to provide enough brake force [6-8]. For this reason, it is important to develop the accurate measurement method to monitor the variation in the thickness of brake shoe and determine the optimal inspection position for the sensor.

In the previous works, researches focus on the limit control method for the thickness of the friction layer. Dennis A.B. *et al*. propose a solution to embed the sensor into the friction layer [9,10]. When the layer thickness is near the limit, the sensor probe touches the brake wheel hub and output a pulse signal to alert the vehicle driver to replace a brake shoe. The above method is available to test whether the layer thickness reaches the ultimate value, however, unavailable to obtain the real-time value of layer thickness continuously. Giovmlll P.P. *et al*. outline another way to measure the rotational angle of the camshaft on the adjusting arm of a brake [11]. The angular displacement is inspected by a rotary encoder and converted to straight-line displacement. It is compulsory to adopt high accuracy encoder to achieve the precision for the indirect relationship between the abrasion loss and the measured rotary angle. Xu G. *et al.* present a strategy employing a circuit to implement the continuous data collection, whereas the complex circuit restricts its application [12]. Furthermore, the optimal location for the wear inspection on the brake shoe is not reported in the previous researches.

The presented study in this paper can be divided into two aspects: in the first section, as the nonlinear variation of the wear loss along the brake shoe, the maximal abrasion is derived to determine the optimal location for installing the sensor. A sensor based on the series circuit is introduced to test the wear of brake shoe in the second section.

Determination of the optimal position for inspection

The tested position of the abrasion should be located on the point with the largest radial displacement of a braking shoe. Fig. 1 is drawn to analyze the movement of the brake shoe. OA_1 is the original position of a brake shoe. O_1 is the center of the brake shoe OA_1. OA_2 is the active position of the braking shoe. O_2 is the center of the brake shoe OA_2. O is the rotary center of the brake shoe. δ is the angle between the original position O_1O_2 and x axis. ζ is the rotary angle of the brake shoe. O_1P is a line section which is perpendicular to O_1O_2. *P* is the crossing point of O_1O_2 and OA_2. θ is the angle between O_1P and negative x axis. r is the radius of the brake shoe. Based on the geometrical relationship, the largest radial displacement of the brake shoe is generated on point P. Thus P is the optimal position for the wear inspection of the brake shoe. The vectors $\boldsymbol{OO_1}$



and $\boldsymbol{OO_2}$ can be respectively expressed by

Fig.1. Movement of the brake shoe

(1) $$\boldsymbol{OO_1} = (r\cos\delta, r\sin\delta)^T$$

(2) $$\boldsymbol{OO_2} = \boldsymbol{R}\cdot\boldsymbol{OO_1}$$

where the rotation matrix $\boldsymbol{R} = \begin{pmatrix} \cos\varsigma & -\sin\varsigma \\ \sin\varsigma & \cos\varsigma \end{pmatrix}$, Then

(3) $$\boldsymbol{OO_2} = r\begin{pmatrix} \cos\varsigma\cos\delta - \sin\varsigma\sin\delta \\ \sin\varsigma\cos\delta + \cos\varsigma\sin\delta \end{pmatrix}$$

$\boldsymbol{O_1O_2}$ is computed by

(4) $$\boldsymbol{O_1O_2} = \boldsymbol{OO_2} - \boldsymbol{OO_1}$$

Subscribe eq. (1) and eq. (3) to eq. (4), the vector $\boldsymbol{O_1O_2}$ can be described by

(5) $$\boldsymbol{O_1O_2} = r\begin{pmatrix} \cos\varsigma\cos\delta - \sin\varsigma\sin\delta - \cos\delta \\ \sin\varsigma\cos\delta + \cos\varsigma\sin\delta - \sin\delta \end{pmatrix}$$

The optimal inspection angle θ is

(6) $$\theta = \left| \arctan\left(\frac{\sin\varsigma\cos\delta + \cos\varsigma\sin\delta - \sin\delta}{\cos\varsigma\cos\delta - \sin\varsigma\sin\delta - \cos\delta} \right) \right|$$

Wear Measurement Method

For installing the sensor to the brake shoe conveniently, the sensor is designed as a hollow screw with an embedded circuit chip in it as Fig. 2 shows. The inner circuit which consists of a voltage divider R_0 and n series resistances R_i (i=1,2,...,n) is illustrated in Fig. 3. The other component on the circuit is composed of n wearing lines l_i (i=1,2,...,n) with a precise constant interval s. The sensor is fixed on the brake shoe by threaded connection. The wearing lines on the end of the screw are abraded with the surface of brake shoe simultaneously. The variation of the output voltage U_0 caused by disconnected lines is adopted to measure the abrasion of brake shoe continuously.

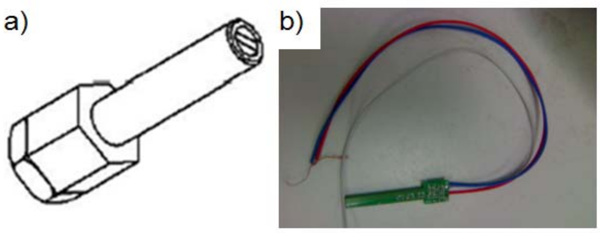


Fig.2. Designed sensor. a) appearance of the sensor, b) electronic chip inside the sensor

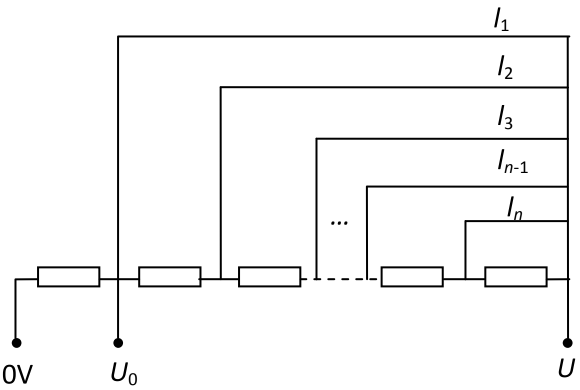


Fig.3. Inner circuit of the designed sensor

When the line l_n is worn out with the brake shoe, the variation of the output voltage U_0 is

(7) $$\frac{R_0 U}{R_0 + \sum_{i=1}^{n-1} R_i} - \frac{R_0 U}{R_0 + \sum_{i=1}^{n} R_i} = kU$$

where U is the input voltage, k is the precision of the measurement which is represented by percentage. Let $x_1 = \sum_{i=1}^{n-1} R_i$, $x_2 = \sum_{i=1}^{n} R_i$ .Then eq. (7) is converted to

(8) $$\frac{R_0}{R_0 + x_1} - \frac{R_0}{R_0 + x_2} = k$$

x_2 is solved to

(9) $$x_2 = \frac{R_0(x_1 + kR_0 + kx_1)}{(1-k)R_0 - kx_1}$$

finally, R_n is calculated by

(10) $$R_n = x_2 - x_1$$

Results and Discussions

The simulations are performed for optimal position of inspection and wear measurement respectively. The simulation result of optimal location for sensor is illustrated in Fig. 4. The optimal point P for sensor locating is described by the installation angle θ which is determined by the original angle δ of the brake shoe OO_2 and rotary angle ζ of the braking shoe OO_1. In general, δ is limited in the scope of 70º-85º, while ζ varies in 0º-20º. Therefore, the optimal installation angle θ should be in the range of 10˚-15˚ as this area accompanies the maximal offset and abrasion on the brake shoe.

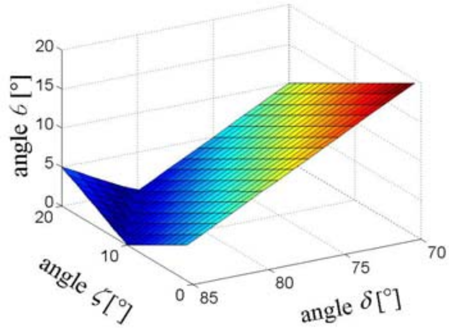


Fig.4. Simulation result of optimal location for the sensor

In order to prove the measurement method for the brake shoe, simulations are performed according to the relationship among resistances R_0, x_1 and x_2 with the different values of measurement precision k, 10%, 5%, 2%, 1%, 0.5% and 0.2%. The simulation results are observed clearly in Fig. 5 which is a guideline of circuit design. The quasi-linearity is obtained between the resistance values after abrasion x_1 and before wear x_2. Furthermore, the variation of x_1 and x_2 increases with a decreasing value of R_0. Oppositely, the smaller wearing variation of x_1 and x_2 is caused by a large R_0. For enhancing the sensitivity of the measurement method and achieving an appropriate combination of resistance values in a widely parametric interval simply, the voltage divider R_0 is selected with the value of 1 KΩ.

A typical case is implemented with the measurement range 10 mm and precision 2 mm to verify the proposed method. The mini-chip resistors with 1% precision are adopted as the resistances which are embedded on the circuit. The resistor values are outlined in Table 1.

Table 1. The parameters of the sensor

Resistor number	R_0	R_1	R_2	R_3	R_4	R_5	R_6
Resistor value [KΩ]	1.00	0.27	0.27	0.56	1.00	1.50	9.10

Experiments are executed on the brake shoe of a truck as Fig. 6 shows. The realized sensor is located on the optimal position where θ is 15˚. The experimental results and simulation data are illustrated in Fig. 7. The 10 mm abrasion total loss is measured by the variation of voltage which is the output of the sensor. The input voltage of the senor is 5 V. 2 mm wear corresponds to a variation larger than 0.5 V. The scope of the voltage variation in y axis is 0.5 V-1 V. The first point designed is greater than 1 V for warning of the beginning time to measure. The simulation results agree the experimental data with the errors less than 0.1 V.

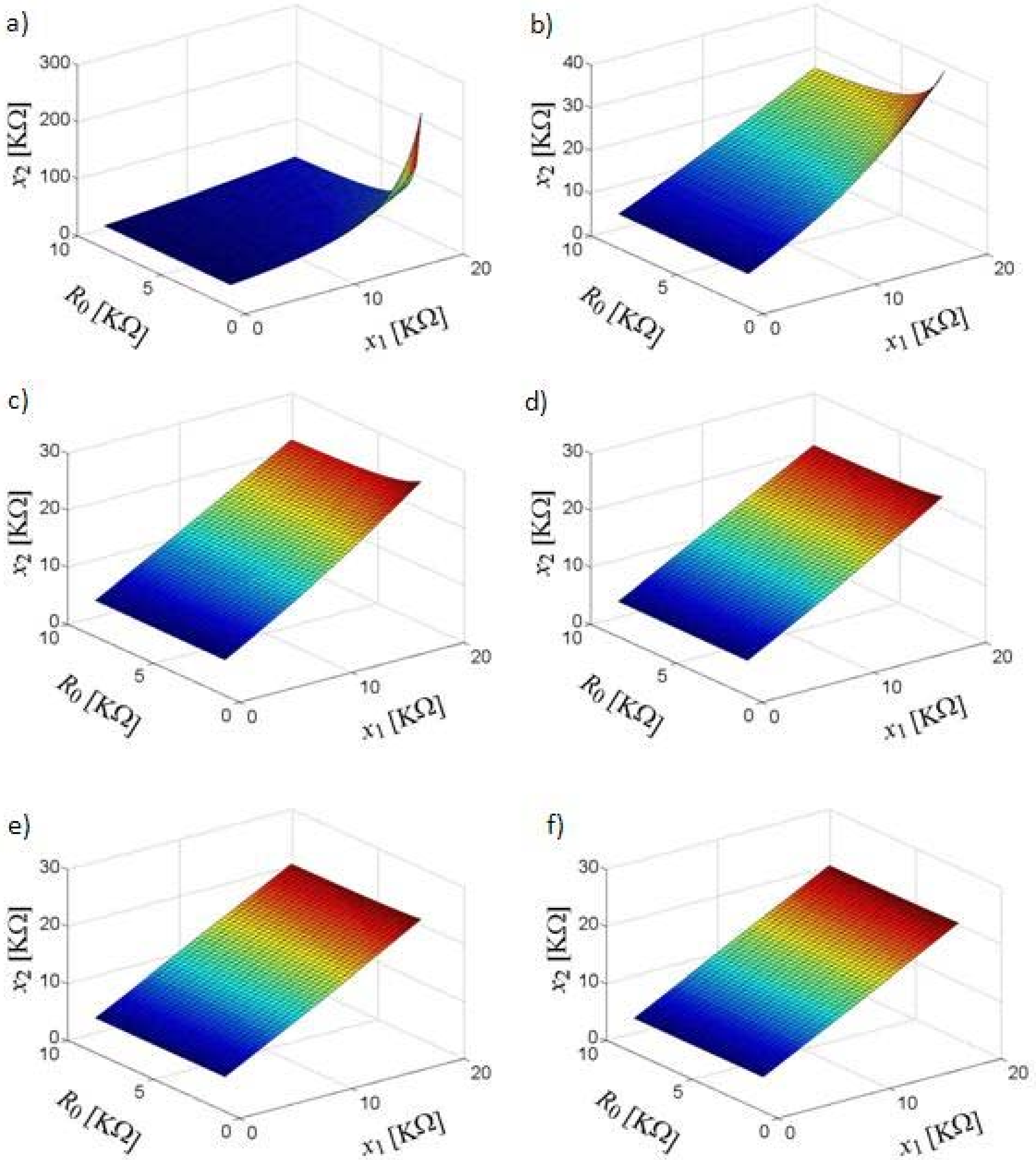


Fig.5. Simulation results for the measurement model of the circuit with different precisions. a) k=10%, b) k=5%, c) k=2%, d) k=1%, e) k=0.5%, f) k=0.2%

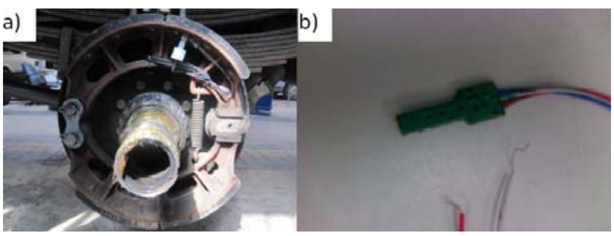


Fig.6. Experiments on a brake shoe with the designed sensor. a) installation of the sensor, b) worn electronic chip inside the sensor

Conclusions

For measuring the wear loss of the brake shoe of a vehicle, a continuous inspection method which employs series circuit is provided in this paper. The circuit diagram and measurement model of the senor are presented to perform the dynamic monitoring the abrasion loss for truck on the expressway. The scope of 10º-15º is derived for the optimal installation angle of the designed sensor as the asymmetry wear is caused by the kinematic relation of the brake shoe.

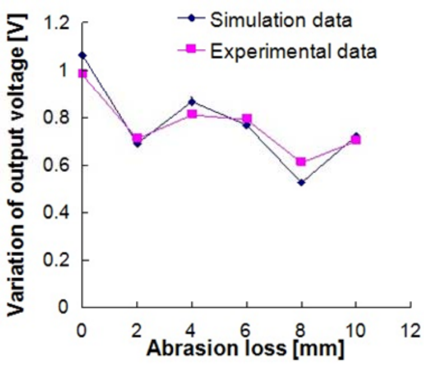


Fig.7. Comparison of the eexperiments and simulation results

Simulations among the on-circuit resistances of voltage divider, total resistances before and after a line worn out with the brake shoe are presented with the different measurement precision 10%, 5%, 2%, 1%, 0.5% and 0.2%, individually. The abrasion loss is tested by the output voltage related to the variation of resistance value on the circuit. Experiments are achieved on a brake shoe of a truck to analyze the performance of the proposed model. The measurement precision on the experimental case is 2 mm considering a 0.5 V larger variation of output voltage with the input voltage 5 V. The simulation results meet the experiment data with a 0.1 V error. For the practical applications, the accuracy will be enhanced by more resistances and subdivision of input voltage as well.

Acknowledgments

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