

Proposed Metrological Method for Identifying Automotive Brake Discs

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ABSTRACT

The main aim of this work is to develop an identification method to demonstrate the crucial surfaces of automotive braking system. Two brand new brake discs manufactured by two different manufacturers are tested. A typical disc to the one of them was put under working condition in actual braking system. Dimensional and geometrical deviations are investigated using advanced engineering metrological technique. Mechanical properties, tribological characteristics and chemical analyses are investigated. A coordinate measuring machine, universal hardness tester, mass comparator and XRF spectrometer are used in these diagnoses. Measurements of dimensional and geometrical deviations such as disc thickness variations, thickness deviations, straightness, parallelism, runout of disc surfaces are conducted. A comparison between form deviations in disc surfaces have been carried out and analyzed. The effect of material properties of the influencing surfaces on the wear rate and hardening of surfaces has been discussed. Wear rate under severe sliding conditions is thus strongly influenced by the geometrical and hardness characteristics. The wear rate of used brake disc rotor induced fatigue phenomena is accurately identified. Correlations between design specifications and real surface characteristics are evaluated. The results showed that implementation of the engineering metrology techniques to understand and predict the dynamic behaviors for auto brake discs are necessary successful. Moreover, repeatability of the measurement results is conducted to confirm their precision.

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INTRODUCTION

Metrology can be used as an identification method for diagnosing of the mechanical system parts. Accurate and precise measurements are necessary to satisfy the compliance of the product design, performance, safety and ride-conformability requirements, especially for auto braking system. Identifying accurate method to link geometrical specification and inspection processes is a wide research topic. The growing use of auto spare parts as feeding industry also needs geometrical and material information as well as other information about the operation and processes to be understood. The main purpose of braking system is to slow down or stop a vehicle by transforming kinetic energy into frictional heat. The auto brake system consists of rotating-disc with caliper or -drum carries brake fluid to enable the brake pads or shoes to be pushed against the rotor (disc or drum) with adequate pressure. Nowadays, brake systems in modern vehicles are mostly designed as one of two typical configurations on the front and rear axles [1]. The braking system on automotive front axle is so important than of rear axle brake due to its applied dynamic load. The brake disc provides braking due to rubbing surface for brake pads against disc rotor surface when brake force is applied. A brake disc rotor is a metallic part with friction surface on both sides. This type of rotors is easy to manufacture, inexpensive and commonly used especially in commercial

transportation like passenger cars, mini- and micro-buses. Normally, brake disc is made of grey cast iron due to its good thermal stability, good castability [2] with good strength material. There are two main types of disc-brake calipers; floating caliper or fixed one. The floating caliper, single piston design has simple guides built up and low cost to manufacture and service. Fig.1 illustrates a typical floating caliper used in automotive disc brake.

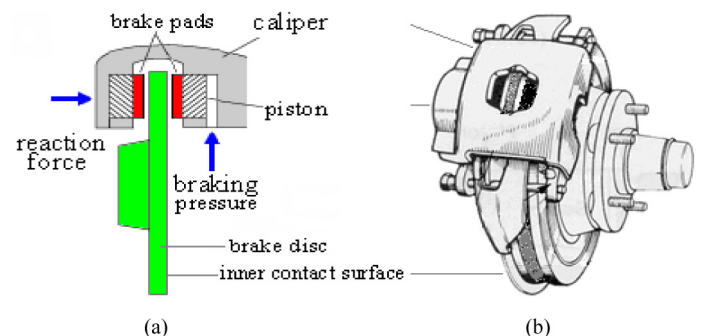


Figure 1. Auto disc brake

Study of dimensions and geometrical parameters has significant influence on the automotive brake design and performance. The study of the surfaces of frictional coupled surfaces surface roughness and

surface shape have direct effect on the braking performance quality and acoustic noise response [4, 5, 6]. Whereas, the type of component and its concentration in the frictional composite materials have important effect on the mechanical properties and friction stability of the automotive brakes [7, 8, 9]. On the other hand, there are other numerous studies focused on the phenomenon according to mechanical and tribological properties under dry surface sliding conditions. The nonlinear behavior of a one-dimensional model for the brake disc and pad contact is examined theoretically to predict the mechanical response of the nonlinearity resulting possible irregular motion [10]. Experimentally, the temperature rise has a significant effective parameter on the tribological properties of the disc material. It is known that the sliding wear is dependent on the modulus of elasticity, where the wear rate increases as the elasticity modulus decreases. Thus, it can be notify that, increases of frictional temperature will increase of the both friction coefficient and wear rate of the friction couple significantly [11]. Thermo elastic instability (TEI) based on generated hot spots in the apparent contact area were analyzed in some published papers [12, 13, 14, 15]. It is used to determine the source of joint effect of wear and thermal expansion at high-temperature hot spots. Other research shows experimental and numerical analysis of the thermal and tribological processes for wheel/ brake block system during braking, particularly in the running-in phase [16]. For crack-tolerant design and remaining life prediction of high-temperature mechanism, it is important to investigate fatigue crack propagation behavior [17, 18]. A large number of research papers are investigated in recent years on fatigue crack propagation. Most of them have been studied on the crack under creep due to thermo mechanical fatigue (TMF) conditions which refer to a thermal cyclic loading under increased mechanical loading effect [19]. The existence of any defect in these parameters produces fatigue and surface crack lead eventually failure to the brake discs. It can be seen that the effect of the dimensional and geometrical deviation on the brake performance needs more research. The main objective of this paper is projected to investigate four proposed identification metrological techniques which can be used to characterize the brake disc rotor experimentally. These metrological techniques include dimensional, tribological, and chemical investigations. Aggressive wear rate of used brake disc has been also investigated. Results of implementing a developed dimensional and geometrical deviation assessment of proposed identification method has been presented, discussed and interpreted. The results of developed method of identifications can be useful to design, quality control in manufacturing processes and safe service assurance during brake system service lifespan. Helps in understanding of TEI and TMF phenomena for auto brake discs due to thermal-mechanical coupled loads are another important objective. Moreover, standard deviation resulting from metrology method has been determined and confirmed the precision degree of confidence in the proposed identification measurements.

MATERIALS AND DIAGNOSIS TECHNIQUES

Specifications of Auto Brake Disc

The overall specification of two widely used commercial brake discs is given in Table 1. The two discs are manufactured by two manufactures to the same specification. A typical disc to the second disc (disc-2) is put under working conditions in actual braking system till fatigue propagation.

Standard Requirements of the Brake Disc

The standard dimensional and geometric specification requirements are shown in Table 2. These values are according to agreement addendum 89: regulation No. 90, revision 3, section 5.3.3.1 [20].

Measurement Method of Brake Discs

Advanced engineering metrology and practical tests are conducted in this research. PRISMO-CMM machine, INSTRON Universal Hardness tester and Sartorius mass comparator techniques have been used. The CMM coordinate measurement system has been used to uniquely determine the position of a point or geometric element. Geometry of form, location, position and orientation have been performed for the basic geometric elements and forms analyses. Disc thickness and thickness variation, parallelism, lateral run out and straightness form have been detected accurately. Hardness and wear rate measurements are also necessary parameters for the brake disc rotors diagnosing, consequently, their evaluation are important. Existence of any defect in these parameters will case different phenomena leads to failure of the brake discs

CMM Measurement Strategy

PRISMO-CMM-bridge-type machine is used with the following mean specifications:

- Head Type: VAST head probe stylus
- The permissible error: $(0.9 + (L/360)) \mu\text{m}$
- The maximum permissible error: $1.9 \mu\text{m}$
- Resolution: $0.1 \mu\text{m}$
- Room temperature: $20 \pm 0.5 ^\circ\text{C}$
- Relative humidity: $50 \pm 5\%$

The CMM is verified using master probe to evaluate Standard sphere and using standard sphere to evaluate used probe to insure the CMM measurement quality [21]. The maximum permissible error according to the ISO 10360-2 Standard [22, 23] of the used CMM machine has been judged. The standard deviation (SD) of measurement in the CMM verification strategically conditions has been presented. In addition, the probe specifications and the operating conditions have also been specified. Table 3 includes the specifications for the CMM set up measurements strategy for brake discs surface detection. Experimental setup of the features measurements using CMM for the brake discs are shown in Fig.2. Fig. 2(a) and (b) show the fixation of new discs on the CMM granite plate, while the used disc is shown in Fig. 2(c).

Table 1. Specifications of the new brake discs

Types of brake discs	New brake disc-1	New brake disc-2
Manufacturer	A	B
Manufacturing Code	KGC	XJ
Serial number	55311-1	---
Part number	945840	---
Material base	Gray cast iron	Gray cast iron
Outer diameter, D_{out} , mm	215.41	215.41

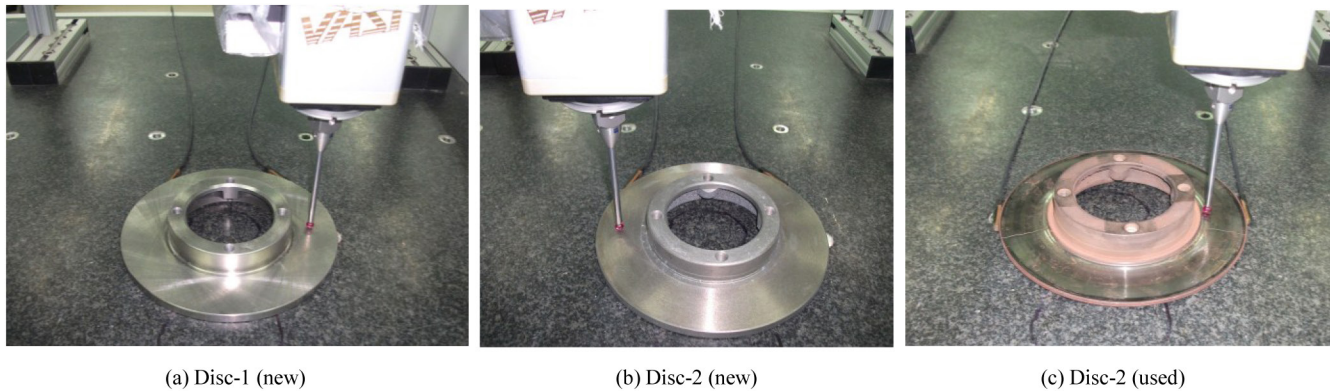


Figure 2. Measurement setup of dimension and geometrical diagnosing for brake disc rotors using CMM

Table 2. Recommended values of auto brake discs

Parameters	Values	
	Minimum	Maximum
Thickness variation (DTV), mm	0.015	0.030
Lateral run-out friction surface, mm	0.050	0.15
Top hat parallelism, mm	0.100	0.100

- Model Type: CC 50002
- Uncertainty: 1.6 mg
- Resolution: 2 mg
- Measuring range: 1-50 kg
- Room temperature: 20 ± 2 °C
- Relative humidity: $42 \pm 3\%$

Table 3. Measurement strategy using CMM set-up for brake discs

Strategic parameters	Brake discs-1&2 (new)	Brake disc-2 (used)
Used probe, R, mm	4.0003	4.0003
Used probe, L, mm	114.5	114.5
Used probe, SD, mm	0.0002	0.0002
Machine speed, mm/s	50	50
Scanning speed, mm/s	10.0	1.0
Contact force ratio, %	100	100
No. of points in 35 mm STR length for frictional surface circumference	34 $\pm$ 1	34 $\pm$ 1
Magnification ratio	1:2000	1:10

Other chemical analysis of brake discs has also been investigated. The high-speed X-ray fluorescence (XRF) spectrometer technique has been used for chemical analysis of metallic samples from discs composition. The XRF spectrometer technique is used with the following mean specifications:

- Model Type: AXIOS^{mAX}-Advanced
- Resolution: 0.0001 gm
- Room temperature: 20 ± 2 °C
- Relative humidity: $43 \pm 5\%$

Samples of the material are formed into plates taken from frictional surfaces of brake discs. The samples are also machined for easy access to ingredients of materials as a bulk. The observed properties of metallic particle are compared to those of other research results for determine the required variation in brake disc formulation. The carried out results are presented details.

Mechanical, tripological measurements and chemical analysis

Mechanical and tribological properties such as hardness and wear rate are measurements. Surface hardness of the brake discs inner and outer faces has been carried out on the INSTRON universal hardness tester using Brinell scale (HB): HBW 1/30 according to ISO 6506-1, 2005 in NIS [24]. The INSTRON universal hardness tester is used with the following mean specifications:

- Model Type: INSTRON-WOLPERT 930
- Uncertainty: 0.485%
- Resolution: 1 HB
- Room temperature: 20 ± 5 °C

Sartorius mass balance comparator has been used to measure the mass of brake discs before and after use in NIS. The Sartorius mass balance comparator tester is used with the following mean specifications:

EXPERIMENTAL RESULTS AND ANALYSES

Dimensional and Geometrical Result Analysis

Parallelism

The error of parallelism variations for three brake discs using CMM measurement strategy is discussed. The recorded results for evaluated brake discs give SD values of 0.0010, 0.0002, and 0.0017 mm, respectively. The maximum SD due to repeatability in measurement for brake disc does not exceed ± 0.0017 mm. It ensures that measurement of new discs is suitable for this work piece to satisfy the high level of accuracy. Fig.3 shows the averaged deviations of parallelism locations between two different new discs (disc-1; -2) compared to the used disc. The relative deviation in parallelism measurement of the new discs may be due to the quality of machining process or microstructural kind of used cast iron alloy. The average of