Non-destructive Research of the Friction Surface of the Brake Discs in the Aspect of Braking Process Evaluation

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Abstract. Because of numerous advantages in comparison to a traditional air block brake, disc brakes, are more and more often utilized in passenger carriages and other railway vehicles. Stable and constant - in the whole speed range- coefficient of friction μ, with the value: μ=0.35 is a basic advantage of disc brake systems. Exploitation of disc brake systems showed that faster wear of friction surface occurs with braking at a very high speed or braking in short time periods. Micro heat cracks appear on the disc surface and enlarge radially at consecutive braking. Stationary tests of brake discs and own liquid penetration tests proved that heat cracks appear yet on new discs after performing a few hundred braking. First heat cracks around inside diameter were noticed only during liquid penetration tests. Next braking on testing station revealed first cracks less than 7mm long. The cracks can be noticed without any magnifying equipment. However, the occurrence of first heat cracks does not exclude further use. Only development to dangerous sizes on the whole brake disc breath requires exchange of the disc or its rebuilding through re-turn of the friction surface. With increasing length of micro cracks increases their depth, which also weakens the material of the brake disc. In further operation may also affect the gap of the brake disc. Length evaluation of micro cracks is easy and simple through methods that allow non-destructive optical or penetration testing. However, in the case of the depth of the micro cracks, the situation is more complex. The wear of the friction surface of the brake disc affects the instantaneous and the average coefficient of friction during braking of the vehicle.

The purpose of this article is to present the research results of the friction surface of the brake disc in the aspect of assessment of the length and depth of the micro cracks methods non-destructive. The second purpose of this article is to present the effects of wear of the friction surface of the brake disc in the braking process, in particular, to the change of the instantaneous and average coefficient of friction.
**Introduction**

In rail vehicles, both in trains and trams a disc brake which cooperates with an electrodynamics brake is also a friction brake. In the case of ED brake, and decrease in braking force, in the last phase of braking, the friction brake is applied. This braking system is found in vehicles equipped with traction engines, which during the braking process work as generators that produce additional resistance. In the case of passenger cars the brake disc is the only primary brake; in some cases of cars it additionally cooperates with the rail brake that runs during emergency braking. [3]

The preservation of the brake system efficiency in the whole process of running the vehicle is an extremely important aspect and is controlled by number of procedures performed during warranty inspection and periodic inspections. After 12-months of utilization, in accordance with [2], an annual inspection is performed. Figure 1 shows a general view of the railway brake disc and the scheme of the brake caliper with the disc.

![a) Railway disc brake, mounted on the wheelset axle: a) view, b) scheme.](image)

In addition to the normal (operational) friction wear of the brake disc surface, which develops as a result of dry friction with the friction pad, on the basis of [5], the ruptures which occur on the working surfaces of the brake disc, have been divided into:

- unilateral cracks across the width of the friction ring,
- cracks on both sides over the entire width of the friction ring,
- cracks on the portion of the friction ring,
- surface cracks (micro cracks),
- concave (concave friction surface grooves),
- grooves and chipping of the disc material.

Figure 3 shows the division of damage and the view of the most common cracks on the surface of the brake discs.

Long-term observation of brake discs showed that the largest group of defects constitute surface cracks (micro cracks) occurring on the friction surface. It is very dominant damage that occurs faster than the normal frictional wear of the brake disc due to the friction of the friction pad against the brake disc [6]. Friction rings for example, ventilated discs have a thickness of 20 mm with an allowance of wear 4mm. With the width of the ducts - 70 mm, the total thickness of the disc in accordance with [4] is 110 mm without applying an excess material.
1. Penetration testing of the braking discs friction rings

Stationary tests of brake discs and own liquid penetration tests proved that heat cracks appear yet on new discs after performing a few hundred braking. First heat cracks around inside diameter were noticed only during liquid penetration tests. Those heat cracks are presented in Fig.3. Further braking on testing station revealed first cracks less than 7mm long. The cracks can be noticed without any magnifying equipment as Fig.4 presents.

Fig. 2. Damage to the brake discs, a) schematic division, 1- single-sided crack on the whole disc brake breadth, 2- double-sided crack on the whole disc brake breadth, 3- crack on a part of disc brake breadth, 4- concavities, 5-surface cracks, 6-grooves, 7-spallings, b) crack view across the width of the brake disc c) crack view on the part of the friction ring, d) view of the surface crack

Fig. 3. The condition of disc after first braking: a) before liquid penetration tests, b) after liquid penetration tests [7]

Fig. 4. The condition of disc after consecutive braking: a) before liquid penetration tests, b) after liquid penetration tests [7]
However, the occurrence of first heat cracks does not exclude further use. Only development to dangerous sizes on the whole brake disc breath requires exchange of the disc or its rebuilding through return of the friction surface [7].

2. Thermal research of the brake friction rings

Friction testing of brakes in both rail and cars, is carried out first on braking position. According to the adopted research programs, various tapes of braking, which simulates the conditions under which the braking system operates are carried out. Braking are made from the specific speeds with different pads pressure to the disc and with different masses to a deceleration. The main parameters recorded during the measurement are: the force of pads pressure pads to the disc, the force on the circumference of the wheel (which allows you to calculate instantaneous and average coefficient of friction according to the equation (1) and (2)), deceleration, disc temperature, braking distance and other.

\[
\mu_a = \frac{F_t}{F_b}
\]  

\(\mu_m = \frac{1}{s_2} \int_0^{s_2} \mu_a \, ds\)

where: 
- \(F_t\) – temporary tangential force relative to the radius \(r\) of the braking,
- \(F_b\) – the total temporary pressure on the brake disc,
- \(s_2\) – braking distance.

Fig. 5. View of the new brake disc: a) scan, b) thermal image

Fig. 6. View of the wear brake disc: a) scan, b) thermal image
In addition, the authors of the article during the position studies have registered images of the brake disc by using a thermal imaging camera FLIR e60. At the stop time IR camera also allows for the observations of micro-cracks, barely visible to the naked eye (Fig. 6) and chipping, as shown in Figure 7. While the view of the new disc with both a digital camera and infrared camera after the first brakes is shown in Figure 5.

3. Surface cracks depth measurement

In the operation and maintenance manual of passenger cars [5] in the maintenance of the brake disc an information about the number and length of surface cracks, the friction ring replacement with a new one or roll are included. In contrast, very few documents provide and additional maximum depth of the cracks, without giving a measurement method and the type of measuring instrument. In such cases of crack it is good to use RMG 4015, a dipsticks cracks interruption probe. Determination of crack depth by means of interruption probe in accordance with the [8] is based on measuring the electrical resistance between two points on the metal surface of the tested object. In case where between these two points is a crack, the electrical resistance is higher than for the surface without cracks. Resistance will grow along with the unknown crack depth. Crack depth (penetration) in the frequency domain for a given material is described by the relationship (3) from [8]:

\[
\delta = \frac{1}{\sqrt{f \cdot \pi \cdot \mu \cdot \mu_0 \cdot \sigma}}
\]

where:
- \(\sigma\) – specific electric conductivity,
- \(\mu\) – Relative permeability,
- \(\mu_0\) – permeability constant,
- \(f\) – frequency.

Figure 8 shows a view of the device RMG 4015 with probes for perpendicular cracks to the surface (Fig. 8a)), and the cracks occurring at a 45 ° angle to the surface (Fig. 8b)).
For a non-destructive testing with the use of the RMG 4015 device, two segments of the brake disc type BK141 were used. The first segment came from the disc, wherein only one break occurred on the part of the disc width (Fig. 9a)), while another segment derived from the disc, wherein only surface cracks occurred (Fig. 10a)).
Fig. 10. The surface cracks (micro cracks) on the ring rail brake disc: a) a grid view of micro cracks on the segment of the BK141 disc type, b) a cross-section through a crack with a length of 64 mm, c) a cross-section through a crack with a length of 24 mm, d) the cross-section through the crack length of 40 mm.

Fig. 11. Coefficient of friction obtained on the new and regenerated braking disc: a) Values of coefficient of friction, b) average coefficient of friction.
The study conducted on the two brake discs (new and regenerated with visible surface cracks after rolling) proved the fluctuations of the average coefficient of friction in the case of the disc of micro cracks. In Figure 11 it is observed that for the regenerated disc, in subsequent brakes with the same initial conditions, some of $\mu_m$ are beyond the lower deviation tolerance of friction which was imposed by the UIC 541-3 card.

4. Conclusion

The most common failures of the brake disc include surface cracks, which grow radially in subsequent braking across the disc surface. This in turn leads to unilateral or bilateral cracking by the merger of the individual micro-cracks. At present it is difficult to give one cause of these cracks. They are mainly the consequence of variable compressive stress and tension occurring during braking. Resistance of the disc material for this type of stress and the type of braking can slow down their growth, which will be connected with the prolonged use of the brake discs.

Surface cracks (micro cracks) of the new brake discs appear first in the vicinity of the inner diameter of the friction ring, which is not visible to the naked eye and gradually grow radially to the outer diameter, which is proved by the authors through penetrate testing.

On the basis of the thermal study on the braking position, it was found that due to the thermal imager it is possible to evaluate the state of the friction surface of the brake disc in respect of the identification of micro cracks and chipping of the brake disc material. The use of IR cameras is an alternative to penetration testing, however, it is necessary to heat up the brake ring by braking even from the lowest speed. In the case of penetration testing, there are no restrictions. Thus, both methods can be used interchangeably in the disc brake study.

The use of the RMG device by Karl Deutsch is the only way to determine the depth of cracks on the surface of the brake disc. It is very important, because due to the thickness of the friction rings (for railway brake discs the range is 20-24mm), it is possible to determine whether the crack is not straight through.

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