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Estimation of Crack Depth and Profile Using DCPD Method in Full Scale Railway Axle Loaded by Rotating Bending

Ivo Černý[1,a]

[1]SVÚM a.s., Tovární 2053, 25088 Čelákovice, Czech Republic

[a]Ivo.Cerny@seznam.cz

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Abstract. Safe life design philosophy has been used as a standard approach in railway vehicles for many years and has been incorporated in railway design standards being used by present days. However, in connection with recent rapid increase of railway vehicle speed, weight reduction of railway vehicles and particularly suspension components and wheelsets as unsprung mass started to be an important issue. A significant weight reduction is not possible without full exploitation of material properties close to their limits. At such circumstances, damage tolerance (fail safe) approach has to be considered. Knowledge about fatigue crack propagation characteristics belongs to most important and most needed material characteristics. Particularly data about fatigue crack rate in full scale components – axles and data about crack shape and crack front are one of the essential characteristics necessary for a safe and reliable application of damage tolerance principles.

The paper contains results of a study aimed at exploring possibilities of use of direct current potential drop (DCPD) method for evaluation of depth and profile of cracks occurred under or near press fitted hubs in a full-scale axle during severe rotating bending loading. DCPD method was applied on section of an axle after fatigue by a specific way and potentials were measured in several circumferential areas of the axle section, when direct current passed longitudinally. Results are analysed and discussed. It was indicated that unlike previous use of the method for crack measurement of different components, even large and complicated, described in the literature, when potentials corresponded to ratio of cracked and uncracked area, in this case of approximately circumferential crack, measured potentials correspond better to relative crack depth in the relevant point of the circumference.

Introduction

In metals, an occurrence of a fatigue crack usually does not result in a observable different behaviour of the component. Fatigue cracking process is strongly localized with no clearly observable global property changes of the component. This is the reason why in the beginning of railway transport, the first enthusiasm was quickly replaced by an occurrence of very serious crashes caused by fatigue cracking of axles, with a lot of people killed [1]. Note that an existence of fatigue S.N curves was namely discovered in connection with fatigue cracking of railway axles.

In railway axles, usually press fitted or shrink fitted in wheels, two main characteristics of resistance against fatigue damage have to be evaluated and proved: (i) sufficient fatigue resistance of the smooth part of the axle on its free surface and (ii) fatigue resistance under press fit (or shrink fit). Railway axle design and certification standards lay down minimum values of fatigue strength for the material used, evaluated using small rotating bending specimens, fatigue strength of full scale axles, considering scale effects and also fatigue strength under press fit, the latter damage mechanism being the most complicated [2]. More sophisticated design, research and verification approaches may need even more detailed information on results of the full scale fatigue tests, like knowledge about depth and profile of circumferential fatigue crack after interrupting the test. The paper contains results of a dedicated study aimed at exploration and verification of possibilities to use direct current potential drop (DCPD) method with the analytical calibration for such purposes.

Experiments

Full scale model of an axle of diameter 230 mm, made of the C45 steel, was shrink fitted in hub. The component was tested in rotation bending using a last model of Sincotec testing facility. During the test, the component was in vertical position, the hub being fixed to the base of the machine and the rotation bending load was applied through an eccentric mass attached to the top of the axle. The test was performed with the constant nominal stress amplitude of ± 90 MPa at the hub edge.

After more than one million cycles, a distinct drop of frequency was observed indicating an occurrence of a crack. Consequently, the test had to be interrupted. The question, however, was, whether a crack in the axle actually was initiated and if yes, where it was located, what was its depth and shape – profile. This information was needed for further analyses and investigations.

In the first step, the axle was pressed off from the hub and the press fit area was carefully examined. No crack was visible on the surface not only by eye, but also after application of capillary NDT method. First indication of a very thin crack was obtained after an application of fluorescent magnetic particle method – Fig. 1.

In the next step, before cutting and sectioning the piece, a sophisticated circumferential measurement using DCPD method [3, 4] was carried out. During the measurement, direct current passed though the axle section in the axial direction and potentials were measured using electrodes, attached close to the area of possible crack at eight circumferential positions – Fig. 2. Potential electrodes, measurement and references ones, were attached at each 45o. Besides main of electrodes near crack mouths, rows of electrodes were placed outside the crack area to be sure that such electrodes no not indicate any crack.

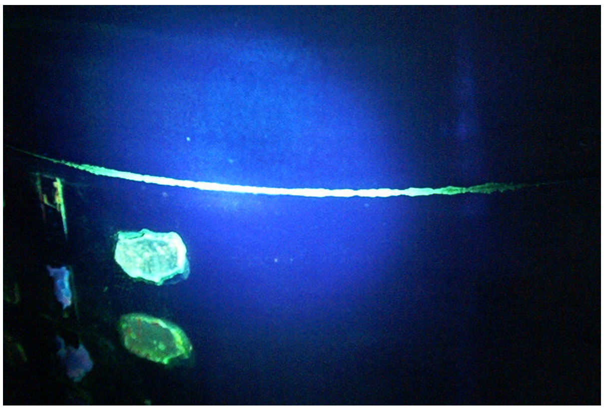

Fig. 1. Indication of fatigue crack using fluorescent magnetic particle method.

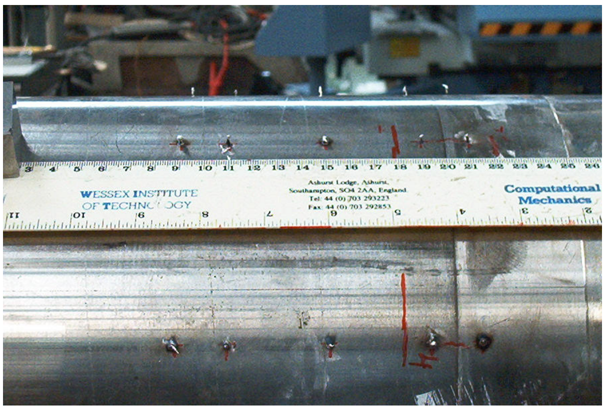

Fig. 2. Rows of potential electrodes at eight circumferential positions of the section.

Experimental Results and Discussion

Results of the DCPD measurement indicated significant differences between values of crack depth along the circumference. The values are shown in Fig. 3. There was a distinct maximum near the position No. 8. On the other hand, concerning the measurement outside the crack, potential values V(a)/Vref were constant over the whole circumference, the ratio value being 0.5, which corresponds exactly to the mutual distance ratio of the electrodes, 20 mm / 40 mm, It indicates that the measurement was correct.

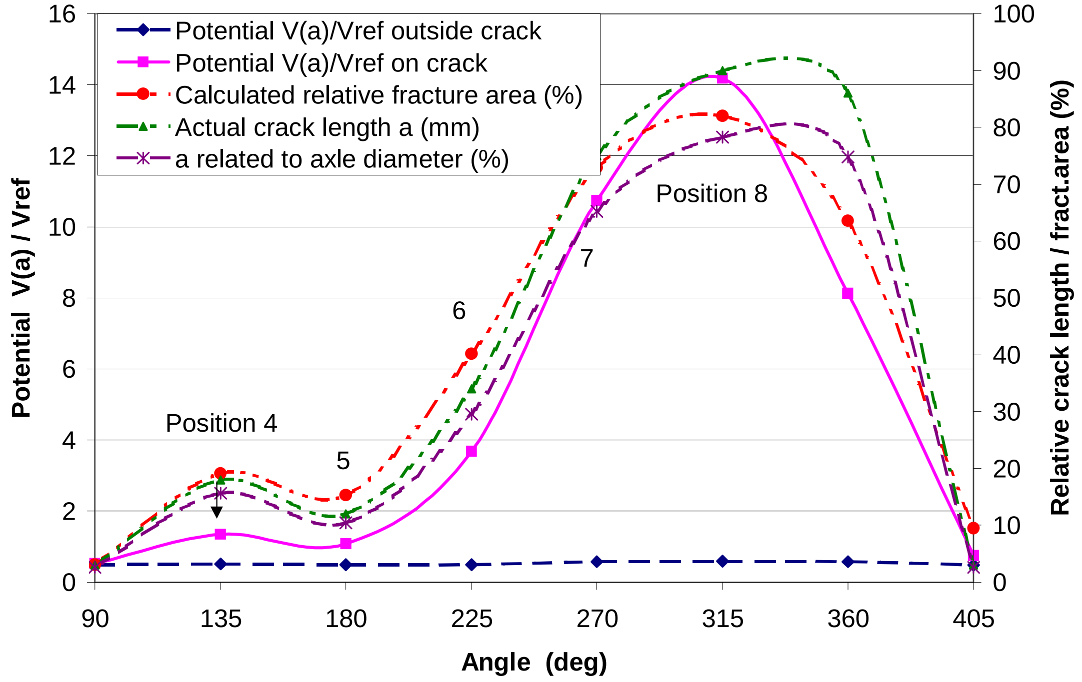

Fig. 3. Results of DCPD measurement outside crack and on crack (related to the left axis) together with calculated length and actual crack length measurement (right axis).

In the next step, circumferential crack depth was estimated by calculations using modified Johnson's formula [4], with the approach of considering ratio of cracked an uncracked part of cross section area. These results, expressed in %, are indicated by red line, against right axis. Additionally, the calculated crack length was expressed in terms of crack length related to the axle diameter.

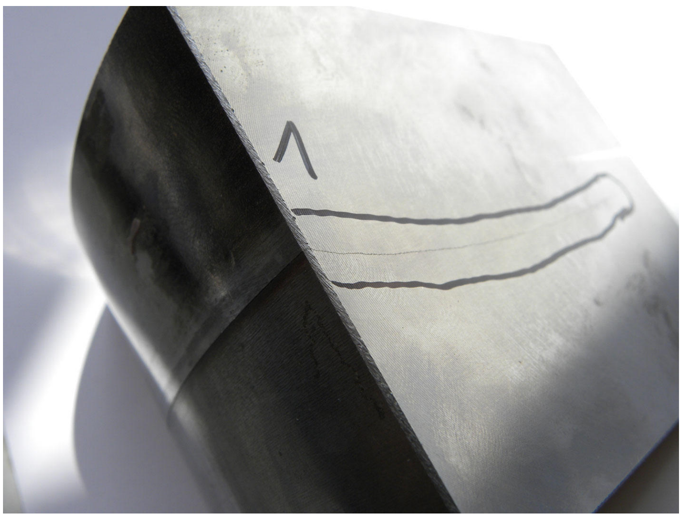

Fig. 4. Thin crack in the axle visible after sectioning.

In the finals step, the axle was further radially sectioned to eight segments and crack depth was exactly determined at the eight positions using metallographical methods. The crack was very thin, but it was surprisingly quite deep. An example is in Fig. 4.

Eventually, actually measured crack depths were expressed graphically – Fig. 5.

The uncracked area represents, with an exception of one point an ellipse with main and minor axis of length 198 mm and 132 mm, respectively. Considering the overall axle cross section of 230 mm diameter, the uncracked area represents almost exactly 50 % of the total axle cross section area. It indicates that for circumferential cracks, unlike thick wall pipes, the approach of relative fracture area is not too exact. It looks that much better agreement can be reached if crack lengths are calculated form the DCPD measurement as a relative ratio of actual crack length to cross section diameter.

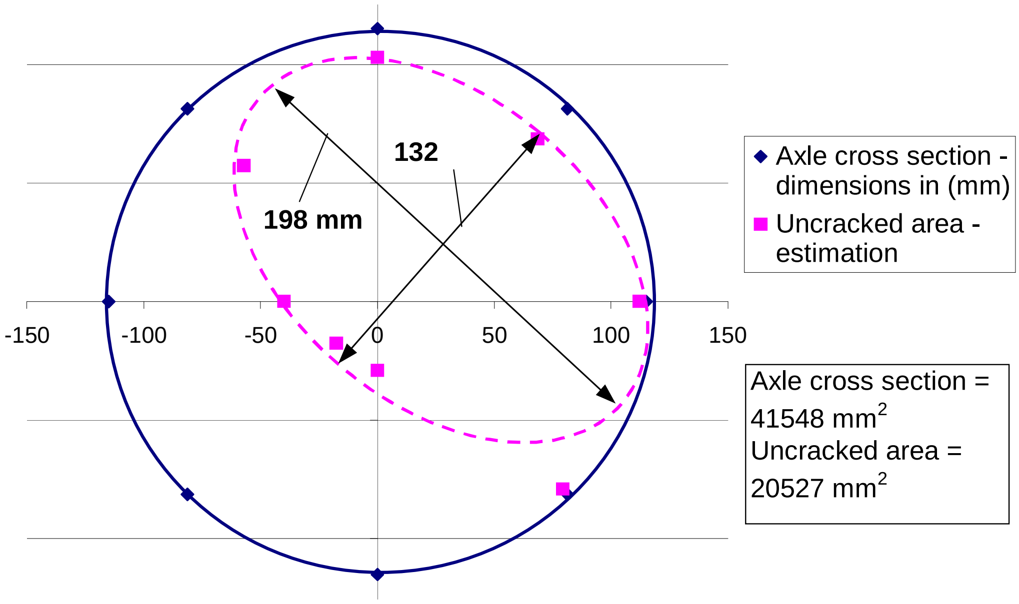

Fig. 5. Graphical expression of approximate circumferential crack depth.

Conclusions

Study aimed at exploring possibilities of use of DCPD method for evaluation of depth and profile of cracks occurred under or near press fitted hubs in a full-scale axle during severe rotating bending loading was carried out. DCPD method was applied on section of axle after fatigue by a specific way and potentials were measured in several circumferential areas of the axle section. The main results can be summarized as follows:

- DCPD measurement indicated significant differences between values of crack depth along the circumference.
- For circumferential cracks, unlike thick wall pipes, the approach of relative fracture area is not too exact. Much better agreement can be reached if crack lengths are calculated form the DCPD measurement as a relative ratio of actual crack length to cross section diameter.

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