

Ultrasonic detection of cracks in wheel set axles

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This paper presents a means of testing railway carriage wheel sets with ultrasonic probes mounted on the cylindrical surface of the axle between the bearing and the wheel disc. The results of tests show that the method provides a consistent coupling efficiency, using liquid coupling, while the probe is rotated on the smooth cylindrical surface of the axle collar.

Keywords: railway carriage wheel sets, ultrasonic testing, fatigue cracks, steel

Railway carriage wheel sets have been ultrasonically tested for more than 30 years^[1]. Nondestructive testing is performed during their reconditioning. The main task of periodic testing is detection of fatigue cracks which may occur at the surface of wheels and axles.

Cracks on the axle usually emanate in planes perpendicular to the axis of the axle. The areas where cracks occur, their nature and geometry are well known, and since the geometry of axles is standardized, automatic axle testing becomes a possibility^[2]. However wheel discs and bearings mounted on the axle limit the accessible surface for ultrasonic probe coupling and cause problems with detection of some flaws. During manual or automatic testing, fatigue cracks in the journals under the bearings are detected from the front face of the axle or, after removal of the bearing and its inner ring, from the accessible cylindrical surface of the journal.

The end surfaces of axles have different shapes depending on the type of axle. Consequently the axle end is not always a suitable site for ultrasonic probes. In addition the surface finish is not conducive to good coupling. Further problems are encountered due to the machining of the axle ends. To accommodate drilled holes, special probes called centre-punch probes are constructed. Surface roughness and small contact areas of such probes with the axle cause coupling problems and consequently maintaining a pre-determined sensitivity of testing becomes difficult. Testing from the end surface also requires special devices for probe positioning.

This paper presents a method of ultrasonic detection of fatigue cracks in the journal and in the axle collar with probes positioned on the cylindrical surface of the axle between the bearing and the wheel disc. Testing with such probes can be conducted without removal of the bearing or its guard and probes are coupled to a smooth surface.

Testing method

Figure 1 shows part of the wheel set assembly with bearing, wheel disc and the position of the flaw on the journal, Crack No 1. Testing for this flaw is performed with two angle probes acting as a transmitter and receiver respec-

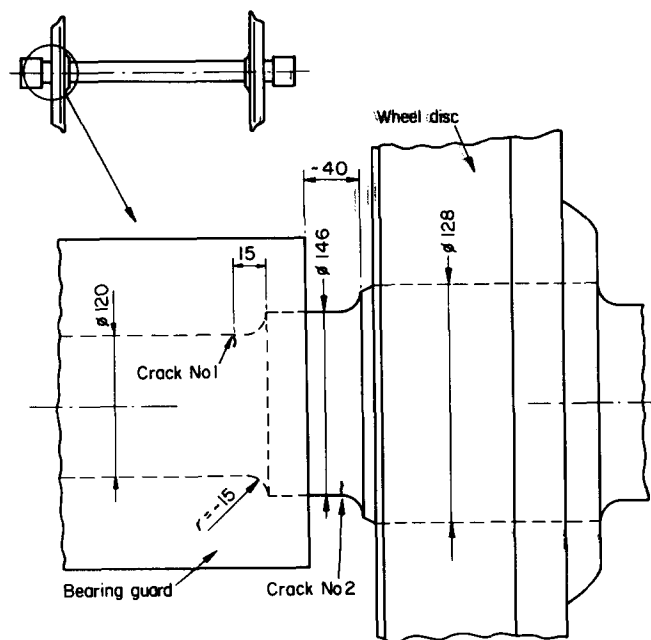


Fig. 1 Wheel set assembly with bearing, wheel disc and position of cracks on the journal (Crack No. 1) and on the axle collar (Crack No. 2)

tively. Both probes are situated on the axle collar symmetrically to the plane determined by the longitudinal axis of the axle and the crack centre. Ultrasonic pulses from the transmitting probe propagate directly to the corner formed by the crack and the cylindrical surface of the journal and reflect to the receiving probe. Its path in the material is shown in projection in Figure 2a. Figure 2b shows the cross section in the plane determined by the ultrasonic pulse path between transmitter and crack, and point O on the axle axis marked in Figure 2a.

The position of the probe centre can be changed by rotation around the axle (angle ν) and by its displacement along the axle (distance A). The axial movement is limited by a bearing guard on one side, by the wheel hub on the other and by the length of the probe.

The geometry of the incident wave is described by angles γ and δ , shown on Figure 2. The values of angles ν , δ , σ and β

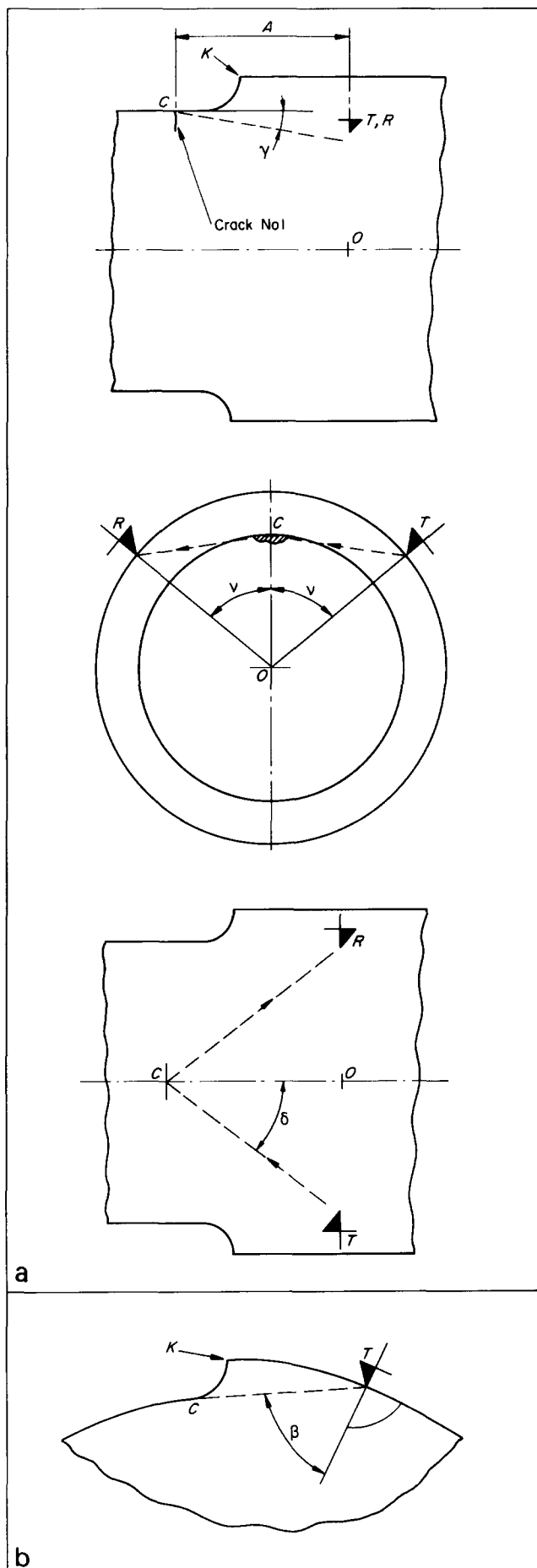


Fig. 2 Path of the ultrasonic pulse in an axle: (a) angle of incidence γ , δ , and position of probes A , v , (b) angle of refraction β

are related to each other and depend on the diameter of axle journal, the axle collar and the distance A . For any position on the probes the angle of refraction β should result in a direct reflection of the ultrasonic pulse from the crack.

For longitudinal waves the transmission coefficients for perspex-steel (T_{ps}) and steel-perspex (T_{sp}) boundaries and the reflection coefficient at a steel-air interface (R) are well known^[1] and are given by:

$$T_{ps} = \frac{2}{N} \cos 2\alpha_t$$

$$T_{sp} = \frac{2}{N} \frac{\rho_p c_p \cos \alpha_l \cos 2\alpha_t}{\rho_s c_l \cos \alpha}$$

$$N = \left(\frac{c_t}{c_l} \right)^2 \sin 2\alpha_l \sin 2\alpha_t + \cos^2 2\alpha_t + \frac{\rho_p c_p \cos \alpha_l}{\rho_s c_l \cos \alpha}$$

$$R = \frac{(c_t/c_l)^2 \sin 2\alpha_l \sin 2\alpha_t - \cos^2 2\alpha_t}{(c_t/c_l)^2 \sin 2\alpha_l \sin 2\alpha_t + \cos^2 2\alpha_t}$$

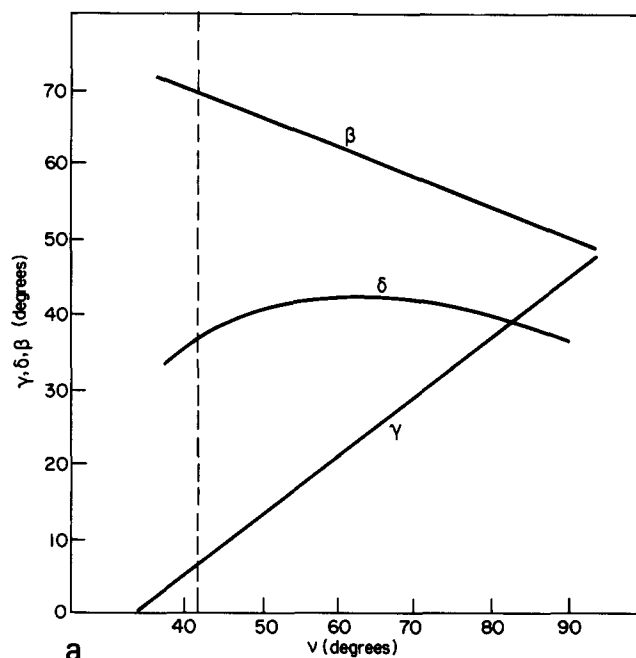
where: ρ_p , ρ_s = densities of perspex and steel; c_p , c_l = velocities of longitudinal waves in perspex and steel; c_t = velocity of transverse wave in steel; α = angle of longitudinal wave in perspex; and α_l , α_t = angles of longitudinal and transverse waves in steel.

When using longitudinal waves for crack detection, the values of these coefficients, neglecting the flaw dimensions, wave attenuation and ultrasonic beam divergence, influence the amplitude of the pulse detected by the receiving transducer. Figure 3a shows the dependence of incident angles γ and δ on the corner and angle of refraction β for different probe positions described by angle v . It is assumed that the crack surface is perpendicular to the longitudinal axis of the axle and the distance between crack and probe centre measured along the axis is 65 mm. Figure 3b shows changes in the longitudinal wave reflection coefficient R_c at the corner. This coefficient is calculated as a product of coefficients at both the crack (R_f) and journal (R_j) surfaces.

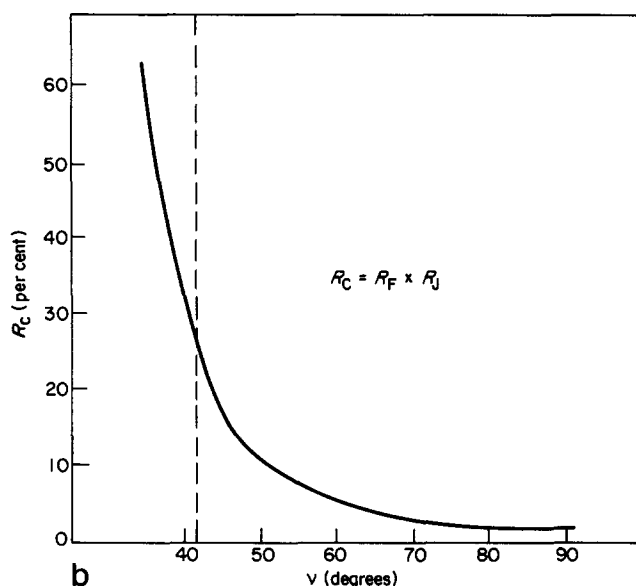
In order to obtain the maximum amplitude of the reflected pulse, the probe position for small values of angle v is optimal, while for angles of v up to about 40° , the crack is covered by ultrasonic pulses due to the axle diameter drop between the journal and collar.

The limiting value of angle v which allows the ultrasonic beam to reflect directly from the corner for crack positions as in Figure 1 is 42° . For such probe positions, on the circumference and at a distance of 65 mm, the values of angles γ , δ and β are 4° , 37° and 71° respectively.

The second flaw which can be detected with probes coupled to the axle collar surface is the crack on the collar situated close to the wheel hub, shown in Figure 1 as Crack No 2. Testing of this region can be performed by means of two angle probes for longitudinal waves acting in transmitter-receiver mode. The angle of refraction for these probes is close to the second critical angle, and the angle between the ultrasonic beams is equal to 37° . A schematic of crack detection with such a set of probes is shown in Figure 4.



a



b

Fig. 3 Relationship of: (a) incident angles γ , δ and refraction angle β with ν , (b) reflection coefficient of the corner R_c with ν for $A = 65$ mm

Spacing between the probes and their dimensions must be small enough to place both of them as shown between the bearing guard and the wheel.

Results

The detectability of flaws was examined with models of ultrasonic probe heads. Testing was performed on artificial flaws of different depth and form, cut on the axle surface where fatigue cracks might be expected. Transducers with diameter 20 mm were used for cracks on the journal and diameter 13 mm for cracks on the axle collar; both were of 2 MHz frequency, with a perspex refraction wedge adopted to the axle diameter. A probe model was built in a housing, its dimensions and position on the axle during testing being shown in Figure 5.

Artificial flaws in the shape of circular segments were selected at 2 mm maximum depth. These are often used as

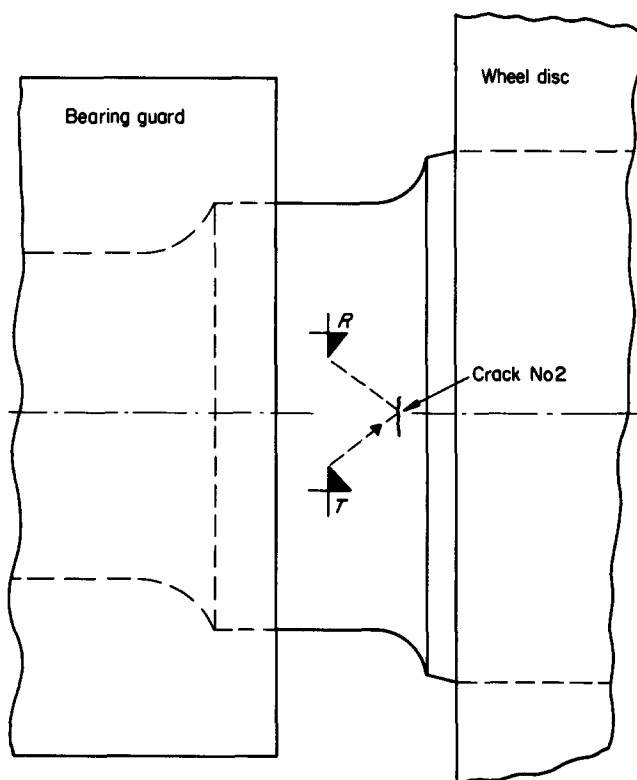


Fig. 4 Method of detection of Crack No 2 with two angle probes for longitudinal waves

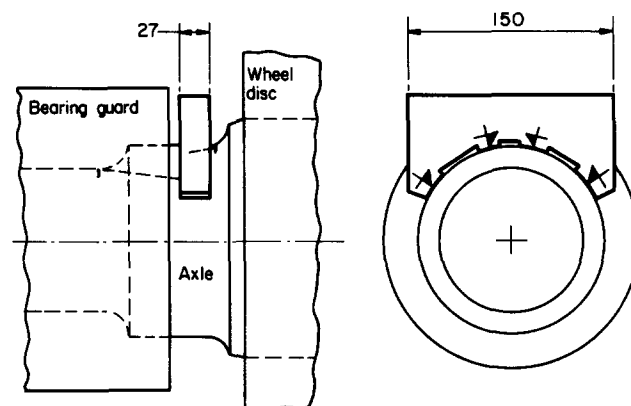


Fig. 5 Model of four ultrasonic probes in housing in working position on axle collar

reference flaws and are easily detected.

A continuous echo with constant amplitude from the corner K (shown in Figure 2) is detectable during testing of the crack on the journal, due to ultrasonic beam divergence. This echo reaches the receiving probe about $7 \mu s$ earlier than the flaw echo and this delay enables the two signals to be resolved. The amplitude of the echo from corner K can be used as a coupling quality signal or as a sensitivity control in automatic testing of axles with different attenuation coefficients.

Tests performed on axles with mounted bearings and without bearings and their inner rings show that practically the same flaw detector patterns are obtained in both cases. The method provides a consistent coupling efficiency, using a liquid coupling technique, whilst the probe is rotated on the smooth cylindrical surface of the axle collar.

References

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