

How to Provide Higher Reliability of Vehicles at the Slovenian Railways by Means of Non-Destructive Methods

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Abstract. The non-destructive testing methods adapted to railway vehicles permit timely repair or discarding of built-in parts, and, consequently, reliable operation. Rapid advances in testing equipment for railway vehicles make it possible to employ them in practice although purchasing options are very limited. Users, i.e. operators, shall have good knowledge of theory and practical experience in using these techniques. The paper focuses on the employment of ultrasonic testing methods developed for and adapted to testing of railway vehicles.

For timely detection of initial cracks at vital parts such as king bolts, spring suspensions and particularly axles and shafts of bogies for locomotives and coaches, good testing equipment and software support shall be provided. This is a basis of quality testing and assessment of the state of vital parts of railway vehicles, which will eventually assure safe and reliable railway traffic.

Recently ultrasonic testing has shown exceptional advances in apparatuses for measurement, storage, and processing of ultrasonic signals. The advances in equipment shall be accompanied by advances in software since this is the only way to provide adequate graphical representations and support in an analysis to result in reliable assessment of the state of vital parts of railway vehicles. Adequate software will allow checking of the state of individual vital parts between periodic checks, good statistical processing of the data obtained, and quality assessment of the momentary state of railway vehicles resulting in efficient and rational scheduling of periodic checks. Some recent approaches to testing of vital parts railway vehicles such as locomotives and coaches will be described.

1. Introduction

The reliability of a diagnostic system is an important issue for operators and for fracture mechanic experts at NDT laboratories. Measuring the reliability is a difficult problem because it depends on a lot of elements.

To ensure safe and reliable railway traffic, a system for efficient tracing of flaws must be developed. At the Slovenian Railway Enterprise the technical staff with their lab equipment for welding mechanical measurements and defectoscopy are responsible for the above-mentioned fields. It is located in Railway Vehicle Maintenance Workshops in Ljubljana, Maribor, Ptuj, Dobova and Divaca. The common equipment for railway ultrasonic control does not provide recording of ultrasonic results directly to paper or a PC. It is up to an experienced operator to put down the exact results. To avoid this problem a computer program was developed. It enables the evaluation of the recorded signals and traces the flaws in the railway material. A comparison of the signals provides the exact condition of the material.

A paper [1] describes ultrasonic testing of shafts and axles using computer-aided automatic devices (A-, B- and C-scan displays). In Slovenia ultrasonic control is carried out with handy devices with the same efficiency but at much lower costs of equipment.

2. EXPERIMENTAL PROCEDURE

2.1 Ultrasonic testing of shafts and axles

Ultrasonic tests are carried out at locomotive axles and shafts having:

- either a full cross section
- or a hollow cross section.

Testing is carried out from the front face with the full shafts and with a special unit for the hollow shafts or axles.

Some measures were taken to increase the reliability of ultrasonic testing. Some mechanical aids and devices were constructed to enable:

- probe guidance over the shaft or axle surface,
- probe positioning in testing from the front face,
- control of hollow shafts or axles,
- front face testing with several longitudinal probes directed at different angles,
- control of ultrasonic probes in terms of the angle of radiation of ultrasonic waves and the distribution of wave pressure,
- storage of up to 200 echograms.

2.2 Steels used for the production of shafts and axles

Locomotive shafts and axles are made of steel 24 CrMo 5 in accordance with railway standard UIC 811-1 (steel A4T) [2]. Blanks are produced by forging and machining, and then they are heat treated. This provides high material strength and favourable dynamical properties of shafts and axles. The final form of shafts and axles is obtained by turning and grinding. Shafts and axles are very carefully formed so that the transition from a greater to a smaller diameter is smooth in order to avoid material failure due to the notch effect.

3. EXPERIMENTAL RESULTS

3.1 The examination of the shafts and axles from the front face

All examinations are carried out at shafts or axles having artificial notches of a known depth and at the same location as those of the natural cracks at shafts and axles.

The arrival of the last locomotives with serial number 342/362 caused the need to examine shafts from the front face. The idea was proposed by the Italian firm CST Centro Sviluppo Trazione from Florence and a firm for mechanical equipment OMFP from Genova. Their collaboration with the Faculty of Mechanical Engineering at first consisted in developing the calculations of ultrasonic wave paths based on technical drawings of a single shaft.

The previous internal railway standard JŽS V3.006 [3] did not include the new method, but preferred the use of a special ultrasonic probe AW 37° developed by Krautkrämer.

To avoid the unnecessary expenses the internal Inspection Office of the Transport Administration has decided to introduce the following instructions [4]:

- to identify the type of ultrasonic signals on the basis of a drawing of a shaft,
- to identify critical points, i.e. to locate flaws (on the basis of critical loads and examples known in practice),
- to test shafts every six months,
- special training of operators,
- before removing a defective shaft, the existence of a flaw shall be confirmed by two operators who are qualified in at least two NDT (Non -Destructive-Testing) methods.

Figures 1 and 2 show a shaft or axle front face with a borehole and auxiliary boreholes at the circumference for mounting a bearing plate. The boreholes at the shaft front face, however, make the access with a probe difficult and thus restrict the testing procedure. Every test should permit a comparison of echograms thus helping to predict the further shaft operation. Because of the front markings, disturbing signals may be found in an echogram, which makes the assessment of the shaft state difficult or even leads to a misleading conclusion on its state.

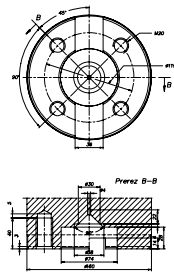


Figure 1: Testing of locomotive shaft from front face. Figure 2: Testing of coach shaft from front face

The method of testing shafts from the front face by means of standard ultrasonic probes is cheap and quick, but it still shows quite a number of deficiencies:

- there is only a little space left for fixing the probe (boreholes for screws, a cone for fixing the tail stock for turning),
- due to markings, there is a weak contact (weak transmission and receipt of ultrasonic waves).
- the ultrasonic probe is not fixed,
- the elements of the shaft (wheels, gear wheels or even brake discs) cause additional signals because of their snug fit, and they diminish the ultrasonic energy,
- It is difficult to identify the size of the flaw and monitor its development,
- it is difficult to confirm the detected flaw by means of another method, because the flaw is usually situated 30-50 mm under the wheel hub.

To avoid some of the above-mentioned deficiencies, tests were made by means of acoustic emission on a railway car shaft. The tests did not invariably give repeated results in spite of the partial location of the flaw. The reason for this is probably the tight fit of the shaft in the wheel hub. The location of the flaw was under the wheel hub.

3.1.1 Positioning devices

Figures 3 and 4 show two specially designed and tested positioning devices permitting accurate directing of sound waves, which results in a permanent and equal distance from the shaft or axle centre. The device makes it possible that with every axle or shaft testing the exact location of reflection of ultrasonic waves is known.

3.1.4 Computer-aided experimental system

To increase the reliability of testing of vital parts of rolling stock, a computer-aided experimental system shown in Fig. 7 was set up.

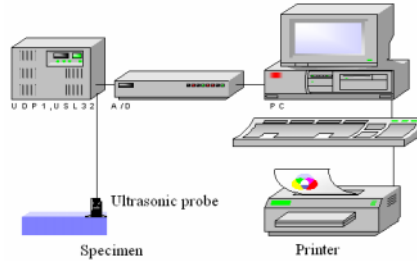


Figure 7. Experimental system for testing of axles and shafts

The experimental system for non-destructive testing of railway axles comprises the following elements:

- defectoscope UDP-1, product of ISKRA, later replaced by defectoscope USL - 32 , product of Krautkrämer,
- a digitizer of analogous ultrasonic signals,
- a personal computer and a plotter,

Capturing of signals was carried out manually using normal 2MHz or 4MHz ultrasonic probes as well as special ultrasonic angle probes for testing from the shaft front face. Inspection from the shaft front face is applied in cases where different machine elements are mounted on the axle thus limiting a direct contact of the probe with the shaft.

For testing of the shafts of the axle-and-wheel-sets of locomotives and trains standard probes and these same probes adapted to permit changes of the angle of incidence of ultrasonic waves were employed. The software elaborated permits theoretical calculations for ultrasonic signals on the basis of input data. Then the desired print-out of the signals of train shafts chosen can be made [5].

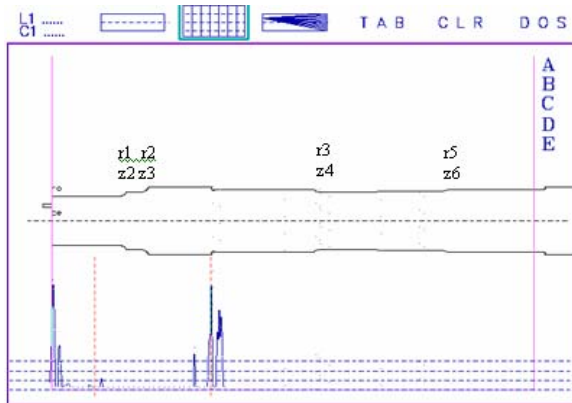


Figure8: Shaft plotted and signals captured

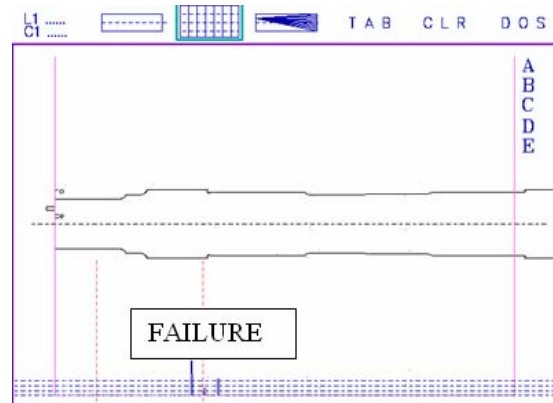


Figure 9: Signals remaining after a comparison of theoretical and calculated signals.

The upper part of Fig. 8 shows a screen shot of a shaft shape plotted and the lower one the signals captured and analysed. Fig. 9 shows the state after the comparison of the actually recorded signals with the theoretically determined signal areas and deletion of the

ultrasonic signals occurring at the same location. Then only the ultrasonic signals representing cracks of suitable size persist.

Given the present state of computer engineering and process techniques, the experimental system may be supplemented with a standard ultrasonic device to be connected to a computer with adapted software for on-line and fast calculation of sound paths. Consequently, the computer program concerned should include the following:

- selection of adequate data on the size, i.e. axle, of a machine part,
- selection of adequate data on the shape of shaft or axle and machine part respectively,
- location of ultrasonic probe on the test piece,
- setting of measuring range of the ultrasonic device used,
- recording of an echogram for the shaft concerned of an axle-and-wheel set of a diesel train and vehicle axle respectively,
- computer-aided checking of theoretical and actual ultrasonic signals,
- a decision on the type and size of flaws,
- storing of echograms and other data on the shafts and axles respectively chosen for testing.

Computer supports the calculation of theoretical signals for a given train shaft or vehicle axle or in a given machine element for testing with given ultrasonic probes. The next step is a comparison of the actual and theoretical signals, which will permit prediction of the state of the train shafts and vehicle axles tested or any other machine part. All the theoretical signals and the signals captured may be statistically processed.

The experimental system proposed makes it possible to carry out the whole procedure using program called ULTRAZ, which is written in Turbo Pascal.

For an efficient comparison of the actual, i.e. captured, ultrasonic signals, first the ultrasonic device used was adapted to communicate with an oscilloscope. Later an interface, i.e. an A/D converter, was built in the experimental system, which permitted the conversion of the signals into their digital form so that a captured ultrasonic signal may be adapted to subsequent computer processing and a final decision on the importance of a flaw may be taken.

3.1.5 Introduction of standards ISO 9000 series

In our country the service for non-destructive testing should be re-organized. The re-organisation should include: preparation of documentation, harmonisation of regulations, personnel instruction, elaboration of instructions for ultrasonic testing, modernisation of equipment, elaboration of atlases of ultrasonic examinations, introduction of hierarchic traceability.

The Slovenian Railways introduced quality assurance in accordance with standard ISO 9001 some years ago. This standard increases reliability primarily by persistent documenting of all tests and monitoring of traceability of all procedures. Detailed instructions for testing all kinds of locomotive and coach shafts and axles were elaborated. Here follow some abstracts from the instructions [6].

Equipment used in ultrasonic testing at CD Ljubljana, Proizvodnja Dobova:

- Devices Krautkrämer (GE) USM 35 XS (AVG, DAC) and USL 32, angle probes Krautkrämer WB 45° 2 MHz and WB60° MHz and B2S with a plexiglass wedge 37° in 54 ° (r80 and r90 mm), and normal probes MB4S and MB2S.

- Reference blocks for calibrating sensitivity (DAC and AVG) shall be made of an axle of 160 and 170 mm in diameter and include 3 mm boreholes with a flat bottom and transverse boreholes of 1.5 in 3.5 mm.
- The range of testing shall include the examination of the entire volume, which should be very accurate.
- The NDT personnel shall be certified in accordance with EN 473 at levels I and II.
- The equipment shall fulfil the requirements of EN 12668-3.
- The calibration range of a normal probe shall be 2500 mm.
- The calibration sensitivity shall be 80% of the specimen back-wall reflection.
- Scanning shall be carried out manually using the pulse-echo technique.
- The couplant shall be oil or grease.
- Prior to ultrasonic testing, a preliminary visual examination of a shaft or an axle in its entire volume or across its entire surface shall be carried out.

3.1.5.1 Testing of the full shaft or axle

The scanning position for normal probe B2S is shown in Fig. 10.



Figure 10: Probe positioning at axle front face.

Such a technique permits to detect oblong plane indications characteristic of such imperfections as cracks, undercuts, non-metallic inclusions, segregations, and solidified and oxidised, not forged-through shrinkage cavities in the central part of the shaft.

3.1.5.2 Ultrasonic testing of the hollow shaft or axle

The testing procedure for the hollow shaft or axle of the electric railcars of series 312 is similar to testing of other shafts and axles. The hollow shaft or axle is thus tested with a special device permitting to guide the probe through the cavity. Fig. 11 shows an aid permitting to push the probe along the hollow shaft or axle to test it.

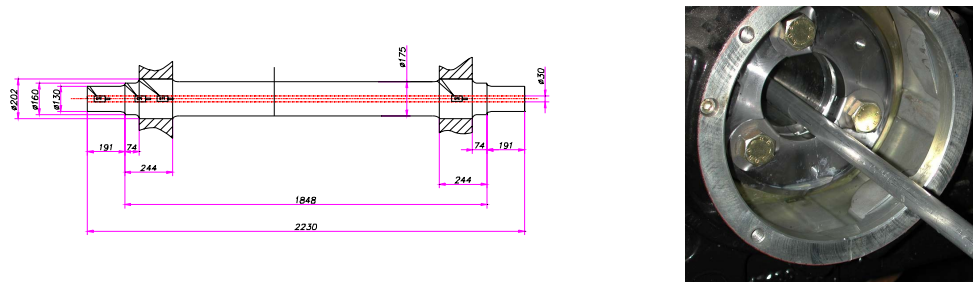


Figure 11: Device for examinations of new electric railcars of series 312

Figure 12 shows two echograms, i.e. one of an axle showing no defect (left) and one of another axle showing a defect (right), and relevant records of the characteristic data on

testing. The data include the calibration of the apparatus to a distance of 2500 mm, velocity of ultrasonic waves in steel being 5290 m/s. there are also data on the delay and the location of signals (distance between the probe and the point of reflection).

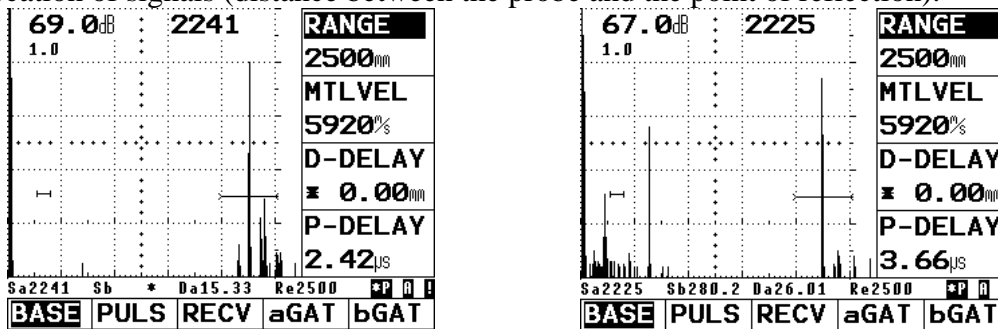


Figure 12: Images of scanning showing no defect and scanning showing a defect.

Acceptance criteria:

- in accordance with railway standard UIC 811-1, no surface indication detected, i.e. no crack, is acceptable.

3.5.1.3 Ultrasonic testing of coach axles

Figure 13 shows ultrasonic testing of an axle with normal probe MB 4 from the left to the right of the axle.

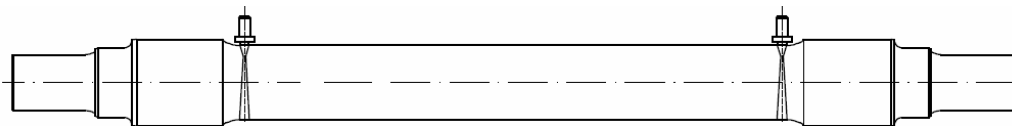


Figure 13: Testing with normal probes.

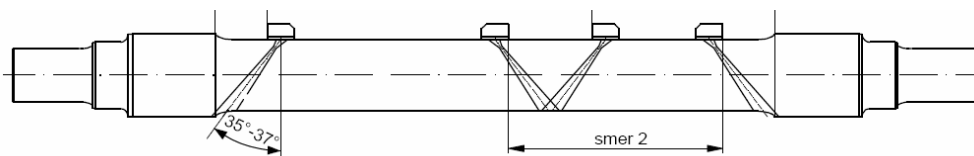


Figure 14: Testing with several angle probes.

Figure 14 shows double-angle testing with an angle probe to ensure more reliable operation.

3.1.6 Most frequent defects

In railway axles and shafts the most frequent defects are cracks. They are mainly due to dynamic loads they are subjected to. There may be also forming defects that remain in the material such as non-forged oxidised shrinkage cavities or gas cavities in the axle or shaft centre (Figs. 15 and 16).



Fig. 15. Forged impurities close to axle centre.



Fig. 16. Forged impurities at axle beginning.

Figure 17 shows echograms of non-forged oxidised surface shrinkage cavities.

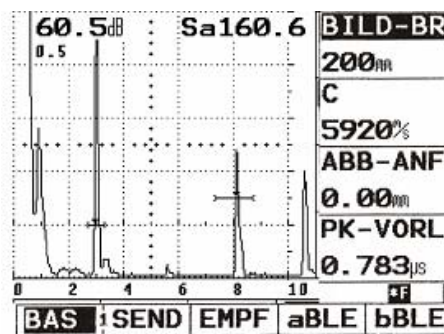
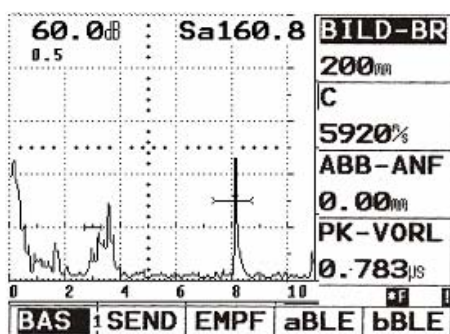


Figure 17: Echogram of non-forged impurity at the axle inside (left) and echogram of planar indication due to impurities (right).

In the cut specimens of the axle, micro porosity and normal porosity, lamination laps, non-forged oxidised spots, impurities in the centre of a forging, segregations, non-forged shrinkage cavities, cracks, and undesired stresses produced in heat treatment due to non-uniform quenching or too high a cooling speed in quenching, cracks due to too sharp grinding resulting in martensite and high residual stresses in the thin surface layer are searched for. None of the above-mentioned imperfections is acceptable according to standards EN 13 261 and ISO 5948 and UIC 811-1.

4. Conclusions

European Railway authorities keep special services for taking care of safety and flawlessness of railway vehicles, and equipment for non-destructive testing of vital parts of vehicles and infrastructure [7]. It is their duty to prescribe and approve to controllers the use of devices, accessories and procedures for non-destructive testing, prescribe technical qualification of controllers and a hierarchic traceability of procedures from the management to performers, and vice versa.

5. References

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