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LATEST METHODS OF NON-DESTRUCTIVE TESTING OF RAILWAY VEHICLES

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ABSTRACT

Non-destructive methods are making a fast progress due to extensive scientific treatment and practical applications of new testing techniques. The application of individual techniques requires of their users good knowledge of the relevant theory and a lot of experience. The experience is the main guideline in choosing the right testing technique. The paper focuses on the ultrasonic testing methods developed for the application to railway vehicles.
In order to detect in time initial cracks at vital parts such as king bolts, suspension, and particularly bogie axles of locomotives and wagons, efficient testing equipment and software support are required. This is a prerequisite for safe and reliable railway traffic. With a view to improve the classical ultrasonic testing method designed for machine parts, an interface was constructed and software elaborated for the purpose. A relevant description follows.
Lately ultrasonic defectoscopy experienced exceptional advances as far as the apparatuses measuring, saving and processing ultrasonic signals are concerned. This should be followed by an advance of software. Some latest approaches to testing of railway tracks and vital machine parts, particularly those of railway vehicles such as wagons and locomotives of German Bundesbahn, will be described.

***Keywords*:** Non-destructive testing, Ultrasonic testing, Experimental system, Axle testing, Rail testing

1. Introduction

Non-destructive testing methods have been applied by the Slovenian Railways for several decades. At first penetrant and magnetic testing methods were used. After World War Two the aid offered to our country by Western countries, particularly the United States, consisted in diesel locomotives (of series 661) in 1960s. In addition to locomotives, the equipment for the detection of flaws in the material of machine parts, particularly axles, pistons, shafts, studs, and crankshafts of diesel engines, was donated too. So a Magnaflux device with a DC of 1500 A was made available too. The device was very useful because it permitted the inspection of machine parts up to a length of 2.5 m. The inspection was carried out in a laboratory of defectoscopy in the Central Workshop for maintenance of locomotives and railcars in Ljubljana. Now the device is located in Maribor.

Fig. 1: Magnaflux device for detecting flaws in the material of axles and crankshafts.

Testing was carried out using a fine-ground iron powder and petroleum, i.e. a liquid that got absorbed into cracks due to its good capillarity. Surface and sub-surface cracks could be detected using developers or a fluorescent addition to the powder, viewed then under ultraviolet light. Later on an isotope Gammamat Ir-92 was purchased. It was stored at the Welding Institute in Ljubljana. Testing was applied to repaired carriers - bogie bodies or structural elements of locomotives. Approval testing of welders was carried out in all workshops of the Slovenian Railways. An X-ray testing device, a Russian product, was used. In order to confirm the presence of the flaws already found in the material penetrant testing methods are used. Cleaning, application of penetrants and developers can prove the presence of imperfections in a material.

2. Selecting testing methods

With reference to quality assurance in accordance with standard ISO 9001 non-destructive testing methods and their traceability is one of the most important factors. There is still lot to be done in the field of testing of axles in wheel-and-axle sets in their assembled state since in preventive maintenance this is the only way of testing them. The Slovenian Railways, the client that requires this type of service, requires now much more reliable testing of vital parts of railway vehicles than before. The majority of difficulties are encountered in the detection of flaws in control checks.

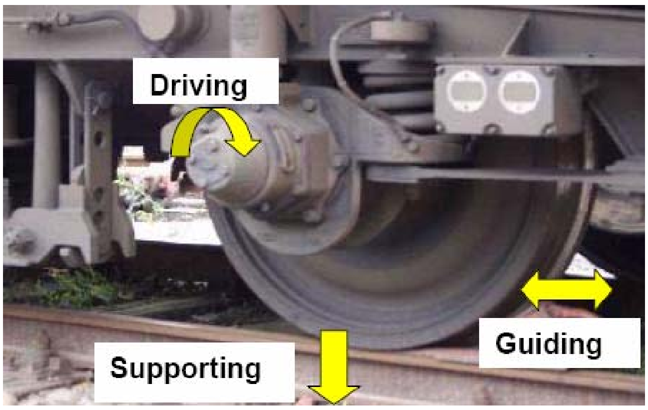

Fig. 2: Bogie with shaft or axle and wheel moving along a rail.

The Slovenian Railways have developed primarily the methods of ultrasonic inspection of vital machine parts of locomotives, wagons, electric or diesel-engine trains, maintenance vehicles, and other railway vehicles. The next figure shows a bogie dynamically loaded during its drive. The inspection is mainly applied to axles as the most sensitive machine parts and to wheel bands. For a safe drive rails are also of vital importance. They are inspected manually or with a machine. All these elements affect each other. A suitable control of machine parts shall be carried out to ensure safety of railway traffic.

A railway regulation [1] requires a mandatory inspection of wheel-and-axle sets in disassembled state using a special ultrasonic probe AW 37, sound being emitted at an angle of 37°.

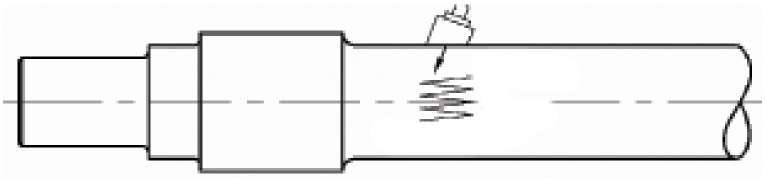

Fig. 3: Testing of axle with AW 37 angle probe.

In order to improve safety in railway traffic the department of defectoscopy of the Slovenian Railways in Ljubljana decided to improve the reliability of testing and early detection of flaws in shafts. To this purpose several systematic analyses were made several years ago. They made it possible to elaborate instructions for ultrasonic testing [2]. Testing with normal probes from the axle front is efficient and often inevitable to detect flaws in a stud and its vicinity in the assembled state and all the elements brought together at a certain angle of incidence of the longitudinal way. In case of testing from then axle front with normal probes various reflections and transformations of waves occur at the transitions. Three questions can be raised:

- Is it possible to detect flaws at all the critical locations by transmission from the same side of the axle?
- With which size or depth a correct recognition of a flaw is possible?
- Which of the normal probes is suitable for efficient flaw detection?

For ultrasonic testing three driving axles and one intermediate shaft were chosen. They were used to simulate various sizes of flaws produced artificially, i.e. of transverse notches at the cylindrical part of the shaft. The areas with notches represented characteristic areas for the appearance of cracks. These areas are further on called "critical areas".

For testing, different normal ultrasonic probes, B2S, MB2S, B4S, and MB4S, were used. The identification procedure was performed from both front faces of the shafts concerned, i.e., at a greater and a shorter distance from the location of a toothed wheel, the ultrasonic tester being set at 1.5 m and 2.5 m.

Fig. 4: Ultrasonic inspection from shaft front.

Fig. 5: Ultrasonic inspection with angle probe to confirm a flaw under hub.

3. Set-up of an experimental system

An 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 printer.

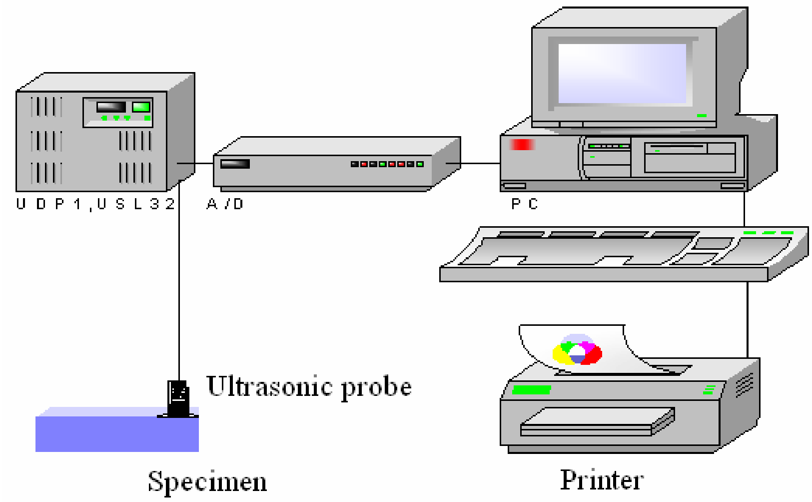

Fig. 6: Experimental system for testing of axles and shafts.

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. Inspection from the shaft front 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 [3, 4] permit 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.

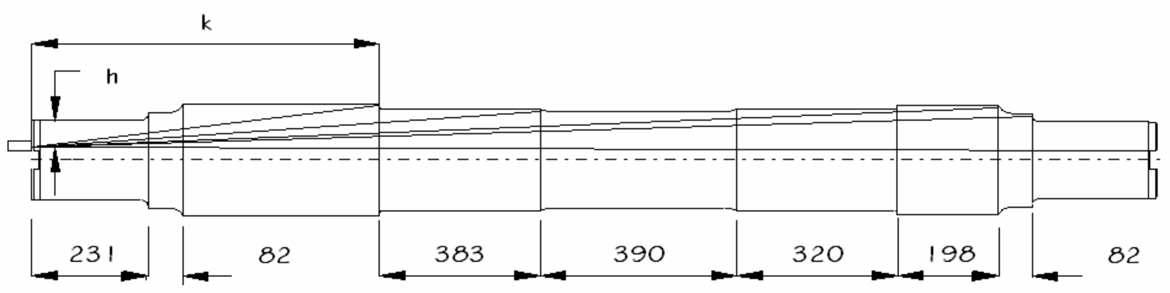

Fig. 7: Ultrasonic probe mounted at side of toothed wheel and ultrasonic signals of type A.

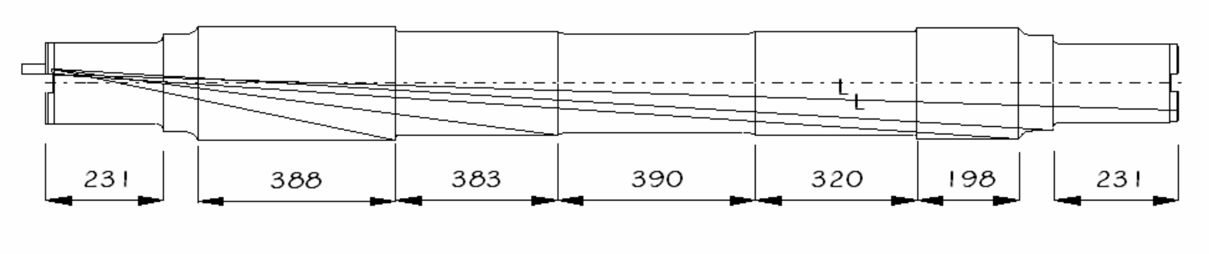

Fig. 8: Ultrasonic signals of type B.

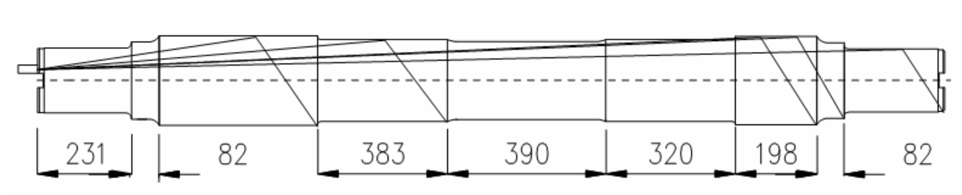

Fig. 9: Ultrasonic signals of type C.

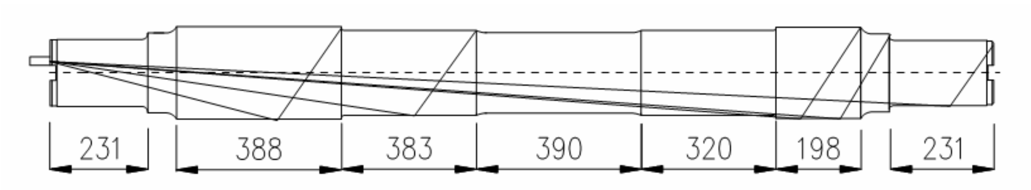

Fig. 10: Ultrasonic signals of type D.

In the axle an additional combination of ultrasonic waves will occur. It transforms first the longitudinal wave into a transverse one, and the latter will again transform into the longitudinal wave due to a suitable angle of reflection. The path of this ultrasonic wave is a bit longer than that of the previous ones, which can be found also by calculation using a formula obtained by the addition of sound paths of the longitudinal waves and the transverse one. Figures 7, 8, 9 and 10 show different sound paths.

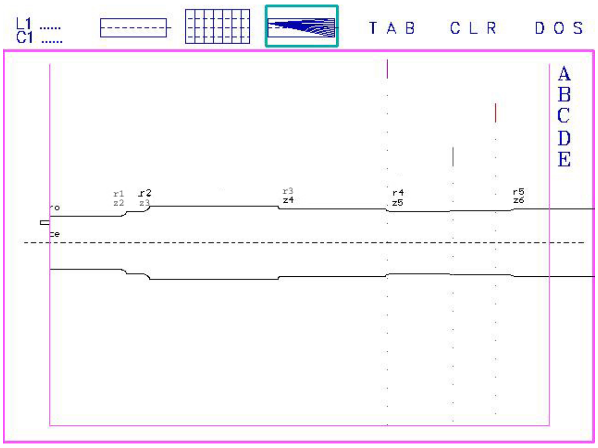

Fig. 11: Computer program for theoretical calculation of locations of reflected ultrasonic waves.

The theoretical signals are than compared to the ones captured at new, flawless shafts and axles respectively. The theoretical signals [5] are determined on the basis of the shape and size of the individual axles and a physical model for calculation of the sound path between the reflections in the material. The program is designed for general use, which means that the size of a test piece and individual characteristic shapes of a shaft and axle respectively or other machine elements to be tested are to be entered.

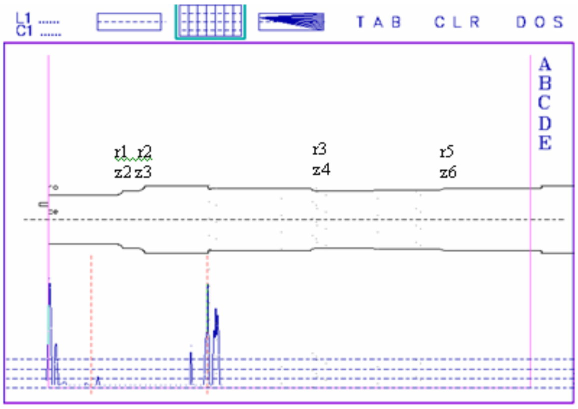

Fig. 12: Shaft plotted and signals captured.

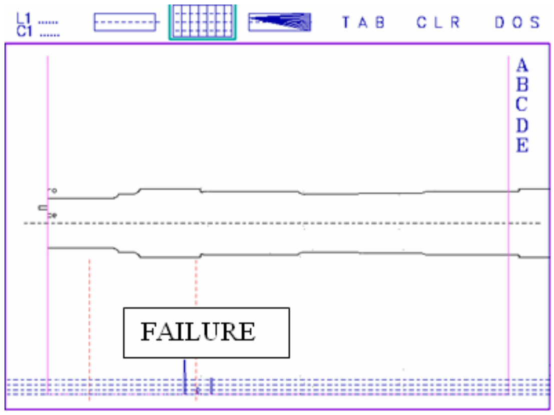

Fig. 13: The signals remaining after a comparison of theoretical and calculated signals.

The upper part of Fig. 12 shows a screen shot of a shaft shape plotted and the lower one the signals captured and analysed. Fig. 13 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 communication 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 [6].

4. Some procedures of ultrasonic testing

4.1 Front testing

At the Italian Railways a device similar to the one used by the Slovenian Railways was constructed and aesthetically improved. Testing is carried out from a shaft front with a system of several probes fixed in a central boring.

Fig. 14: Probe system for shaft-front testing used at the Italian Railways.

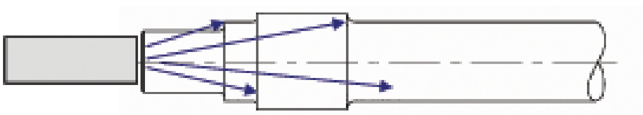

Fig. 15: Principle of operation of several longitudinal probes at different angles.

4.2 Front testing with Kirner probe

For testing of shaft studs the so-called Kirner probes are employed. They have already been tested at the Central Workshops in Moste. Ultrasonic waves are emitted at an angle of 29° and up to 90°. By rotating the probe the stud area usually occupied by a bearing may be inspected thoroughly.

Fig. 16: Kirner probe for testing of shaft studs and axle ASW 29/90.

4.3 *Examination of hollow shafts and axles with special devices for detecting cracks from the inside*

In 1980/81 with diesel shunting engines of series 732 the first fractures at shafts were noticed. An ultrasonic device [7] for testing the shaft through a hole was manufactured. Its ultrasonic probe supply ultrasonic waves at an angle of 45°. The ultrasonic probe was moved in the direction of x-axis and rotated by 360°. Thus all the locations at the shaft, particularly those where the shaft diameter changed, could be scanned. There cracks were initiated most frequently. The method turned out to be very efficient so that after a thorough examination of all the shafts numerous shafts showing inadmissible flaws could be set apart.
At the end of the last year the first two-part electro-motor modular train sets called Desiro, manufactured by Siemens, and designated SŽ 312 were set to rails.
These railcars also have a hollow shaft. An ultrasonic device similar to that for series 732 but with a different diameter was manufactured [8]. Regular preventive examinations every 6 months and accurate monitoring of any changes in the shafts make it possible to avoid possible shaft fractures.
A basic aim of the study was to introduce an as reliable as possible and as usable as possible method of non-destructive testing of underframes of railway vehicles without having to dismantle mechanical assemblies. Thus the time of keeping locomotives and other vehicles in a Maintenance Workshop was made as short as possible.

Fig. 17: Device for examinations of diesel shunting engines of series 732 and a device for examinations of new electric railcars of series 312.

4.4 Inspection of profiles of bogie wheels

For testing of monoblock wheels and wheel bands a special device is used at the German Railways. In our country an angle probe is employed for wheel profile testing, but a similar home-made device is being tested [9].

Fig. 18: Left: testing with angle probe; Right: testing with special ultrasonic device.

4.5 Inspection of rails

For safe ride sound rails should be provided. On several years basis they are tested with a specially adapted shunting engine automatically marking suspicious rail sections. The latter are then inspected manually with a SE probe or an angle probe (tandem procedure). The same procedure is followed in the inspection of thermite-welded joints in repair and maintenance of railway tracks.

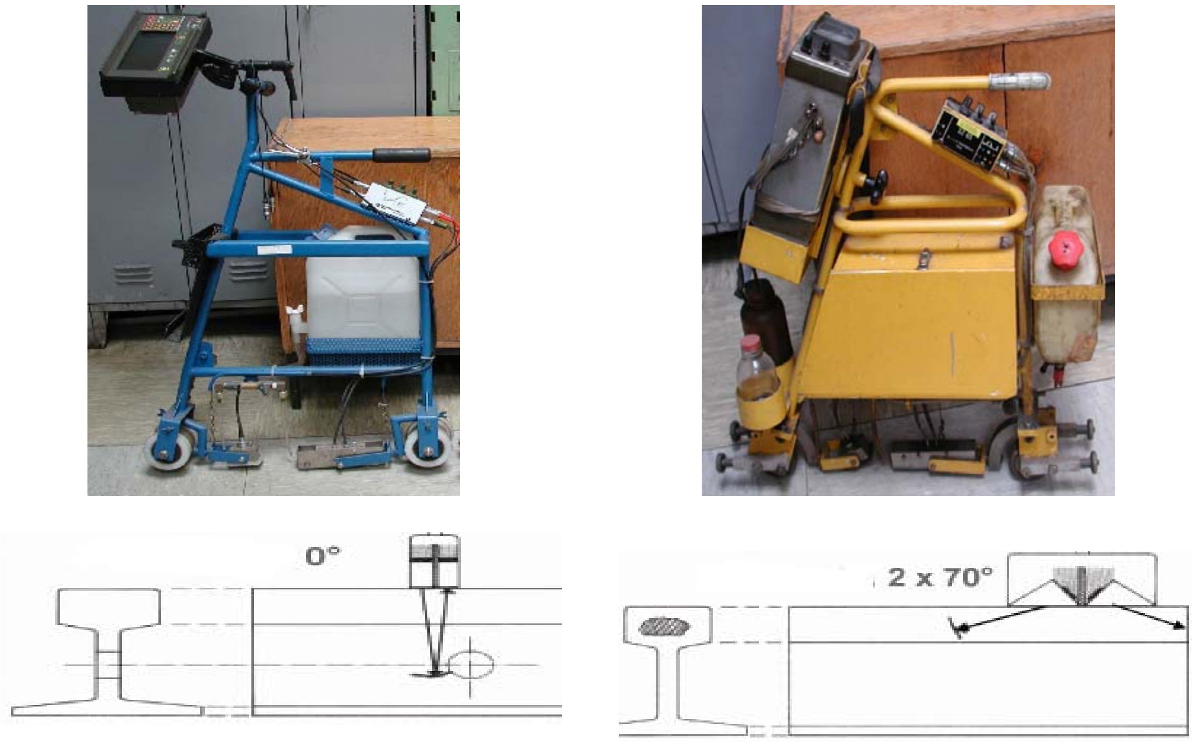

Fig. 19: Rail inspection with single and double ultrasonic probes.

4.6 *Inspection with several ultrasonic probes and display by means of scanning*

An up-to-date procedure for testing of fast-running axle-and-wheel sets performed in Germany, trains reaching speeds exceeding 160 km/h, consists in testing usually with angle probes and shaft rotation and using a very expensive scanning device. Such a testing system is shown in Figs. 20 and 21, where testing is performed from the shaft inside by scanning. In case that a shaft is damaged the image will be discontinued. The shaft is additionally tested using some other method to confirm the flaw detected.

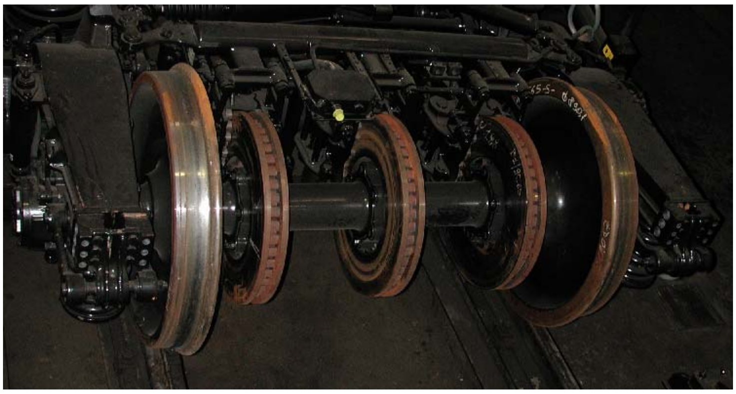

Fig. 20: Inspection of railway shaft using phase transmission.

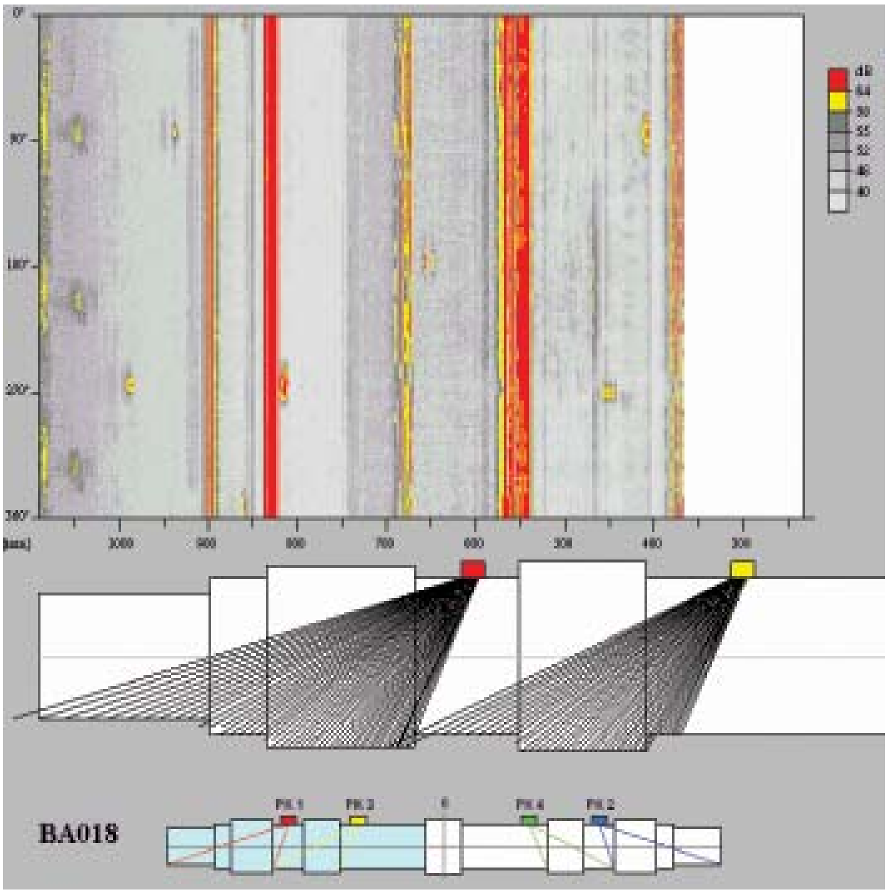

Fig. 21: Testing by scanning.

5. Conclusions

European Railway authorities keep special services for taking care of safety and flawlessness of railway vehicles and equipment by non-destructive testing of vital parts of vehicles and infrastructure. 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. They also control the implementation of the examinations prescribed. For practical purposes they have special atlases of geometries and procedures for each type of shaft separately, required settings of apparatuses with a certain type of probe. For practical comparison they have at their disposal reference shafts with flaws simulated at critical locations.

In our country the service for non-destructive testing should be re-organized. The re-organization should include: preparation of documentation, harmonization of regulations, personnel instruction, elaboration of instructions for ultrasonic testing, modernisation of equipment, elaboration of atlases of ultrasonic examinations, introduction of hierarchic traceability [10].

In the paper the applicability of different non-destructive testing methods, particularly ultrasonic ones, being the most appropriate for the railways, was shown. In the neighbouring countries more up-to-date methods, such as flaw scanning, are already being employed. They are, however, comparatively costly and not realisable in Slovenia.

It turned out that the application of simple resources produced by our services of maintenance make it possible to relatively accurately detect flaws in railway machine elements.

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