POSSIBILITIES OF AUTOMATIC INSPECTION ON HOLLOW AXLES

Viktor Jemec¹, Janez Gorše², Janez Grum³
¹High school Domžale, SI, viktorjemec1@gmail.com
²Slovenian Railway VIT Ljubljana, SI
³Faculty of mechanical engineering Ljubljana, SI

ABSTRACT

Electro-motor passenger trains of Italian firm Fiat Pendolino with mark ICS 310 and of German firm Siemens with mark 312 and the newest 541 drive on Slovenian railways. All these vehicles have hollow axles. Refractions of axle often occurred round the year 1980, therefore suitable employment of quality control on Slovene railways was necessary based on. Calculations of ultrasonic ways of signals of hollow axles for special examinations with at home made probe. Special ultrasonic probes were made to examine mentioned motor trains. Automatic inspection of wheels is still in initial phase of development. Detection of transversal and longitudinal failures and possibility of evaluation of signals will be presented in this contribution.

Keywords: Non Destructive Testing (NDT), hollow railway axles and shafts, wheel sets, failure, crack, testing with ultrasonic method

1. Introduction

The railway traffic concerns both transport of passengers and transport of dangerous materials that is why an increased safety and reliability of operation of all railway vehicles is demanded. That is why technical systems maintenance protocols are necessary as they prescribe appropriate NDT methods and testing procedures, which meet the demanded traffic safety and order. The traction vehicles are also equipped with appropriate safety devices, which exclude subjective mistakes of the operators during the operation, to prevent catastrophic failure of the parts or systems. Safe operation of locomotives and motor trains can be assured by detecting defects in the vital elements of locomotives, wagons and carriages, and with regular checking of rails. NDT methods that have to be both fast enough for testing and sufficiently reliable and cheap are often applied to detection of defects. Control of the characteristic parts is executed precisely according to the prescribed internal standards and regulations, which, beside the regular, also prescribe extraordinary tests after collisions, derailments or grazing of railway vehicles [1]. We tested the reliability of the subsystems and determined the critical parts, which need to be periodically checked so as to ensure the prescribed safety.

Wheel-set axles are among the most loaded parts of railway vehicles and their defects or cracks in them lead to substantial material loss as well as endanger the lives of passengers and railway workers. That is why internal standards were elaborated, which prescribe obligatory ultrasonic checks of wheel-set axles. They were later supplemented with additional descriptions and instructions [2].
2. The extent of testing and repairs

Slovenian State Railways SZ placed an order in July 2004 for 20 three-system High-Performance Locomotive SZ 541 locomotives, you can see on figure 1, based on the Euro sprinter family and exercised an option for another 12 vehicles in January 2008. SZ is the second customer after Austrian Federal Railways to decide in favor of this locomotive platform. The Class SZ 541 is suitable for operation in both national and international passenger and freight sectors. It is to be deployed in Slovenia, Germany, Italy, Croatia, Austria and Hungary. In addition, service in other countries (e.g. the Czech Republic, Slovak Republic) is also technically possible.

![Figure 1: The newest locomotive Siemens Taurus series 541](image)

Inspection of hollow axles is by automated ultrasonic with a group of rotating probes in a similar way to the service inspection. Methods of inspection at depot and overhaul and degrees of automation vary from country to country. In Germany, highly automated phased array ultrasonic methods are used at overhaul, whereas in the UK surface methods such as MPI are used most commonly at this time. Hollow axles are also used, particularly for high-speed passenger trains, where the loss of weight has advantages, and the ultrasonic used in this case is an angled beam scan from a rotating probe in the bore. This inspection is mechanized. This inspection requires incrementing and rotating the probe, a very slow process. Portable devices for use in depots have been manufactured but these tend to be unreliable due to the long reach and sensor rotation required. There is also some uncertainty in their capability for crack detection in the radius between the axle body and the wheel seat. Manual methods of inspecting the wheel seats of hollow axles (using high angle scans from the axle body) have been introduced for inspection without removal of the end caps. Surface inspection on site can be carried out by manual eddy current methods, and these can scan the radius. These are highly sensitive but are also subject to the expertise of operators.

Electric and diesel locomotives as well as electro-motor and diesel-motor trains comprise numerous assemblies. For each regular check of locomotives or trains, there is a prescribed kind and extent of testing, performing of repairs or part exchange, which is prescribed in the instructions for testing of the individual elements with the appropriate description of procedures. In 2014 we began the maintenance of multi-system electric locomotives Siemens for our new customer RTS. RTS is an Austrian operator who specializes in supplying construction machines and material to rail construction sites all across Europe. One of their locomotives, a Siemens Taurus (ES 64 U4) electric locomotive labelled Class 1216-901, arrived to Center Ljubljana for a P12 control check all the way from Croatia, where it runs service on a track-renewal construction site. As this particular model is almost identical to SŽ Class 541, the work on the orange newcomer largely followed the usual practice applied to SŽ locomotives of this type.

Overall, RTS owns a total of three such locomotives, which are the same age as SŽ locomotives.
The company first turned to us last year when the same Class 1216-901 required a replacement of the pantograph, which was carried out at the Gredelj Workshop in Zagreb, Croatia. Afterwards, talks began about performing control checks on their locomotives, and soon the first P12 annual check was provided in line with their work procedure manual. Additionally, we also replaced the drying agent (silica gel) in the locomotive’s compressed air system. Following the first check, we also replaced the arm of the pantograph at the workshop in Zagreb [3]

NOTATION: Periodic checks: P1 - every month, P3 - every three months, P6 - every six months, P12 - every year, MP - minor repair, SP - medium-size repair and VP - major (general) repair

Figure 2: Prescribed periodic checks and the levels of maintenance interventions

Since the frequency of repairs of individual subsystems is known, the entire sequence of all scheduled interventions and possible repairs between two general checks with a period of four to five years can be determined. The experts in the field of safety management in railway traffic have to determine the frequency of NDT checks and individual repairs according to the state of a machine part. In the initial phase of device or machine operation, there are demands for new devices or machines, which are different from repairs after a longer operating time. For machines which were in operation for a longer period of time there is a certain documentation available on maintenance interventions as well as the material used and the type of built-in or replaced parts. The archive data on maintenance include comprehensive information, which need to be used during further maintenance interventions in order to determine new dates of the scheduled checks as well as repairs as stated in figure 2. From the database of checks and maintenance interventions, we can prescribe the changes in testing procedures. In the elaboration of instructions, the frequency of checks as well as the frequency of maintenance interventions—with a multiple of the shortest period is still included.

Maintenance evolved from urgent repairs to highly professional activity, which demands specialists from field of planning, executions and controls. The need for specialists in this field is growing, since with the development of production activities, more and more demanding working means for execution of maintenance processes are used. The maintenance is becoming very important activity in today's period, if we wish to ensure prescribed useful life of machines and of devices, and her undisturbed operation. This means, that the maintainer of works has to be very well educated to be able to control the above devices and machines in the right moment. Slovenia adopted the standard SIST EN 13306:2001 [4], which defines the expressions for all types of maintenance. Management must define his maintenance strategy round next main criteria of maintenance:

- to assure accessibility »of product« for demanded function, with optimized costs,
- to consider safety demand, for users of product, and as also for maintainers at quality execution of maintenance procedures,
- to assure useful life of product at keeping of his quality

Good execution of maintenance assures reliable and quality use of the product with high
exploitability. The standards enables the user and maintainer to better understand the maintenance demands. The expressions in standard are very general, because they employ technical and also activities from preparing of documentation to planning. The scheme was prepared in accordance with the appointed standard (Figure 3), where maintenance is distributed in two groups:

- preventive maintenance and
- corrective maintenance

3. **Condition based maintenance**

The maintenance department constantly assesses the condition of machines and devices to enable undisturbed operation. This is the concept of preventive maintenance, where the decision concerning activities of maintenance occur on the basis of periodical or uninterrupted control of technical condition of system in operation. The preventive maintenance got into rule after 1970 with the development of transmittable electronics and informatics.

4. **A testing of hollow shafts and of axle with special ultrasonic probe for search of cracks from inside**

Wheel sets of high-speed trains feature hollow axles which have to be inspected periodically by ultrasound to detect potential defects and cracks at an early stage. The axles are tested from the bore hole for internal defects and cracks in the outer surface. Areas of interest are especially the axle journal, the dust guard seat, the wheel seat, the brake disc seat and all transitions of diameter. Hollow railway axels have a hole the entire length of the axis, most commonly the diameter of 60 or 90 mm. It does not, however, weaken the durability of the axel. Hollow axles are becoming more and more popular, being used in a lot of new equipment. The hole allows for ultrasonic examinations without taking apart the entire set. Tests on the hollow axel are performed on the entire volume of the material, placing the head into this hole. Because this is a place not easily accessible it is necessary to perform studies specifically designed for this system.

Within year 1980/81 first refractions on shafts of diesel shunting of series 732 started to appear. Ultrasonic device [5, 6] for examination of shaft through bore was made. We were renting out ultrasound under corner to 45° with ultrasonic head. All surfaces on shaft was gradually checked with ultrasonic probe in direction x-axle and with rotation for 360° [7] including surface of crossings next to diameters of shaft, which is seen on figure 4.

![Figure 3: Distribution of maintenance round standard SIST EN 13306](image-url)
Figure 4: Ultrasonic testing principle of hollow axles or shafts and display torsion refraction on shafts of series 732

Something years back electro-motor set of Siemens group of modular trains Desiro (marked SŽ 312) appeared on Slovenian railways. These motor functions have right such hollow shaft. Mr. Mitja Šipek made similarly ultrasonic device like at series 732 [8], only with other diameter. We avoid possible refractions of shaft like this, if we are carrying out protective examinations regularly 6 months with accurate observation of interior of shaft. Basic goal of task is to initiate extremely more reliable and useful manner checks of undercarriages of railway driven with NDT procedures without dismantlement of mechanical assemblies because of protective examinations. Procedure is ensuring shorter time of retention of locomotives and remaining vehicles within workroom. We concentrated on most vital part of vehicles - these are shafts and axles, that they must be faultless for safety of traffic. Beginnings of cracks were appearing at crossings. Procedure was systematic and very efficient.

Figure 5: Ultrasonic probe for an examination of hollow shaft of series 732 and photograph of entry of probe in hollow shaft (right)

5. Realization of a test

We are carrying out tests on driving and free axles and shafts of series 312 round internal instruction [9]. Material of specimen: EA4T round railway standard UIC 811.1. Object of testing is axle by wheels and bearings.

Figure 6: Free axle and driving axle

On figure 6 and 7 are showed free and driving axle to electric series 312. Axles are hollow, which is making testing possible for us with specially ultrasonic probe.

On Slovene railways (SŽ) is organized suitable job for maintenance, traction and technically wagon activity. It is unique, because services for reliable and safe operation of the railway vehicles offer it all on one address. Job is carrying out complete solutions for partners on all locations round Slovenia.
Maintenance job is ensuring quality and reliable services on three key fields: diagnostics, repairs and maintenance of the railway vehicles. Job is arranging entire maintenance of car pool of Slovene railways, professional personnel for needs are ensuring a haulage contractor in passenger and freight traffic and it worries so above technical condition and equipped of the railway vehicles. Services of maintenance of all kinds of the railway vehicles are known and appreciated also outside of frontiers. Quality maintenance demands specific knowledge's and competences, so they are braced for every new challenge at owners of vehicles on wider European market. Numerous partnerships are created with state railways and some largest private owners wider round Europe both in Slovenia. They were finished careful tests on full and hollow axles and shafts in laboratory for NDT at Slovene railways. Positions of special ultrasonic probes are determined in hollow axle, that they would check foreseen critical position surely, above all in places from change of diameters of axle. On figure 8 and 9 are showed both kinds of axle. Beside plan of scanning within interior of axle with corner probe also expected repulsions are showed without failures at axle or shaft.

<table>
<thead>
<tr>
<th>Reference number</th>
<th>Depth of probe within axle (mm)</th>
<th>Path of ultrasonic wave (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>349</td>
<td>121</td>
</tr>
<tr>
<td>2.</td>
<td>867</td>
<td>122</td>
</tr>
<tr>
<td>3.</td>
<td>1879</td>
<td>121</td>
</tr>
<tr>
<td>4.</td>
<td>1974</td>
<td>91,9</td>
</tr>
<tr>
<td>5.</td>
<td>2180</td>
<td>70,7</td>
</tr>
</tbody>
</table>

On base of movement of special probe made still calculations of sound ways from probe to fringes on hollow axle that an operator knows, where ultrasonic repulsions are appearing on which distance on screen.

<table>
<thead>
<tr>
<th>Reference number</th>
<th>Depth of probe within axle (mm)</th>
<th>Path of ultrasonic wave (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>349</td>
<td>121</td>
</tr>
<tr>
<td>2.</td>
<td>1536</td>
<td>122</td>
</tr>
<tr>
<td>3.</td>
<td>1879</td>
<td>121</td>
</tr>
<tr>
<td>4.</td>
<td>1974</td>
<td>91,9</td>
</tr>
<tr>
<td>5.</td>
<td>2180</td>
<td>70,7</td>
</tr>
</tbody>
</table>

Figure 7: Device for examinations of new electric railcars of series 312

Figure 8: Plan of scanning with corner probe and table of repulsions of driving axle-gearbox side

Figure 9: Plan of scanning with corner probe and table of repulsions of driving axle- opposite side of gearbox
Next probes were chosen for plan of scanning:
- normal straightens probe of 2 MHz B2S or 4MHz B4S for test from the front of full axle or shafts,
- special corner probes 2 MHz WB45 for scanning hollow axles or shafts.

We chose calibration range:
- for normal probe and position of scanning of full shaft from front is $S_j = 2500$ mm,
- for specially corner probe and position of scanning in hollow shaft is $S_j = 250$ mm.

Calibration samples of axle are being used for calibration and determining of sensitivity with artificially created referential search lights and natural failure are being used for calibration of sensitivity.

![Figure 10: Checks of hollow shaft with corner probe with mistake](image)

In accordance with regulations on maintenance of the railway vehicles the performer of the NDT testing of wheel sets records in technical documentation realization of maintenance intervention on an individual vehicle. The expert in workroom must to lead special records on investigation with access of the report for inspectors.

Records must contain next data:
- reference number, checks date, number of axle, year of making of axle,
- kind of the NDT testing,
- drove number with built-in wheel sets,
- result of the test with signature must an authorized specialist.

A report can be issued per special demand of a client.

![Figure 11: Ultrasonic probe for Fiat Pendolino and for Siemens Desiere hollow axle or shaft](image)

6. **Better detection of defects**

Improved detection of defects will be enabled through an improved/innovative NDT methodology that will permit more accurate measurements of the axle condition and detection of defects. The technology will detect possible defect-induced failures before they occur, thus leading to fewer axle failures and accidents. An improved knowledge of the fatigue properties of used steel and understanding of crack creation and propagation will enable an optimized regime for in service inspection by NDT, MPI, and possibly other new methods. These measures lead directly to a lower probability of crack creation, axle failure and vehicle accidents. In addition, the common approach to RAMS/LCC analysis defined in EURAXLES can serve as a starting point for unified safety and cost evaluation of railway systems in general and wheelsets, in particular within the European railway industry. The results will ensure an ever-high level of safety of rail transport, and will ensure an improved and cost effective maintenance process,
which will have an impact on the competitiveness of the sector as a whole (operators and manufacturers).

EU project Framework 7 is EURAXLES. EURAXLES aims to bring the risk of failure of railway axles to such a minimum level that it will no longer be considered as a significant threat to the safe operation of the European interoperable railway system; at the same time, it shall keep the cost of maintenance to a reasonable level and minimize the risk of service disruption. The global concept approach for axle design, production and maintenance includes:

- A design approach development, including a risk analysis method which could offer a simple design route by combining loads with difference occurrences including loading specificity of vehicles and service conditions together with the axles resistances, including new materials and methods in order to predict the ‘failure probability’.
- New developments will also include: o improved axle protection against corrosion, including protection of already corroded axles o improved adhesion of coatings with a study of the roughness influence (adhesion and fatigue behavior)
- New, innovative coating solutions. The new solutions will also aim to fulfil environmental requirements to avoid or limit VOC emissions.
- New/improved NDT inspection methods will allow the in-service inspection of axles in order to guarantee safe service conditions with a low impact on the vehicle availability.

The EURAXLES global concept will not only guarantee the current level of safety, but improve it in an interoperable network at optimized cost.

WP5 is dedicated to Non destructive testing’s (NDT) and verification of the reliability of axles in service. WP5 is focused basically in the study of the NDT methods applied by railway operators and maintenance companies in railway axles, to verify the detectability of these in order to guarantee safe service conditions with a low impact on the vehicle availability. The main objectives of the Work Package are as follows: Review of the current practice NDT techniques used in preventive maintenance in railway axles, to highlight the weakness and strengths of each method and to find possible points of improvement and solve potential risks that are not addressed by these methods. The study of a new inspection method based on a new on-board continuous measurement technique. This technique describes a new methodology of diagnosis and classification of flaws in order to develop a new robust NDT method for axle inspection that could be classified as a condition based maintenance technique. This method is based in a sophisticated signal processing procedure that uses vibration signals obtained during rotation of the axle. Verification of the influence of surface damage and corrosion in service using standard electrochemical and other NDT techniques. Different NDT techniques are reviewed for monitoring of corrosion and cracking in train axles without the need of disassembly. The investigation of a novel crack detection method based on the change of the elastic resistive behavior of an adhesive plug using electrochemical techniques, to detect cracks in railway axles [11, 12, 13]

Automated realization of testing of wheel sets is planned with a particularly feed device, that will be programmatically watery and therefore quicker and more reliable for detection of internal inclusions. Large industrial systems demand a bursting an extremely quicker testing just represents extremely shorter time of loss of a vehicle from operation.
7. Conclusion

Testing hollow axles or shafts with ultrasound method with special probe is very reliable. At series 732 felt so far learned and prematurely excluded from traffic regarding 20 axles or shafts still before the introduction of control with ultrasonic probe through hollow axle or shaft. At newer vehicles with use of special probe for the test of hollow axles and shaft was not to detect mistakes and the bursting in material and no cracks were found.

In future Slovene railways plan automated special ultrasonic testing of wheel sets with different shaft bore diameters with longitudinal and transverse waves with the comprehensive analysis of signals and low space requirements on dismantled hollow axles or shafts. A device must be extremely smaller, it will be ensuring high adjustability and have high measurement accuracy with possibility of filing of data for further statistical treatment at investigation of different shapes of hollow axles at repeatable results, swiveling probe head construction, short testing time and easy changing of probe heads. The device for investigation of hollow axles must be simple for installing of probe and she must ensure short times for investigation. With consideration of standard of DIN 27201-7, a good educated specialist restrained procedure of investigation on universal device. For automatic work will be ultrasonic device also to future ensured high quality of testing of hollow axles or shafts regardless of their form features and geometry.

8. References

[1] Internal Standard of JŽS V3.006, Zajednica JŽ, Službeni glasnik ZJŽ br. 9, Beograd 1971
[3] Description of works for control examinations P0, P1, P3 in P6 for 342, Ljubljana 1987