Digitalization for Railway-NDT

Daniel WERNER\textsuperscript{1}, Andreas FRANZEN\textsuperscript{1}, Frank HENRIX\textsuperscript{1}, Uwe PHILIPPS\textsuperscript{1}, Paul BUSCHKE\textsuperscript{1}

\textsuperscript{1}Waygate Technologies, Huerth, Germany, Phone: +49 2233 601115, Email: d.werner@bakerhughes.com, andreas.franzen@bakerhughes.com, frank.henrix@bakerhughes.com, uwe.philipps@bakerhughes.com, paul.buschke@bakerhughes.com

Abstract
High-speed trains, as they are used by leading train operators in Germany e.g., are inspected with underfloor testing machines. During inspection testing machine detects condition of wheels, including rim, tread, inner and external face and wheel disk, without disassembling wheel. Due to its innovative testing procedure, high automatization level and user-friendly controlling and inspection tools, this third generation of inspection machine is a good example of how to use Industry 4.0 ideas in non-destructive testing. To increase producibility inspection system allows inspection of a wheel in approx. 90 seconds. Inspection system supports operator with a straightforward workflow-based inspection procedure, several visualization and inspection tools. Internal, or external experts such as NDT competence center can support in case of difficult results without being on-site. Solutions for connectivity and tools for stand-alone-evaluation also increase flexibility of evaluation process. Thus, human factor can be reduced, and inspection reproducibility is maximized.

Keywords: Wheel inspection; in-service inspection; UFPE-WheelStar; rail; high speed trains; testing machine; high automatization level; ultrasonic testing (UT); NDT4.0; industry 4.0

1. Introduction
For highspeed trains several definitions exist, but they all have a minimum travelling speed of 190 km/h in common. Of course, many highspeed trains travel much faster than 190 km/h. Due to fast travelling speed safety is indispensable to avoid catastrophes. Thus, leading train operators in Germany e.g., inspect wheels of highspeed trains regularly by using ultrasonic testing (UT).

Ultrasonic testing includes inspection not only of running surface, but of the complete wheel, including wheel disk, inner and external face, rim and tread (figure 1).
Areas shown in figure 1 are inspected in parallel to other maintenance work. Details on inspection areas are described in DIN 27201-7 [1]. Disassembling of the wheel is not necessary, so that inspection does not mess with maintenance work, which is relevant to realize inspection without blocking capacities of trains.

2. Underfloor inspection system

Therefor underfloor testing machines drive in a pit under the train. Figure 2 gives a schematical view to describe inspection process:

- Moving underfloor inspection system «WheelStar» under the train
- Lifting wheelset
- Rotating wheelset
- Fully automated coupling of probes at 1st wheel
- Inspection of 1st wheel (within one turn in approx. 80 sec) and evaluation by operator
- Fully automated coupling of probes at 2nd wheel on opposite side
- Inspection of 2nd wheel (within one turn in approx. 80 sec) and evaluation by operator
- Decision and report
First, underfloor inspection system is moved to the wheelset to be inspected. This wheelset is lifted and rotated by a hydraulic system integrated in the underfloor inspection system. Next, probes are coupled to the wheel. After a wetting turning (water is used for coupling) inspection of the first wheel starts. Lifting and rotating of wheel as well as coupling of probes is fully automated. Within one turn (in approx. 90 sec) wheel is inspected (incl. rim, tread, inner and external face and wheel disk). Operator evaluates testing results by using visualization and support tools, which are described below. Next, probes are coupled to the second wheel on the opposite side and second wheel is inspected, too. After evaluation of second wheel, operator decides about wheel condition, while using a straightforward workflow-based inspection procedure and saves data and test results. Finally, underfloor inspection system is moved to the next wheelset to be inspected. A water reservoir with approx. 250-300 liters on board allows to inspect without any interruptions for refill during shift.

At the beginning and the end of each shift inspection system is validated during a Check-/Recheck procure at a test specimen with defined flaws. During Check-/Recheck procedure a failure management system supports operator in validation.

Underfloor inspection system »UFPE-WheelStar« (figure 3) is third generation of underfloor inspection machines and has increased ergonomic conditions and comfort for operator. Therefore, controller and inspection system (in the pit under train) are self-sustaining and linked to each other wireless. Wireless linking not only eliminates risk of broken cables, but also increases comfort for operator. Climbing into pit to fix cables are eliminated. In addition, comfort is increased by a user-friendly workflow-based Human Machine Interface (HMI) for controlling and by user-friendly evaluation software opportunities to validate results. A straightforward workflow-based control concept allows to proceed within logical steps and makes complex inspection task easy to handle. Due to the standardized (workflow-based) proceeding and a high level of automation operators work gets comparable and human factor during inspection is minimized. If there are any doubts during evaluation inspection results can be shared with internal or external experts (e.g. NDT competence center). Experts can support evaluation even from out-of-side or retrospectively. In case of any trouble remote support of OEM is also possible and helps to maximize availability of inspection systems.
3. Digitalized in-service wheel inspection

Before discussing 3rd generation of underfloor inspection system in context of industry 4.0 or NDT 4.0, first we have to define industry 4.0 or NDT 4.0 in context of in-service-wheel inspection.

Industry 4.0 is one of the top priorities for many companies and universities, but a generally accepted definition does not exist [2]. Federal Ministry for Economic Affairs and Energy in Germany realized »Plattform Industrie 4.0« to coordinate activities for digitalization of industry in Germany. In this context the ministry defines industry 4.0 as the intelligent networking of machines and processes for industry with the help of information and communication technology [3]. But unfortunately, this definition is not concrete and does not give any concrete suggestions to digitalize products or organizations. Hermann M. et al. discussed in a literature-review six principles of how to realize industry 4.0 scenarios in organizations: virtualization, service orientation, real-time capability, interoperability, decentralization and modularity [2].

Although a testing machine is not an organization, let’s discuss about how to use these six design principles for digitalization of NDT. How do we use these six design principles within new generation of underfloor inspection system UFPE-WheelStar and what are the benefits?
3.1 Virtualization - One turn for inspection

Virtualization is what ultrasonic inspection is about: Ultrasonic inspection is used to make defects inside of a specimen (under materials surface or within volume) visible. Here, we use ultrasonic inspection to get information about train wheels condition. This includes condition of rim, tread, inner and external face and wheel disk (see also figure 1). After wheelset is lifted and rotates, probes are coupled automated to the wheel and wheel is going to be inspected. Due to 14 probes, which are used simultaneously (in sum inspection system has 19 probes) and phased-array technology a train wheel is inspected within one turn and in less than 90 seconds. After digitalization A-scan, TD-scans and different projection views are available for evaluation of testing results (figure 4).

3.2 Service orientation - Straight forward workflow-based inspection procedure

Due to high inspection speed there are lots of data within short time interval. To keep overview over all data on the on hand and to handle complex inspection system on the other hand, an intuitive straight forward workflow-based inspection procedure is realized and different supporting tools for operator are available. Support for operator is not only during evaluation necessary, but also during complete inspection process. First, positioning and coupling of probes is fully automated. Thus, positioning and coupling of probes is not affected by human factors and results get comparable. During validation of inspection system (check and recheck to reference testing machine at the beginning or ending of each shift) a specimen-reflector-management pre-evaluates flaws based on an automated comparison of flaw and calibration data. Operator uses pre-evaluation to get information about probe condition and to validate inspection system and inspection results. During evaluation different tools for visualization summarize A-data in projection views or patented difference-method masks circumferential echoes. After evaluation workflow-based inspection procedure guides operator through decision making process as well as creation of protocol and data storage.

Figure 4. Digitalization of a train wheel within one turn [4]
In case of any trouble, an integrated condition monitoring helps OEM to support operator remotely – including remote-control (if operator allows access).

Figure 5 summarizes support for the operator during inspection procedure, evaluation and in case of any trouble.

Support of inspector during use of inspection system and evaluation of results increases comfort, machine availability and comparability of inspection results and thus increased security, due to human factor is minimized.

### 3.3 Real-time capability – Data management and exchange

For any kind of support, data mining and data transfer are essential. In concrete relevant data are ultrasonic specific data (e.g. TCG-curves, calibration and virtual probe gains), comments, protocols, data of condition monitoring, data about operator and of course inspection results. These data are collected and saved on the inspection system. Data is saved in a for UFPE-WheelStar-inspection systems and stand-alone viewer system compatible, exchangeable format. Due to compatible and exchangeable format, data can be transferred to other UFPE-WheelStar-inspection systems or stand-alone computers (with stand-alone-viewer software installed) or can be stored on serves or in a cloud (depending on operators IT-periphery). Of course, data has to be secured. For example, data relevant for inspection can not only copied and passed from another system but has to be validated by inspection supervisor before first-time use.

### 3.4 Interoperability & Cooperation

Exchange of UFPE-WheelStar-data increases cooperation and interoperability within company, especially if many UFPE-WheelStar-inspection systems are used and several operators (perhaps placed on different locations) cooperate (figure 6).
Data or opinion exchange is beneficial during decision making process: In case of any uncertainty from operators point of view, interoperability allows to consult internal or external experts such as inspection supervisory or companies NDT-Competence Center. Due to a stand-alone viewer software and options for data exchange inspection supervisory or companies NDT-Competence Center can support operator during evaluation even if there are not on site. So, decision making process does not depend on operators experience or opinion anymore, but evaluation process gets more comparable. In case of any trouble interoperability also means remote support, mentioned above.

3.5 Decentralization - Decision making from everywhere

These ideas lead to a centralized decision-making process but to a decentralized working surrounding. Know-how and experience are transferred over limits of sites. To do so, standards for data exchange have been developed for UFPE-WheelStar-inspection system.

Next step is to integrate data exchange in operators IT-periphery, respecting IT requirements.

3.6 Modularity - One Interface to control & evaluate

Although inspection task of wheel inspection and evaluation is very complex and an inspection system with a high automatization level is complex, too, operator does not take any notice of this complexity. Within UFPE-WheelStar-inspection system there is only one human machine interface to control evaluation software, machine hardware, ultrasonic electronics, data storage and secure relevant functions (figure 7).
Figure 7. Modular designed hard- and software architecture of UFPE-WheelStar-inspection system

Due to its modular design of hard- and software architecture of UFPE-WheelStar-inspection system, inspection system can be adapted to different wheel types, probe types, test failures, etc. For example, probes can be replaced or added to UT electronic. Protocols and documentation functions can be adapted to customers wish.

4. Benefits and conclusion

Due to respecting six scenarios to realize industry 4.0-ideas figured out by Hermann M. et al. [2], UFPE-WheelStar-in-service-wheel inspection system is a good example of how to realize NDT 4.0 in wheel inspection. NDT 4.0 in wheel inspection helps to benefit from digitalization. Concrete benefits from operators’ point of view during inspection procedure are increased comfort during usage. Due to wireless connection and water reservoir time-consuming works within rail track are eliminated and job preparation schedule are reduced. High level of automation and straight forward workflow-based inspection procedure help to reduce causes of error and optimized software opportunities for evaluation and transfer during decision making process, increase comparability of test results and minimize human factor during inspection and evaluation. Operator can concentrate on what is essential: Evaluation of wheels condition. Operators company benefits due to increased acceptance in face of complex inspection and system technologies, short inspection duration (<90 sec/wheel) and increased system availability due to options for short-term remote support. Thus, UFPE-WheelStar-inspection system is one of the key factors for quality assurance and maintenance of rail.

Many thanks to DB Systemtechnik GmbH and DB Fernverkehr AG.
References
1. DIN 27201-7 State of railway vehicles - Basic principles and production technology – Part 7: Non-destructive testing, June 2020, Beuth Verlag, Germany


3. Federal Ministry for Economic Affairs and Energy Germany, URL https://www.plattform-i40.de/PI40/Navigation/DE/Industrie40/WasIndustrie40/was-ist-industrie-40.html, called 03.07.2020