MODULARIZATION OF ELECTRONICS AND TESTING MECHANICS IN AUTOMATIC ULTRASONIC MATERIAL TESTING SYSTEMS PRESENTED IN PRACTICAL APPLICATIONS

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Abstract

Cost pressure is an issue that also applies to ultrasonic testing systems as an asset invested. Intelligent solutions with high functionality and reasonable expenditure are the target. With an appropriate modular design that combines simple elements to a complex testing unit investment can be minimized without suffering any loss of performance.

The latest development of the IANUS ultrasonic electronics with its scalability and the matching software will be presented in inspection systems for weld seams, rails, wheel sets, strips and heavy plates. The basis is a hardware that can be globally used for many inspection tasks. The definite function is determined by firmware that can be loaded into an FPGA und software running on Power PC cores in the FPGA.

What is valid for the electronic concepts applies also to the mechanical parts of an inspection system. Probe holders and guiding elements are designed in a way that they can be mounted in sub-assemblies forming a complete testing mechanics. All that comes along with minimization of cabling and other connections for media supplies.

For interfaces to control systems and other computers mainly industrial standards (e.g. TCP/IP or Profinet) are used in order to generalize connectivity.

IANUS Ultrasonic Electronics

The abbreviation IANUS stands for .... The targets for the development were:
- highest flexibility in configuration for simple and complex systems
- no limitation of the number of channels
- state of the art performance for flaw detection systems

A IANUS system can be composed of six different modules:
1. **Housing with backplane** - Accommodates all the modules listed below. All modules are cooled by thermal conduction using of wedge locks.
2. **Power-Supply** - Generates all necessary voltages including the supply for the transmitters. It is to be provided by a 24 V power supply what is easy to get in industrial systems.
3. **Central Processor** - Holding the main devices for configuration, data acquisition, evaluation and computation. There is an FPGA with two Power PC cores in BGA housing. Two Ethernet ports are available to connect the unit to a PC.

4. **Process I/O** - In order to make IANUS a real time system, information on process and position (e.g. encoder) signals as well. There are 16 input and 8 output signals (24 V level) which could be directly connected to a PLC. Further, there are inputs and outputs for the so called CTP (cycle trigger pulse) which can be used for synchronization between IANUS units.

5. **US Transmitter** - Providing eight needle transmitter channels with selectable termination resistors. They can be individually configured as pulse/echo or T/R-channels. The supply voltage for the transmitters can be preset.

6. **US Receiver** - Making available eight receivers with appropriate digital filters, an ADC with 80 MHz sampling rate and 14 Bit resolution.
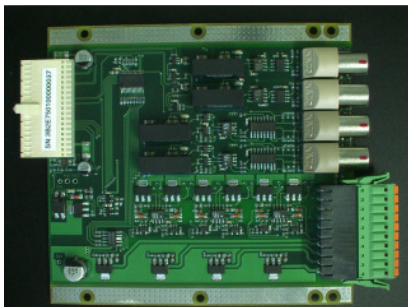

1. Housing with backplane
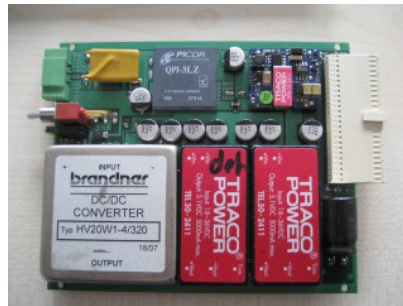
2. Power Supply (ISDC)



3. Central Processor (ISCP)


4. Process I/O (ISIO)

5. US Transmitter (ISHV)

6. US Receiver (ISAP)

Building a Unit

To build a functional unit, the described components can be used in different configurations for different applications. One functional unit comprises always the housing with backplane, the power supply unit, the central processing unit and the process I/O board. Depending on the application, a variant number of US boards can be used to fulfill the task.
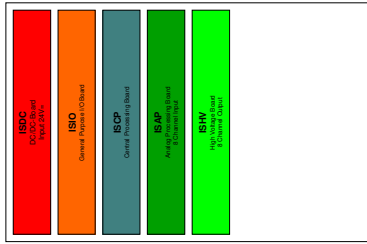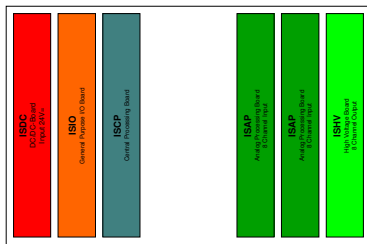
8r8t -This configuration has 8 receivers (multiplexed) and 8 transmitters. It is applied in simple or widely distributed systems.
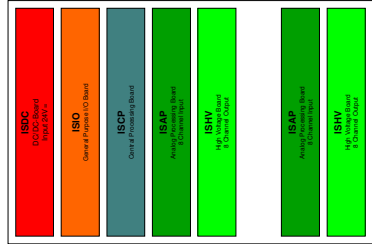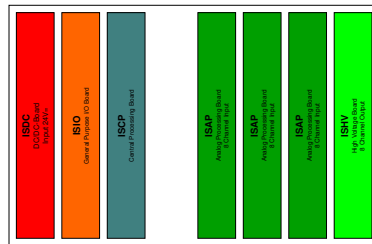
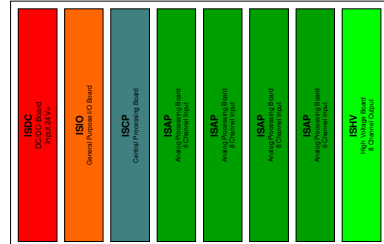**2*8r8t** - Same as before, but doubled. Both groups can work in parallel.
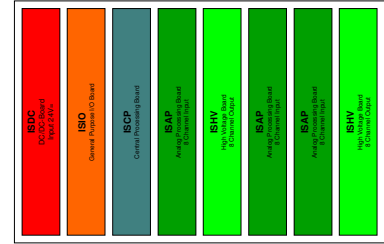
8r8t+16r8t - Two multiplexed groups working in parallel. For applications with separated transmitter and receiver probes (e.g. TOFD or Tandem)
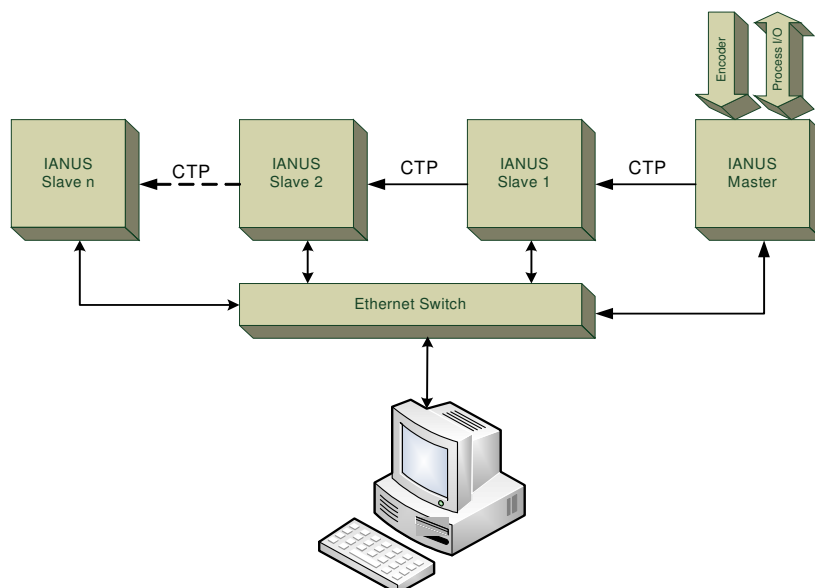

16r8t

24r8t

32r8t

The shown configurations are mainly meant for probes with one transmitter and 2, 3 or 4 receivers, as they are known from heavy plate inspection systems. All receiver boards work in parallel, whereas within one board 8 channels are multiplexed.

Since the modules are to be placed on the mechanics close to the probes, the cables have the shortest possible length what improves also the signal quality.

Building a System

Units have to be put together to complete systems and inspection tasks have to be synchronized. Thus, there must be a means to transfer synchronous trigger information as well as I/O status information without extensive wiring between the process and all modules.

This is dealt with by the Cycle Trigger Pulse (CTP). It does not only carry the trigger signal, but it also transports information like cycle number, coordinates which are to be combined with the inspection results and enable signals for individual channels . Physically the CTP is a two-wire LVDS cable. The CTP can be generated by one IANUS unit,

acting as a Master and is transferred to a number of units in a distance of up to five meters between each other. Many of such Master/Slave subsystems can exist within a complete inspection system.

The next step is to build an entire system. Since all inspection result data collected in the individual IANUS units are permanently bound to a coordinate and other process related signals, there is no demand for high speed real time transfer to an evaluation computer. Consequently the data can be requested and retrieved from a PC via Ethernet with TCP/IP protocol. Only the A-scan data and flaw indications for visualization on the graphical user interface (GUI) are cyclically transferred to the PC.

There has to be an interface between the PLC and the US electronics as well. As already mentioned, real time signals are to be connected to the ISIO Process I/O board. For global, non-time-critical control, PLC systems with Ethernet and TCP/IP interface are used to hook up to IANUS through a determined port.

IANUS Firmware and Software

All functions for cycle control, signal generation, data acquisition and so forth are put into a Field Programmable Gate Array (FPGA), the firmware, or they are implemented in software running on the two embedded Power-PC (PPC). As the FPGA has to be loaded after start-up and the PPC's memory also has to be prepared, the user is free to load a functionality which is appropriate for the respective inspection task.

All firmware and PPC software is stored on the PC's hard disk. The only permanent software on the IANUS is a boot loader program that uses a standard FTP-Server running on the PC. After start-up of the system IANUS will get the firmware and software via the TCP/IP connection from the PC. In fact, the functionality of IANUS will merely be determined by the loaded files. There is already a variety of firm- and software for different applications available (e.g. gate-based evaluation and ALOK method, etc.).

The start-up procedure makes it also very simple to substitute or upgrade software within a few minutes, if remote access to the PC is feasible.

In addition to the basic functions, configuration and parameter data have to be loaded to completely determine the complex function of the system.

Data Evaluation Unit (DEU) Software

The **DEU** software is a Windows- and .net-based application software that consists of a flexible and modular structure as well. The main targets for the development were:
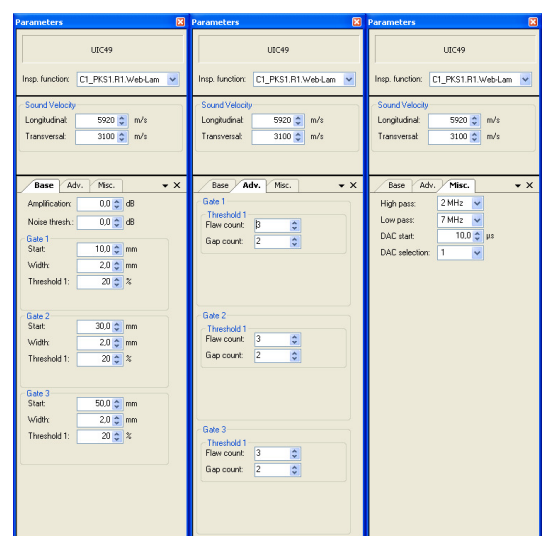
- High configuration ability - A new system would not require a new program, but just a new configuration. A project engineer should be able to do that. The operator's language has also be configurable by means of an initialization file for the menu texts. The configuration includes the definition of
    - the layout of the inspection system, its inspection tasks and cycle schemes
    - probes, electronics modules and their wiring
    - marking units and their assignment to inspection tasks

- Standard menus and display windows - For system administration, configuration, administration of user permissions, parameterization, A-, B-, C- and TD-scans, bar charts, defect lists etc. should be solutions which are applicable for most of the inspection tasks.

- A standard protocol format set to choose from - The protocol forms should cover most of the applications.

- Standard interfaces to a superordinated system in order to integrate the inspection system into the production line. Those interfaces are mainly based on Ethernet and TCP/IP using e.g. simple socket connections, OPC client/server or Oracle SQL structures. Data for the testing subject can be received and results can be sent to the superordinated system.

The picture on the right shows an example of the DEU windows for a rail inspection system. The GUI layout is fully configurable. The different windows can be individually switched on or off. Size and position of the windows can be adapted as well. The operator is free to set up the GUI in a way that adapts it most to the actual job.
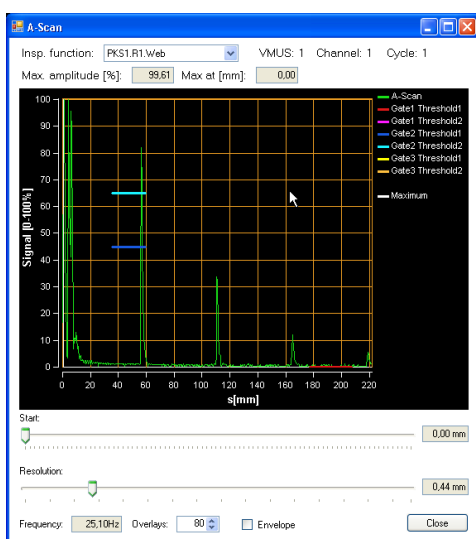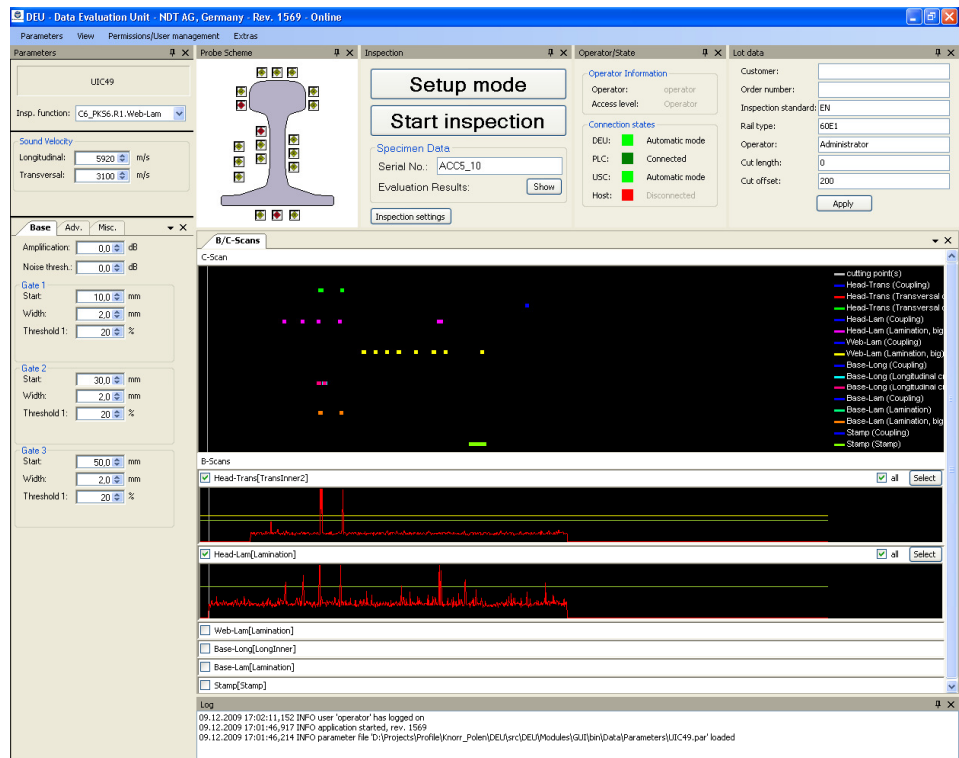
On the left, the A-scan presentation is shown, what can be superposed to the main window. On the right, the window of a parameter set for one channel is pictured. All menu and display windows are generated by use of a graphical standard library. As a consequence, cost and time for development and maintenance were minimized.
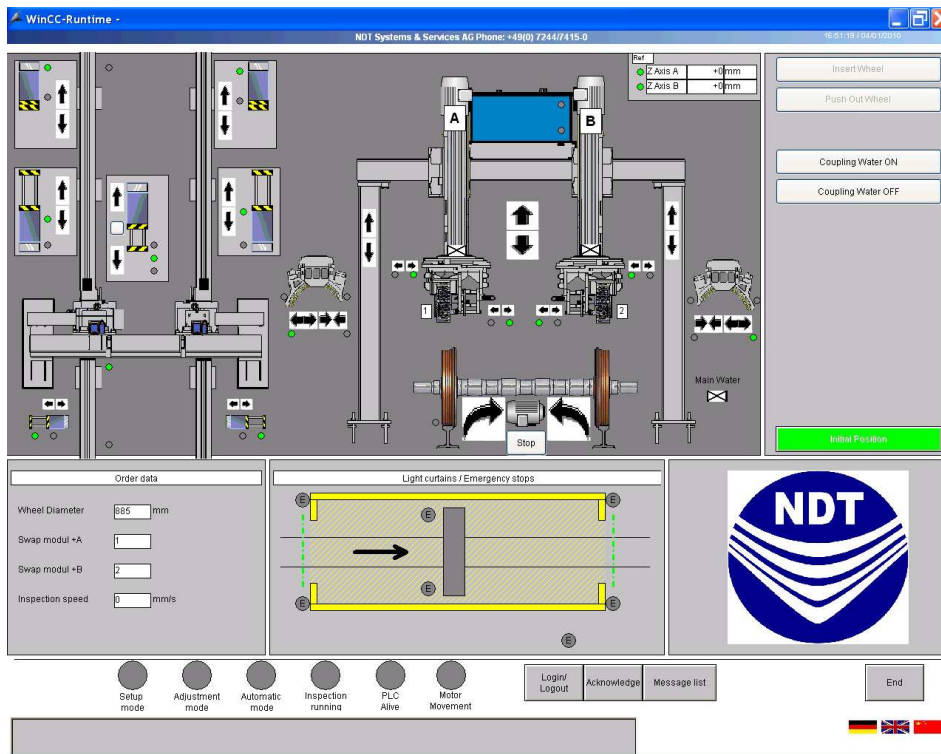
Control System

Control tasks and inspection tasks are always separated, due to easier development and testing. Both subsystems can be independently tested and verified. In case of a malfunction it is advantageous that there is not much interdependence between the systems, provided the interface is kept simple.

Control systems are generally built with SIEMENS S7-PLC hardware with the associated tools for software development (STEP7), unless there is another requirement. As far as possible standard techniques for software design and development are applied. In order to reduce wiring on the machines, remote I/O modules will be used to an reasonable extent. The remote modules are connected on the basis of PROFINET.


For visualization, manual operation and error messaging including alarm list mainly the SIEMENS WinCC system is used. Firstly because of easy interfacing to the S7 PLC, secondly due to its superior graphical features and thirdly to faster implementation compared to graphical Operator Panels. Although the purchase costs for the hardware might be higher, finally the overall costs are rational. From a 3-D CAD system generated JPG-files can be used as a basis for visualization. WinCC display elements are added to show the current status of the machine. The picture above shows the visualization of a system for rail wheel set inspection. For maintenance purposes files, for instance circuit diagrams or setting instructions in PDF-format, can be opened on a special command linked to a display element. Switching between different languages is also easy to achieve.

For tracking or follow-up purposes inspection systems are nowadays equipped with laser scanner devices. The raw data of the scanner can be read out via Ethernet an TCP/IP. Different algorithms, which are in-house development, complete the device to a system that can recognize edges (for plate inspection systems) or weld seams (for SAW pipe inspection systems) and control the follow-up and guiding of probes along the inspection path. The picture on the right shows devices with different working ranges. Also here the hardware base is fix and the modularity will be achieved by the software.
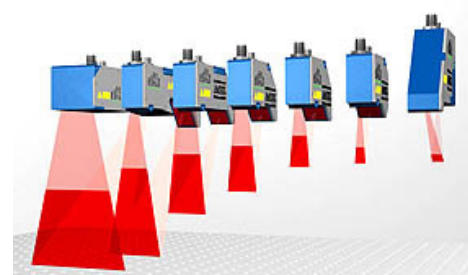
Testing Mechanics

With increasing requirements for inspection tasks expenses for the system will also increase. Future-proofed designs, which allow later on upgrading without any difficulty help to keep current investments low without limitation for further extension to new requirements if additional investment pays off.

Our systems are composed from building-blocks carefully designed for modular extensibility.

Example 1: Heavy Plate Inspection System

Ultrasonic inspection of heavy plates is basically performed by vertical incidence of the ultrasonic signal from above or below of the plate. The modular structure of testing mechanics is explained in more detail, using the example of the system type „Inspection from above",
Using a modular system an efficient adaption of the mechanical main components is achievable to a plate width up to 5.400 mm to be inspected as well as the adaption to the local conditions on customer's site.

The plates are conveyed through the inspection system at a testing speed of 1m/s. The plate body and edges are inspected for cracks and volume defects using so-called body inspection and edge inspection carriages. The number of probes installed per inspection carriage depends on the maximal plate width and the requirements of edge inspection.
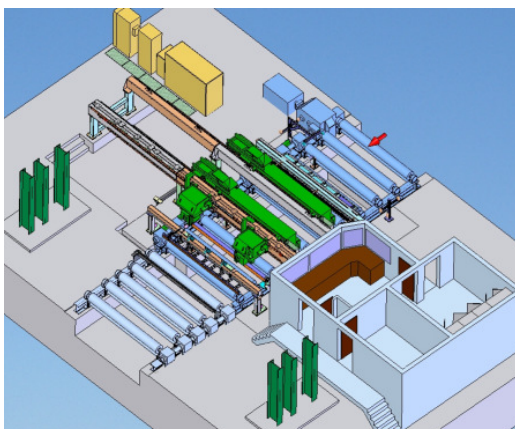
The inspection carriages can be moved to service position for the purpose of maintenance and service which is located outside of the area of roller conveyor, as seen in the picture on the right side and in the drawing on the left side in plate feed direction.

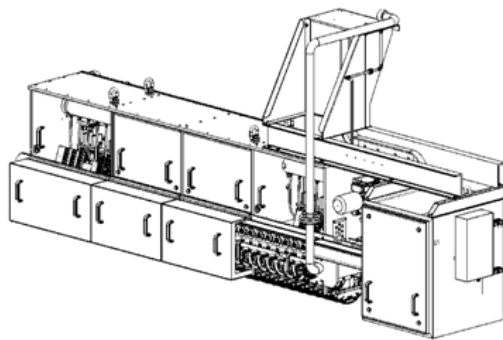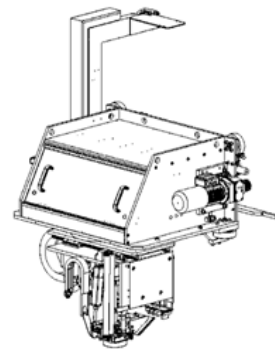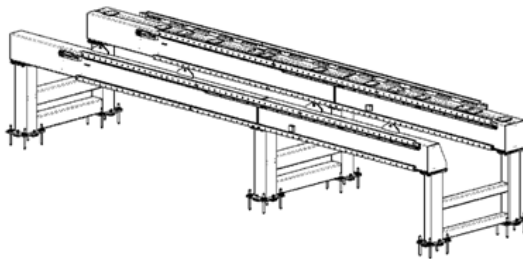The following picture illustrates the main components of the modular system.

Plate Body Inspection Carriage
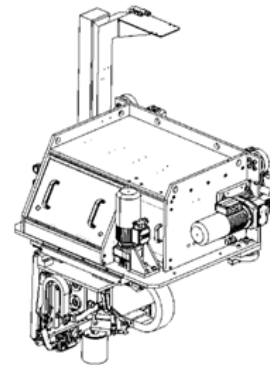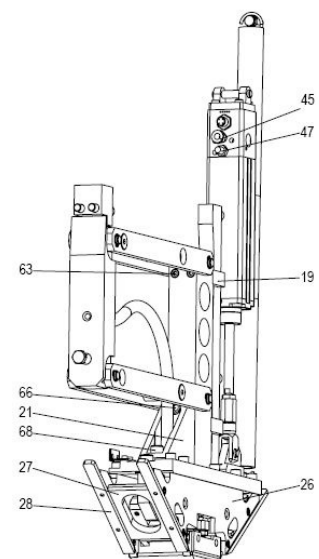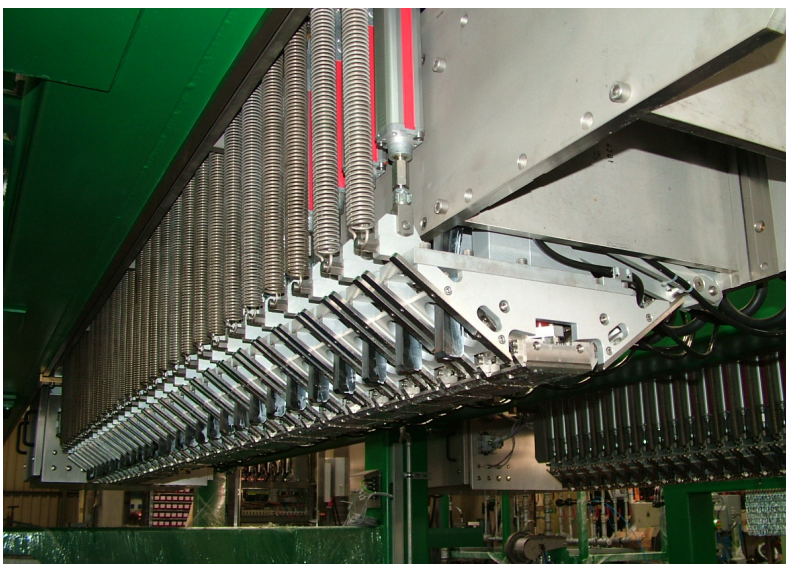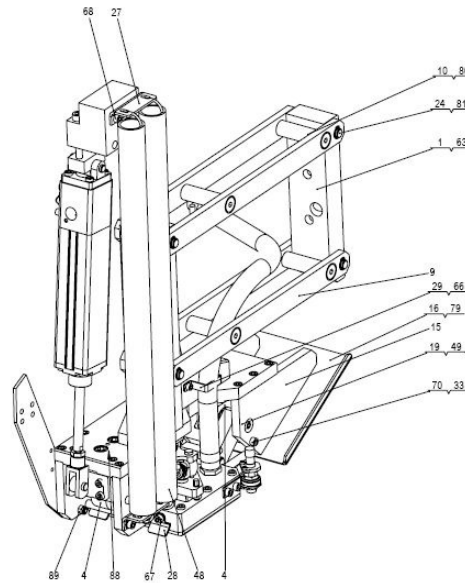

Plate Edge Inspection Carriage

Portal

Plate Edge Inspection Carriage, swivel

All modules can be adapted to the customized local conditions, if required.

The **plate body inspection carriages** - usually two - are adapted two plate width and the location of the service side. One type of probe holders is used for all application. A quick-coupling allows a fast replacement of the complete module including pre-adjusted probe.

The **plate edge inspection carriages** are equipped with two or three probes to cover the required edge inspection width. The swivelling carriage is applicable for the inspection of the longitudinal as well transverse edge inspection.

All inspection carriages are installed on a portal. It consists of standard elements with customized dimensions.

Further modules are available for

- plate income recognition, check of the plate height and temperature
- detection of the plate position
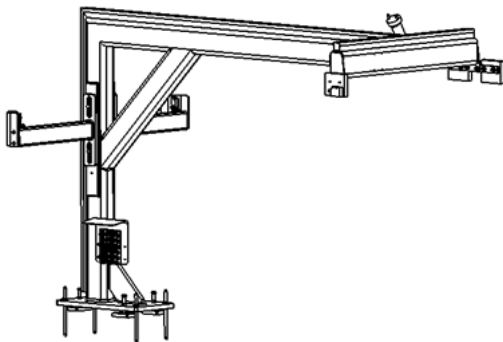- removing of the coupling water
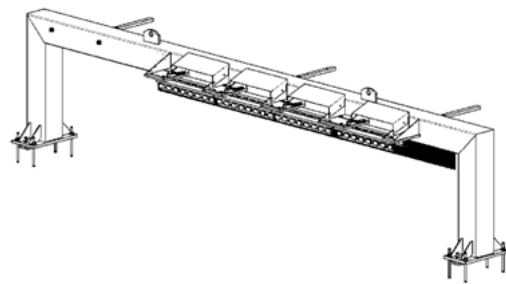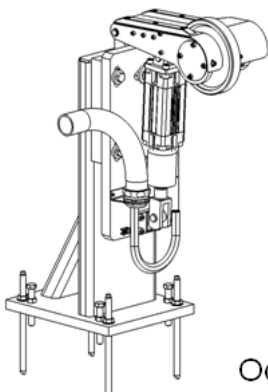- monitoring of the plate feed
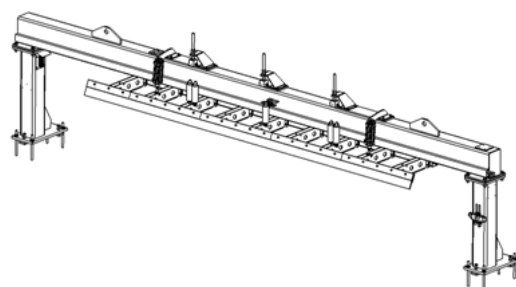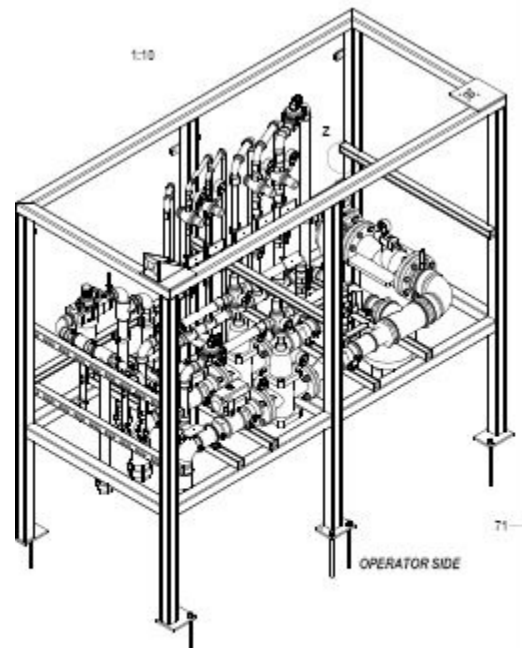

Plate Income Recognition

Plate Position Detection


Odometer

Water Wiper from above

Finally, a modular media distribution system is applied in order to provide coupling water for the ultrasonic inspection and air pressure to control the pneumatic components.

Example 2: Weld Seam Inspection

Modular designed components are available for the weld seam inspection of longitudinal or spiral welded tubes which are applicable for ultrasonic testing of the tubes in the welding line (on-line inspection) as well as for the inspection of the weld seam of single tubes (off-line inspection).

The main components of the modular system are shown using the example of an weld seam inspection equipment off-line.
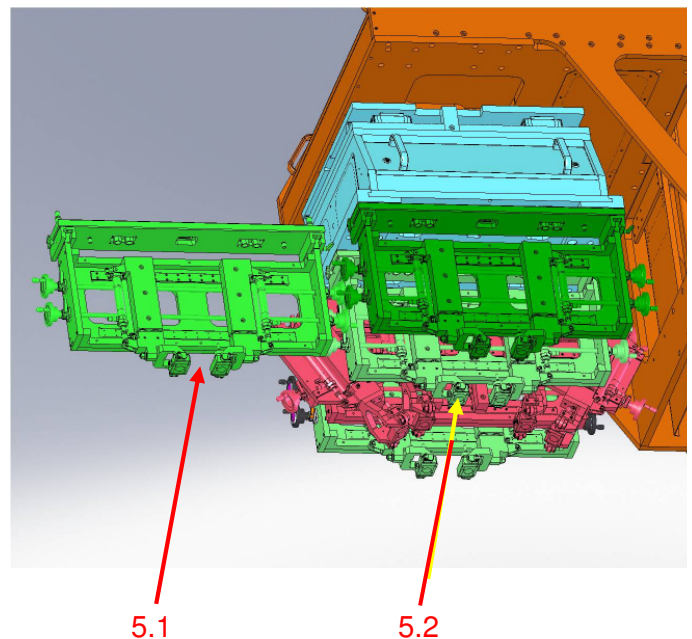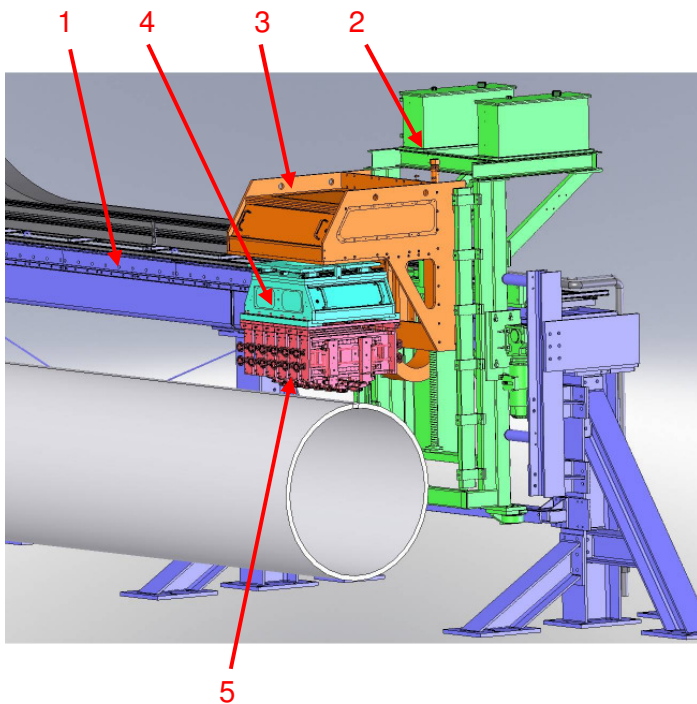
|	Module	Remarks
1	portal construction	number of segments according to the max. tube length
2	main carriage	motor-driven, with coupling water supply
3	vertical carriage	vertical adjustment to the current tube diameter
4	transverse carriage	transverse adjustment to the current tube diameter
5	probe holder modules	configurable to different probe arrangements
5.1	basic module " I "	applicable for probe constellations: I, K and K
5.2	basic module " T "	applicable for probe constellation: Tandem

A simple and fast adaption of testing mechanics to the required inspection task is achievable by exchanging the different probe holder modules using a combined quick-coupling for the ultrasonic signals and coupling water.

Example 3: Rail Wheel Set Inspection

Finally, the modular design of NDT testing mechanics is illustrated by means of the ultrasonic testing system for dismantled rail wheel sets.

Wheel sets have to be refurbished at regular intervals in heavy maintenance workshops. For this process the wheel sets have to be dismantled from the train.

After refurbishment of the wheel profile the non-destructive testing by means of ultrasound and eddy current of the wheels and axle is required.
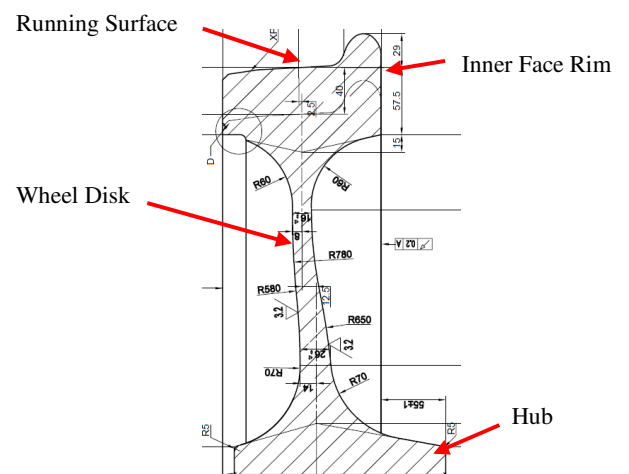
The wheel rim and disk are inspected for surface cracks and volume defects.


The testing mechanics consists of modular designed components.

The portal is equipped with two motor-controlled vertical axes for adjustment of probe assembly support to the current wheel set diameter. The support on each axle has pneumatic driven guide units in mirrored arrangement.

A rack module above the support contains the on-site ultrasonic electronics and automation electronics.

Depending on the design of the wheel to be inspected and the required inspection areas, different probe assembly modules are used.

The probe assembly for wheel rim and disk inspection consists of two fixed modules, applicable for all types of wheel set. These modules are used for the roller surface and the inner face rim. Additional hot-swap modules adapted to inspect specific wheel disk configurations are applied to detect defects in the wheel disk.

hot-swap module
with probe system
for wheel disk
inspection
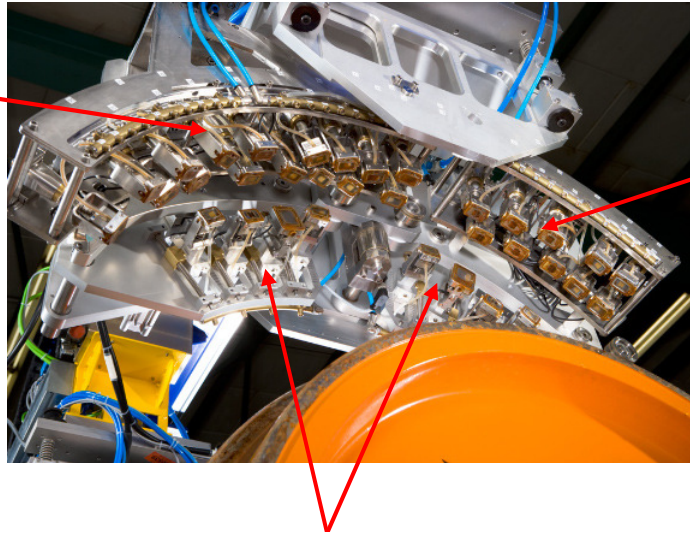
fix module with
probe system for
running surface
inspection

fix module
with probe system
for inner face rim inspection

The probes of modules are pre-adjusted in incidence position. Thus the module handling is very easy and the change-over time to another wheel set very short.

Conclusion

Modular design reduces individual development costs and the delivery time. Absolute expenditure for spare part provision can be optimized. Maintenance costs will also decrease and the responsible personnel can be flexibly assigned to maintenance task.

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