High-End Ultrasonic Phased-Array System for Automatic Inspections

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Abstract

Customer requirement trends on automated NDT test systems require higher productivity as well as improved defect detection capabilities. These incremental demands transition into advanced instruments with high processing power, fast communication links for the signal evaluations and adequate display of the measurements. Applications like pipe, bar, plate or aerospace components for inline inspections require high inspection channel counts for increased test coverage and subsequent fast evaluation algorithms to provide the results.

To fulfill these specifications, a new system with a flexible architecture has been designed. The scalable phased-array system will allow driving linear and 2D array ultrasound probes from single to several-hundred elements. Very large apertures with wide steering angles for flaw detection or wall thickness measurements can be realized. More than 20 bit of digitized signal dynamic range allows precise evaluations and full original data post processing. The high channel count, system clock and signal dynamic combined with parallel evaluation channels generate data transfer rates up to 2.5 Gb/s. Several high-speed links are provided to transfer the information.

Data of all channels and modules are transferred via Ethernet to the control PC which provides the application specific software to give the user an easy-to-use interface of a complex system. Also a customer-specific interface is available to allow access to the raw data for subsequent signal evaluations.

Keywords: Scalable ultrasonic phased-array system, large apertures, high signal dynamic, real-time evaluation, automated testing.

1. Introduction

The requirement of higher productivity and improved probability of detection for automated ultrasonic inspections need new system architectures which allow high data rates and high processing power for fast signal evaluations. New technologies like PCI Express (Peripheral Component Interconnect Express), ATCA (Advanced Telecom Computing Architecture) and advanced signal processing provide the possibility to fulfill this and also to design scalable systems for the market needs. Applications using large apertures with linear or 2D array probes can be supported with this new flexible architecture, also taking in account a user-friendly operation of the system.
2. New Technologies for Ultrasonic Systems

2.1 PCI Express (Peripheral Component Interconnect Express)

Today's automated systems use bus oriented architectures like VME (Versa Module Eurocard), VXI (VME Extension) or other standards which define the maximum data transfer rate of the system. This can limit the system when large apertures or the control of many elements like for 2D array probes are needed. The new connection bus PCI Express defined by PCI-SIG [1] is a point-to-point data communication using serial links which can consist of multiple lanes. Using PCI Express Standard 1.0 each of the lanes has a data rate of 250 MB/s and up to 32 parallel lanes can be realized. The standard is continuously further developed to increase the data rates. Having this system communication structure allows to transfer A-scan, gate and event data internally at very high speed and having the flexibility to generate a proprietary communication topology enabling performance scalability of a complex system. The graph in figure 1 shows the enhancements on PCI Express to increase the data rates over the years.

![Figure 1: PCI Express data-rate roadmap](image)

2.2 ATCA (Advanced Telecom Computing Architecture)

The requirements for a new system rack, which contains the electronic modules, are driven to be able to use many parallel phased-array sensors with ultrasonic modules to improve the measurement quality. These need to have a high communication speed between the ultrasonic modules and provide the processing power for the large number of channels. Also the form factor, thermal control of the components and the cost for the packaging of the electronic components define the demands for the new system housing. With the ATCA industry specification [2], defined by more than 100 suppliers, a standard for rack design was found to also fulfill these requirements for a new ultrasonic system. It was first established for the use in the telecommunications industry and has the following objectives, which are also keys for future ultrasonic systems:

- high level of modularity
• support interfaces up to 40 GB/s
• very high reliability
• volume efficiency
• system scalability

The standard allows for the customization of the backplane, which is divided into three zones to accommodate the power supply, high-speed communication using PCI Express, and individual communication signals. The form factor for the modules is defined and it is possible to get rack sizes with different slot counts with a maximum of 14 slots in a 19” rack, which is used for the current ultrasonic system [3].

2.3 Signal digitization and processing

2.3.1 Signal Digitization

High signal dynamic and resolution are keys for an accurate digitization of the ultrasonic signal. Phased-Array probes up to 10 MHz require sampling frequencies of 50 MHz or more and real-time interpolation algorithms to increase the temporal resolution which can be some nanoseconds. The dynamic range of ultrasonic signals used in the instruments is in order of 90 dB. To be able to digitize this full range with sufficient signal amplitude resolution digitizing concepts are used to capture the amplitude with more than 20 bits. This allows a full digital gain adjustment and enables to store the full A-scan dynamic, change the A-scan display between linear and logarithmic or change the gain within the full range in steps of the sample frequency.

2.3.2 Local Gain

Digitization of the ultrasonic signal with a high dynamic allows one to change the gain in very small temporal increments with a high dynamic. In previous ultrasonic instruments high dynamic changes, such as for the TCG (Time Controlled Gain) or backwall attenuation have been realized with separate analog amplifiers and had limitations on the slope. The backwall attenuation is needed to detect defects near the backwall. It generates an echo with high signal amplitude and can cover the defect echoes. This can be improved by reducing the signal amplitude of the backwall and/or increasing the amplitude of the defect signal. The local gain feature enables the user to have, within the different gate areas, different gain settings to get good defect visibility. Different colors within the A-scan show the areas of different local gain adjustments including overlapping areas, s. figure 2.
3. System overview and key features of the new ultrasonic system

3.1 Electronics to provide high performance

The new ultrasonic system is a full parallel system to drive many phased-array probes. The system electronics are built into the ATCA rack which consists of the ultrasonic module PA64 and the Box Controller. Each PA 64 can drive the transmitting and receiving of 64 ultrasonic elements; up to 12 modules can be plugged into one rack, which allows for 768 elements to be driven in parallel. This enables the system scalability to support linear and 2D probes. The aperture size can be up to 256 elements and be moved across all UT modules in the system. The box controller realizes the interface using the Interbus connection to the PLC (Programmable Logic Control) and the encoders to synchronize the evaluation data with the position of the inspected part. For the internal data communication PCI Express is used and the communication with the control PC is done with Ethernet connection. If more than 768 elements are needed up to eight racks can be combined to support up to 6144 elements, which demonstrate the scalability of the system.
To get a high ultrasonic performance of the system adjustable 200V rectangular pulser, which can fire with a pulse repetition frequency of up to 20 kHz and high dynamic, low noise receivers are available, also to support the local gain feature. Scanning, beam steering and focusing in 2048 cycles with a delay resolution of 2.5 ns are used to drive the phased-array probes. Possible sub-cycling, which does not require new ultrasonic shots for different receive beams optimizes the evaluation speed of the system. Eight possible parallel beam formers with eight evaluation channels having five gates in the same cycle for each ultrasonic module give a high grade of parallelization of phased-array probes for high inspection coverage. Signal up-sampling for high temporal resolution, a digitized signal dynamic of 20 bit for each channel with 24 bit for the formed beam and individual adjustable digital filters ensure high signal quality for precise measurements.

### 3.2 Software to simplify the use of the system

Complex phased-array systems require a software architecture which supports a structured and easy-to-use operating interface which is able to adapt without a significant effort to applicationspecific solutions from the market. The core server US PAR (Ultrasonic Parameter), which administrates all the ultrasonic parameters to drive the system, connects to the TCP Server to
communicate to the ultrasonic system and provides the information to be displayed in the application-specific Graphical User Interface (GUI). For generic set ups a basic GUI is also available to have full access to the system.

Figure 4: Block Diagram of Software

Two examples represent the menus to operate certain functions of the system. In figure 5 the Gate menu shows the adjustable parameters for all five gates which can be processed in parallel for each cycle. The full digital amplifier concept enables adjustments of the TCG or the rectification mode individually for each gate and to apply the local gain. For precise wall thickness measurements the mode for the time-of-flight can be switched between flank, peak and zero crossing.
For easy system set up it is useful to see the A-scan of different ultrasonic cycles in parallel. The Multi A-scan window shown in figure 6 gives an example for four A-scans which can be individually scaled, up to eight A-scans are available in this window. The left A-scan represents the accumulation of many cycles.
4. Application example for high inspection productivity

To achieve high inspection speed and productivity the Paint Brush Method is used for pipe inspection to detect longitudinal or oblique flaws [4]. This method uses many parallel transmitters to send a plane wave into the material and processes the received signals by using sub-apertures applying delays. This leads to an increased signal-to-noise ratio for flaws which are oriented in different angles and also optimizes the evaluation time lost in the water path. The new system allows use of all available channels to generate a broad Paint Brush, combined with many parallel-processed apertures, leads to increased test speed. The right image of figure 7 demonstrates the improvement using the sub-cycles to get a clear flaw indication after the interface echo.

Figure 7: Paint Brush method

5. Conclusion

The new system architecture having a high processing power enables a new phased-array system for automated inspections which is scalable to the customer needs for higher productivity. It combines high ultrasonic performance with an easy-to-use application interface for the operator and is prepared to use 2D array probes for better defect detection. The system will serve the segments of rail, automotive, aerospace, oil and gas, and power.
References

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