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PC-Based Systems for Ultrasonic and Eddy Current NDT

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Summary

In Germany, the last light water reactor (LWR) was put into service in 1989 (Neckar-2) [1], and due to the current political atmosphere no new LWRs are being considered for construction by the utilities at this time. Therefore, nondestructive testing (NDT) for new construction is no longer an attractive business, and is only required after component repair and/or component replacement. The techniques developed over the last two decades for government sponsored research and development (R&D) programs are assumed to be reliable for this purpose - especially after discussion of the results of the OECD program for the inspection of steel components (PISC) [2]. The emphasis on technique and application optimization according to the state-of-the-art in research *and* technology (required in Germany by law) is concentrated on the enhancement of inservice inspection and lifetime management strategies (e.g., for improved lifetime prediction and lifetime enhancement). Therefore, now is the time to introduce new quantitative NDT techniques, new evaluation procedures that use improved flaw sizing techniques and have linkage to fracture and/or fatigue mechanics. These techniques have to be established by taking into account risk-based considerations and uncertainties in the NDT data due to some degree of statistical vagueness. In parallel with the demand for quantitative NDT is the appeal of more intelligent inspection systems (hard and software 'enablers'). In most cases, these systems assist the nondestructive testing personnel in performing the inspection by using automated or semi-automated manipulation of the NDT sensors, which permits fast data acquisition (essential for reducing radiation dose) followed by accurate offline data evaluation (e.g., flaw sizing using enhanced image analysis and documentation). The development of these new quantitative and intelligent NDT systems has been greatly enhanced by today's miniaturized hardware components and their implementation as plug-in-boards in standard high-speed personal computers (PCs). This contribution has allowed the development of newly available systems for ultrasonic and eddy current inspection.

Introduction

In accordance with the German government nuclear safety research and development (R&D) program, nondestructive testing (NDT) techniques have to be developed that provide redundant and diversified information pertaining to the safety status of nuclear power plants' (NPP) primary loop systems [3]. Safety, according to the guidelines, has to be primarily and deterministically planned and designed into the components using appropriate materials and manufacturing technologies and a well-managed documentation of the design quality [4]. Using specified and validated NDT techniques, the quality is documented during component production and later during inservice inspections (ISIs). The required detectability of discontinuities is very strict; for example, magnetic particle testing results indicating surface-breaking cracks must be recorded if the length exceeds 1.5mm. In ultrasonic inspections, frequencies of 2MHz are required, which (from the physics standpoint) provides a sensitivity equivalent to a flat-bottom hole reflector with a diameter equal to or larger than half the wavelength (0.75mm for the shear wave) [5].

During ISIs [6], the recording threshold for magnetic particle and liquid penetrant testing are 6mm for linear surface indications. The reflectivity (sensitivity) for near-surface ultrasonic testing (depth range ≤ 10mm) and embedded reflectors is compared to the reflectivity (sensitivity) of surface-notches (6dB increased gain to detect oriented indications) with various notch depths as a function of different wall thickness. For example, the highest recording sensitivity is determined using a 1.5mm deep notch for a thickness range from 8 to 20mm. The bulk of the volumetric inspections is performed with ultrasonic search units using compression waves (shear vertical and shear horizontal) in pulse-echo, tandem, and mode conversion techniques. The recording limit according to the DGS diagram [7] is provided by the reflectivity of the 10mm diameter flat-bottom hole and 6dB increased gain to detect oriented indications. If tip-diffraction techniques are applied in backscatter mode or forward-scatter mode, such as time-of-flight diffraction (TOFD) [8], the highest recording sensitivity is determined from a flat-bottom hole of 1.5mm diameter for a wall thickness of >8 mm to ≤ 20 mm.

Discussions involving eddy current techniques primarily address the inspection of wall thinning of heat exchanger tubing in pressurized water reactors (PWRs) caused by wastage corrosion. Unlike the USA, France, or Japan, Germany selected Incoloy 800 (which is insensitive to IGSCC) as the proper material for heat exchanger tubing material. In combination with controlled water chemistry in the secondary circuits of PWRs, relevant tube damage has not been observed over service years in Germany [9]. The recording threshold for eddy current heat-exchanger tubing inspections in PWRs is set to 20% wall thinning. In addition, eddy current techniques can also replace magnetic particle testing or liquid penetrant testing for surface-connected crack detection. Test specimens containing artificial flaws are used to determine sensitivity and recording limits if magnetic particle or liquid penetrant testing methods are replaced by eddy current testing methods.

Considering that new NPP constructions are currently not part of any political discussions in Germany, and the belief that nuclear power costs more than power produced the old fashioned way by fossil plants in Poland or Russia, etc., the German utilities have no new constructions plans and continue to buy electricity directly on the free European market. However, existing NPPs continue to stay in service up to their financial depreciation and their lifetimes should be extended as long as the component safety is guaranteed. Besides well-known defect detection strategies, the development and use of reliable flaw sizing techniques is now on the top of the utilities wish-list. In a lifetime extension scenario, most of the essential NDT techniques are non-standard techniques requiring specific qualification and validation procedures. Therefore, extremely flexible inspection systems combining the advantage of high speed PCs with plug-in intelligent modules that are based on miniaturized microelectronic components, such as digital signal processors (DSP), application-specific integrated circuits (ASIC), and field-programmable gate arrays (FPGA), are required. These inspection systems enable the inspection personnel to evaluate and document inspection data and images nearly online and in real-time.

Ultrasonic Inspection Systems

Scientists and engineers of the Fraunhofer-IZFP have developed a new family of ultrasonic testing systems based on miniaturized electronic modules. In combination with a modular designed software architecture and suitable PC hardware, these new products permit custom configurations for a wide range of client-specific applications, from simple PC-aided manual ultrasonic inspections through fully automated inspections using compact portable systems with up to four channels or very sophisticated multi-channel systems for the ultrasonic inspection of heavy components.

Highly integrated electronic circuits and the powerful processing capabilities of today's PC systems allow the integration of electronic components even for multi-channel systems into portable computers, thus providing compact and simple to operate instruments to the ultrasonic inspector in the field.

The inspection software contains modules for setup, examination, analysis, and reporting. Various database modules provide substantial information on inspection parameters such as inspection procedure requirements, component geometry and history, material characteristics, heat treatment, operating temperature, and pressure. The integration of the synthetic aperture focusing technique (SAFT) analysis module provides three-dimensional views of the inspected zones in various cross-sections. This tool helps the qualified technician to accurately determine type, location, and size of detected material discontinuities important for fracture and fatigue mechanics analysis; for example, for use in the assessment of a component's lifetime.

Single-Channel Ultrasonic Boards PCUS 10 and PCUS 11

The PCUS 10 and PCUS 11 ultrasonic boards were designed for PC-aided manual ultrasonic inspections and certain automated applications. All analog and digital components, for example pulser, receiver, amplifier, A/D converter, A-scan processor, and PC-interface (ISA or PCI bus), required for ultrasonic inspections, are contained on a single PC board. Figure 1 depicts the PCUS 10 card, which requires a ¾ length ISA slot on the PC motherboard. The PCUS 11 card was designed especially for automated or semi-automated inspections at high scanning speed (high data rates) by using the fast PCI bus.

These plug-in boards can be used in either portable PCs or in any size desktop PC having a vacant ISA or PCI slot. The low power consumption of the PCUS 10 (less then 5 W) along with a power-suspend feature permits the operation with battery-powered portable PCs. Regarding the short length of the board, the PCUS 10 can be integrated even into notebook computers. Depending on the selected host PC, splash proof (see Figure 2) and/or cold-weather packages permit use of the system in harsh field environments.

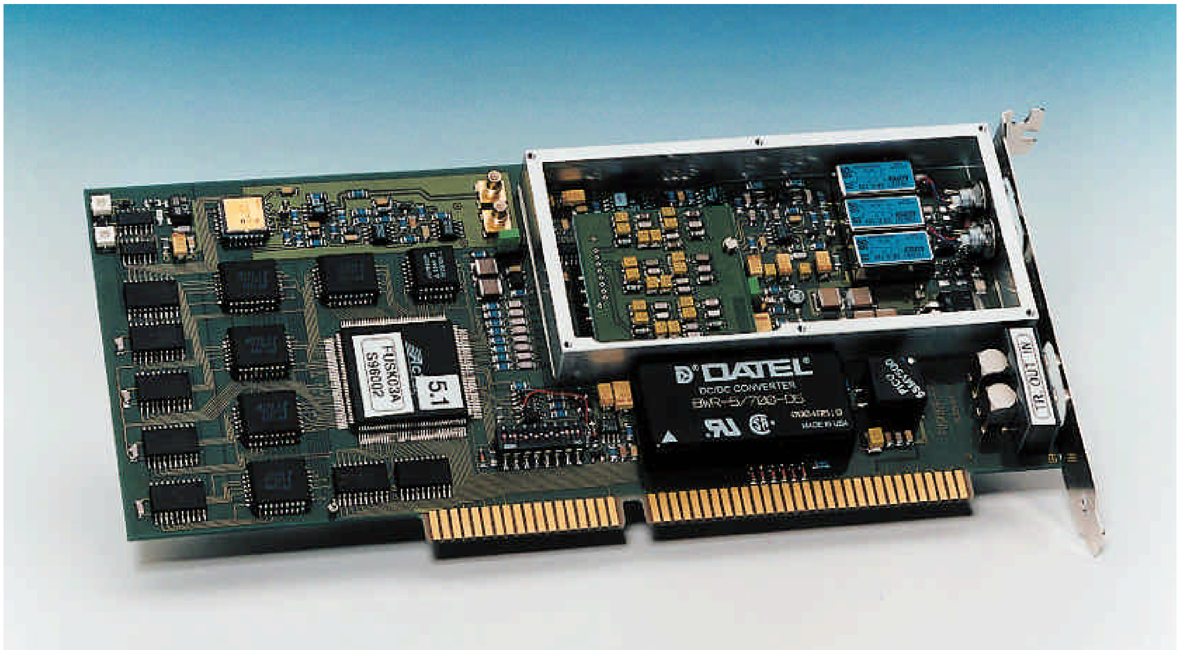

Figure 1: Single-Channel Ultrasonic Board PCUS 10

Figure 2: Ruggedized Notebook PC with PCUS 10

The technical capabilities of both the PCUS 10 and PCUS 11 ultrasonic boards are comparable to modern digital scopes for ultrasonic testing. The frequency ranges from 0.5 MHz to 20 MHz (-3dB) at a dynamic range of 100 dB (110 dB for the PCUS 11). Four narrow band filters allow tuning of the receiver to closely match the frequency of the search unit in use. Optional plug-in filter modules for specific applications are available. The ultrasonic signals are digitized using an 80 MS/s A/D converter with 10 bit resolution for the PCUS 11 and 8 bit for the PCUS 10. In addition, the PCUS 11 features a hardware-TGC with a range of 40 dB that permits setting of distance-amplitude-correction curves with a maximum of 256 points.

2™ software, running under Windows 3.1® and Windows 95®, a complete digital ultrasonic testing instrument is available for a large variety of laboratory and field applications. All system functions are controlled from the PC monitor using the keyboard and/or computer mouse. The user interface layout can be arranged to meet the users needs and to match the screen resolution. A databank provides support for effortless managing of inspection parameters such as search unit data, component data, calibration settings, etc.; moreover the software includes tools for interactive system calibration. Figure 3 depicts the PCUSware2™ main menu.

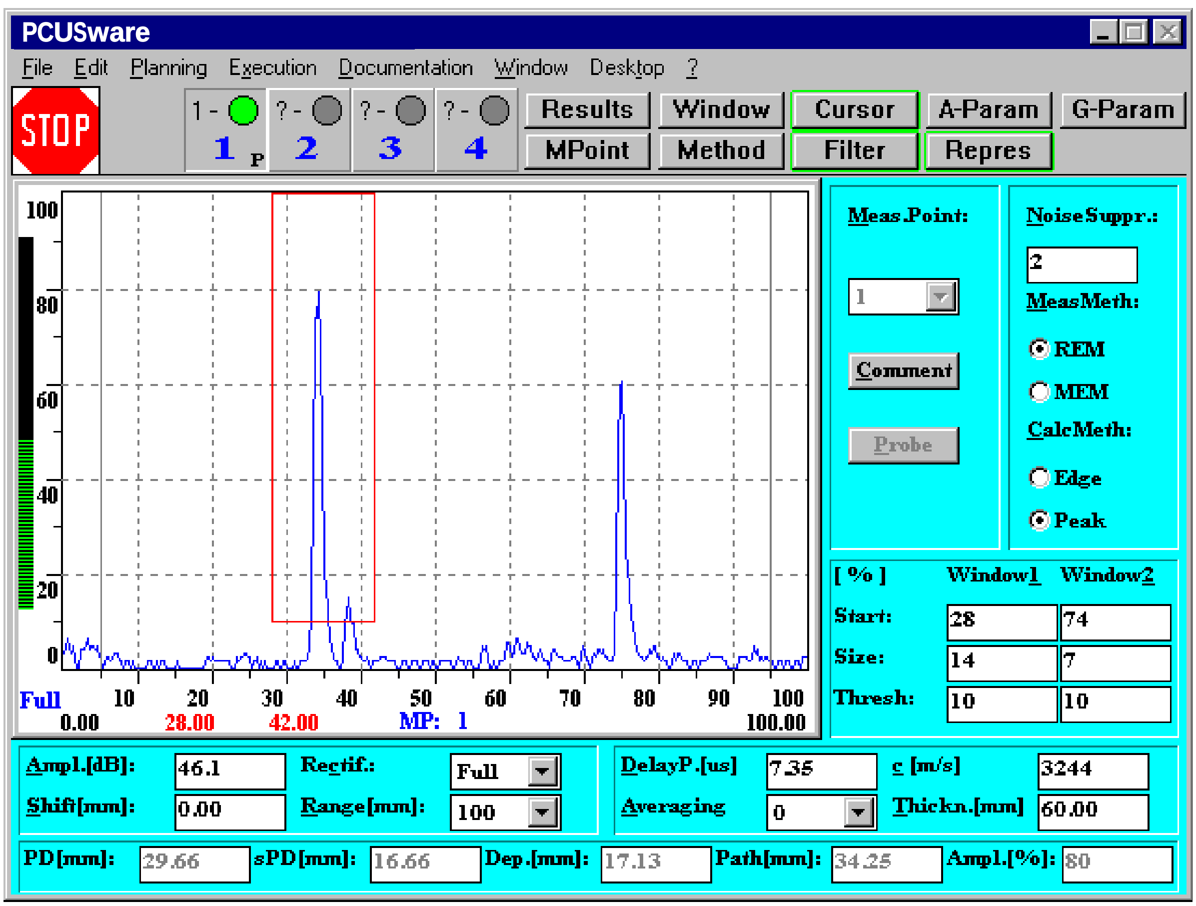

Figure 3: PCUSware2™ Main Menu

Two gates are available for the display of amplitude height and soundpath information during angle beam or straight beam inspection; amplitude readings can be displayed for edge or peak mode. A-scans can be displayed and recorded in full-wave mode, RF mode, and positive or negative half-wave mode. The A-scan display mode may be changed even after recording during analysis of individually recorded A-scan data (see Figure 4). Echo dynamics can be recorded and signals can be averaged for a maximum of 32 consecutive individual A-scans using PCUS 10, and a maximum of 128 consecutive individual A-scans using PCUS 11.

The system can store up to 100 individual A-scans along with their associated parameter settings in a single data file. The number of data files is only limited by the available space on the hard disk. Furthermore, the system allows storage of comments entered by the user for all recorded A-scans.

For reporting of inspection results, the system can provide hard copies including the A-scan image, current system settings and complete result data along with the user's comments. Previous system settings as well as previously recorded inspection data can be recalled at any time.

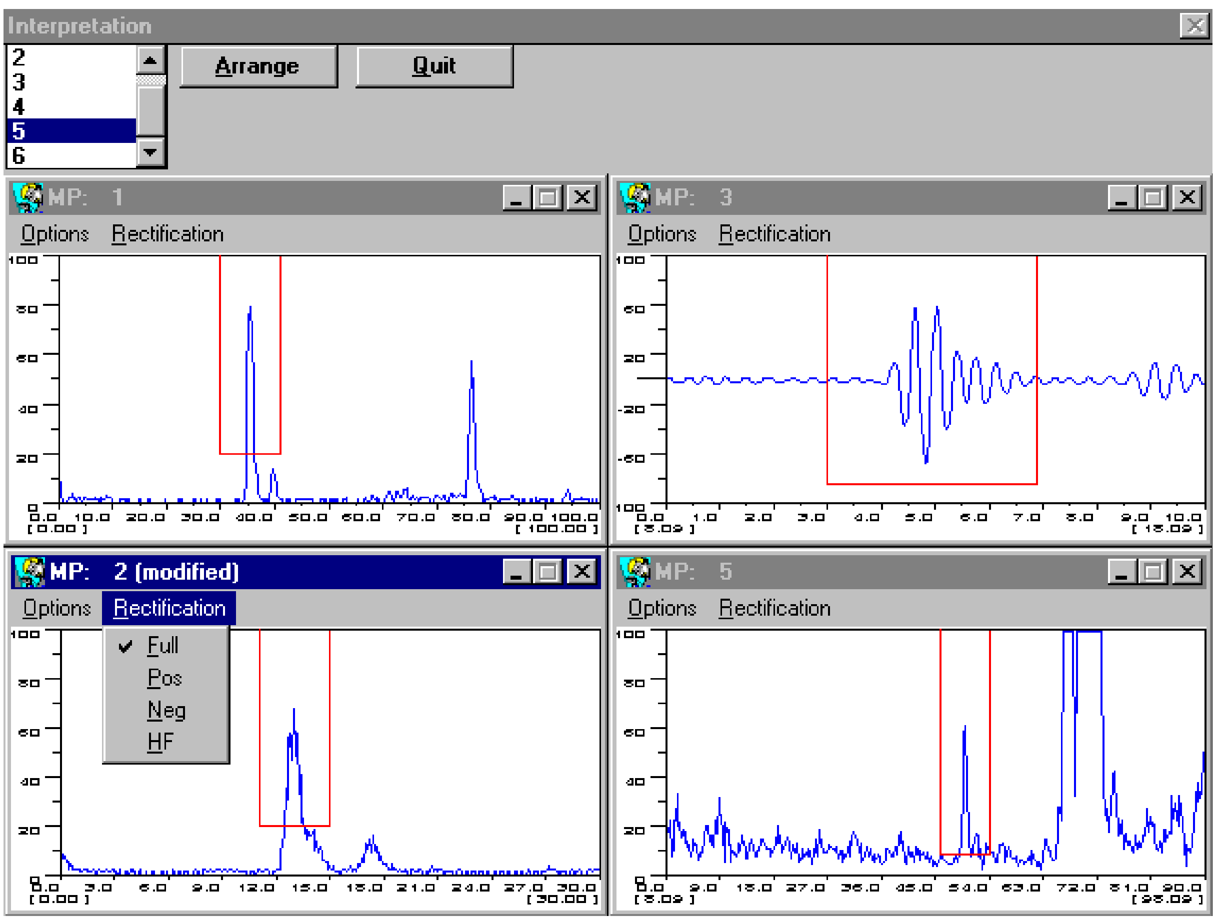

Figure 4: Multiple A-scan Display

The integration of up to four PCUS 10/11 boards permits operation as a multi-channel ultrasonic testing instrument for applications with multiple (up to four) search units in series, hardware configuration permitting. A maximum of four different parameter sets (different search units, wave modes, material velocity, sweep range, etc.) can be assigned to four (logical) channels when using a single card configuration.

UT systems based on PCUS 10/11 can be combined with a manual scanner or with any automated scanners. An optional interface card provides for transfer of search unit(s) positioning data for small scope piping inspections or analysis scans. The PCUS 11 card was designed especially for automated or semi-automated inspections at high scanning speed (high data rates).

Automated or semi-automated (manual scanner) ultrasonic inspections would utilize the CPS™ software package. The CPS™ software contains the necessary input modules required for system setup, data acquisition, data analysis and data reporting. Individual and composite A-scans, C-scans, and composite CBD-scans providing top, side, and end views of the examination volume are available for data analysis. Drivers for various operating platforms are available for the integration of PCUS 10/11 boards in third-party software and/or inspection systems.

Synthetic Aperture Focusing Technique (SAFT) for Flaw Analysis

Since the PCUS 10/11 system records all ultrasonic data in their native RF format, more advanced analysis tools, such as SAFT, can be used for the evaluation of ultrasonic indications. The optional SAFT [10] analysis module provides processing of three-dimensional displays of the inspected volume to allow determination of type, location, and size of discontinuities. The following example of a post-processing SAFT analysis of a pre-heater nozzle [11] where cracking typically occurs in the root area and in the backing strip weld area, demonstrates the need for advanced techniques. The automated examination was performed from the vessel shell using 2MHz and 4MHz, 70° shear wave search units as shown in Figure 5.

Data analysis was performed utilizing B-scan, D-scan, and D-scan presentations of ultrasonic data post-processed by the SAFT algorithm. Position and depth of defected flaws were determined from the B-scan images. Figures 6 displays the reconstructed image with a 9mm flaw-height at the root of the nozzle-to-shell weld.

Grinding, as part of the repair process and following the examination, confirmed the essential information (flaw location, size, and depth) provided by the SAFT-reconstruction analysis.

Figure 5: Automated Pre-heater Nozzle Examination

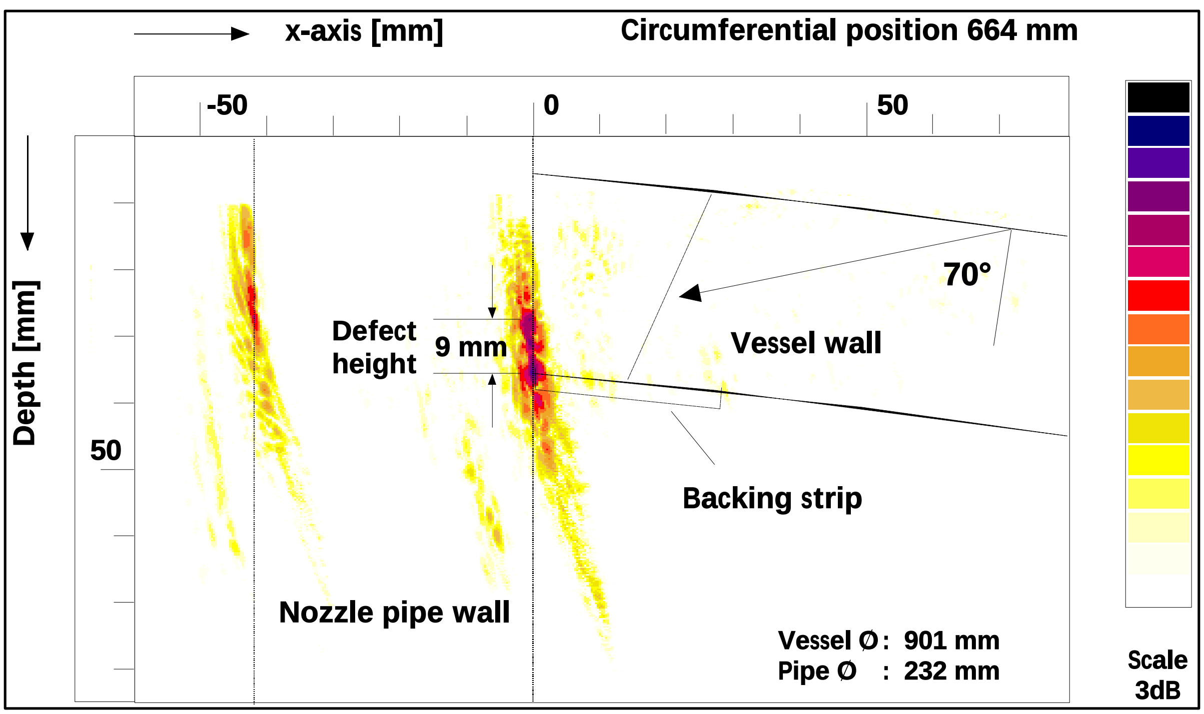

Figure 6: SAFT Reconstruction of Root Cracking; B-scan, Search Unit MWB70-2

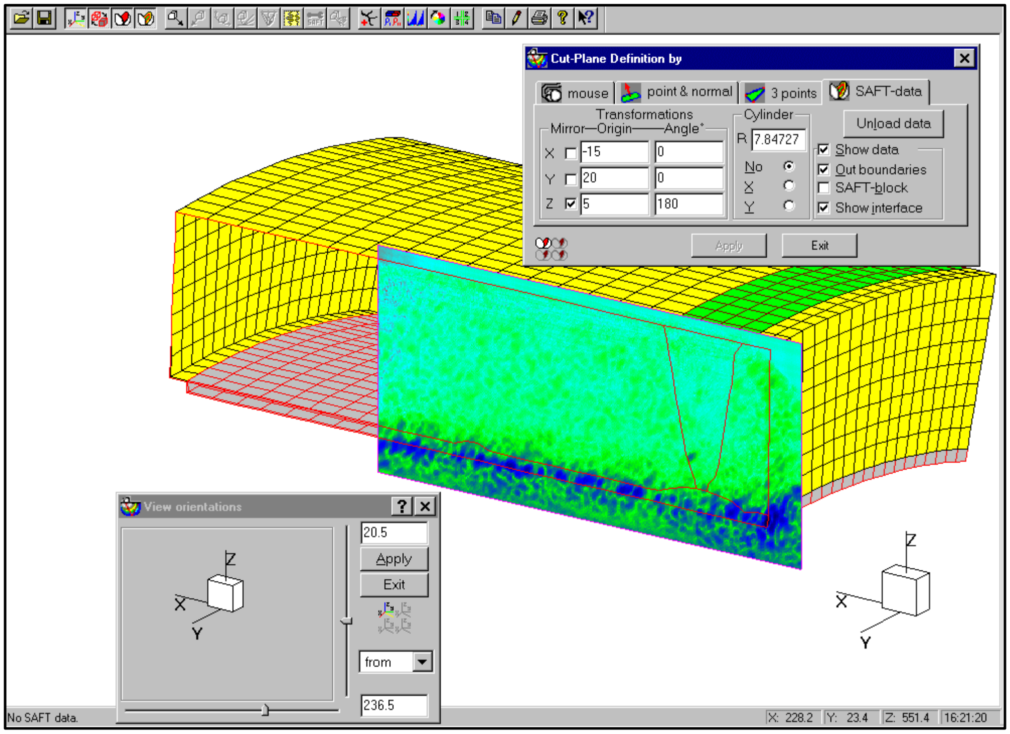

Figure 7: Superimposing of SAFT-Image and Test Object Geometry

An essential pre-requisite to determine the precise position and size of a flaw is the ability of the reconstruction process to consider the correct geometry of the test object, particularly for objects having a complex geometry. The results of the reconstruction process are superimposed onto the object image that was generated using a CAD software program. With such a tool, it is possible to display arbitrary views of the inspected volume. Figure 7 shows a perspective view of a coated pipe segment with a circumferential weld. The cross-sectional display includes the imported SAFT (B-scan) data. The dialog boxes are used to set the display parameters.

Multi-Channel Ultrasonic System PCUS 40

The modular design of the PCUS 40 system components allows the arrangement of compact and economical multi-channel systems for various automated ultrasonic inspection applications. Modern software packages provide the ultrasonic inspector with the necessary support for examination setup, data acquisition, data analysis, and documentation (reporting) of the inspection results. The PCUS 40 ultrasonic instrument consists of several boards installed in a commercially available PC. The basic PCUS 40 version comprises all electronic components for a four-channel ultrasonic instrument expendable to 64 channels. The flexibility of the PCUS 40 system provides custom tailored configurations for ultrasonic testing of piping and vessels in chemical, petrochemical, and power plants or production-line and pre-service inspection of steel (and other suitable) products.

The usable frequency of the PCUS 40 system ranges from 300 kHz to 15 MHz (-3dB) at a dynamic range of 100 dB. A TGC (Time Corrected Gain) module permits entry of any characteristic lines (DAC or DGS) for the compensation of acoustic and/or other material-related energy losses in a range of 40 dB. For the analog/digital data conversion, two A/D converters are integrated (80 MS/s, 10 bits and 40 MS/s 12 bits) that are selected depending on the inspection task. The sampling rate can be reduced to 10 MS/s to match to the search unit frequency. Figure 8 shows a schematic diagram of the PCUS 40 electronics.

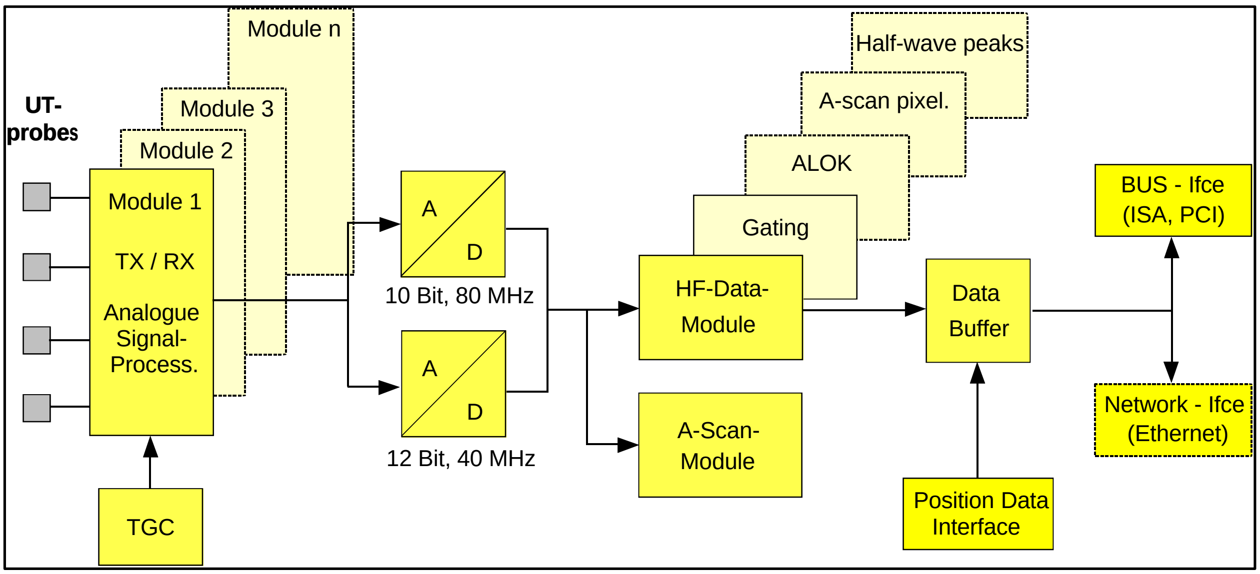

Figure 8: Block-diagram of the PCUS 40 Multi-channel System

Various data acquisition modes can be selected to correspond to the individual inspection task requirements. For example: If SAFT analysis is required, the system would be set to acquire the ultrasonic data in the RF mode; or, if massive amounts of data from a reactor pressure vessel examination are expected the system would be set to collect data in the ALOK mode. The ALOK method (Amplituden- und Laufzeit-Orts-Kurven, which means Time-of-flight Local Curves) has been proven advantageous for ISI of reactor pressure vessels, inspection of heavy plates in the production line of a steel plant, and for ISI of oil- and gas-pipelines (using intelligent multi-channel pigs), e.g. when high inspection speed and large amounts of ultrasonic data call for high detection sensitivity and data reduction [3, 4]. The ALOK signal processing procedure permits the detection of all relevant echoes (amplitude and time-of-flight) within the RF-signal without any restriction by gates (Figure 9).

The resolution of reflector signals corresponds to the resolution of an A-scan analysis. Compared to RF-signal recording, a data reduction rate of about 98% is achievable.

The PCUS 40 system is available as a portable system with a maximum of eight ultrasonic channels as shown in Figure 10.

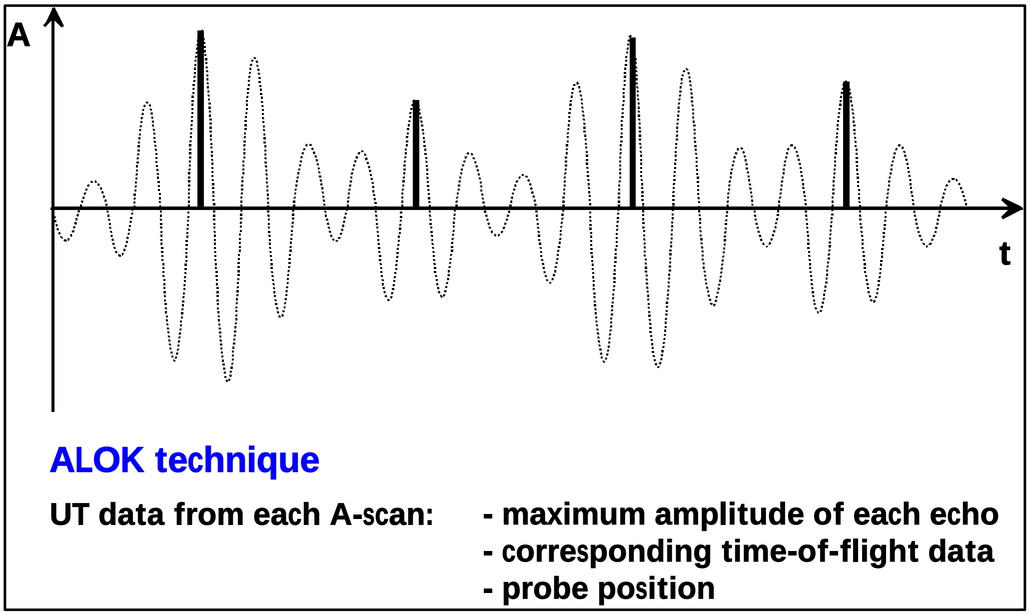

Figure 9: Signal detection by ALOK processing

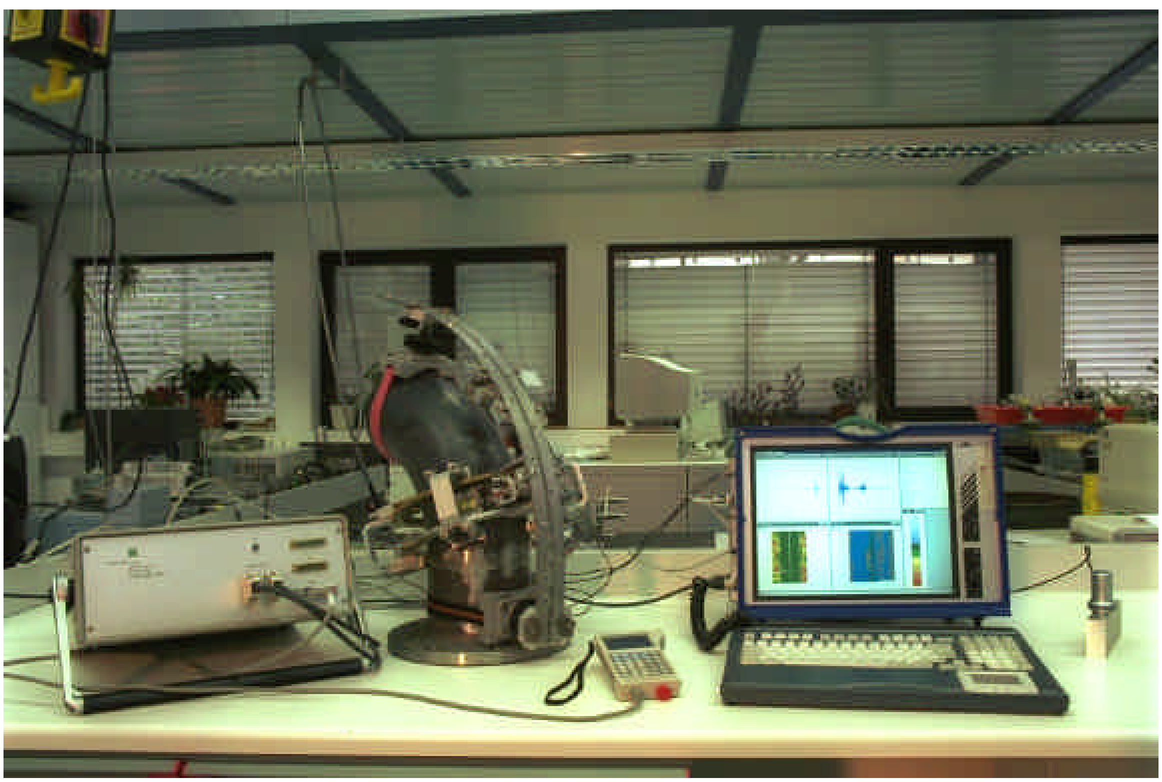

Figure 10: Portable PCUS 40 System w/ Pipe Scanner and Scanner Control

Other system configurations to accommodate a maximum of 64 channels have been designed using industrial PC casings, stand-alone rack-mount systems or combination rack-mount systems, where the operator console is separated from the electronics compartment.

The CPS-N™ software (operating under Windows NT®) comprises setup menus including device setting, search unit, component and global parameters, data acquisition menu, data analysis menu, and reporting menu.

A calibration mode is available to check the system linearity, measure echo signal data by means of cursor functions, and for quick adaptation of device settings (e.g. amplification, filters, and data acquisition range) before data acquisition. Using these functions, the A-scans of up to four channels can be displayed on the screen in full-wave mode, RF mode, and positive or negative half-wave mode (Figure 11) at once.

The data acquisition menu displays A-scan and/or C-scan presentations of up to four ultrasonic channels simultaneously (online) to support real-time control of system and search unit functions as depicted in Figure 12.

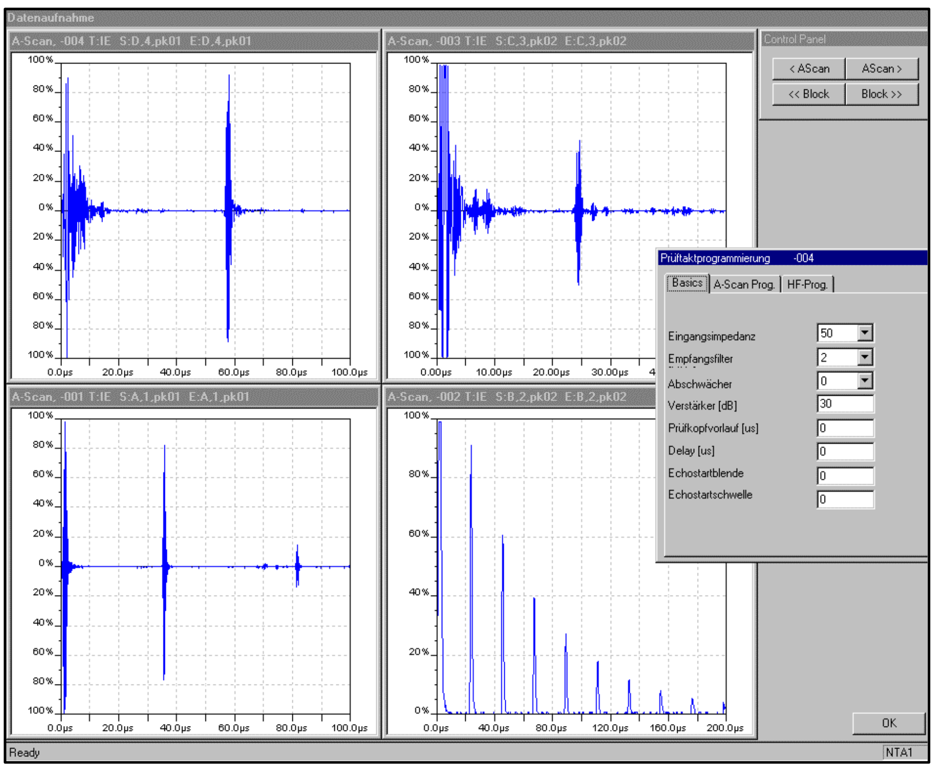

Figure 11: CPS-N™ Calibration Mode

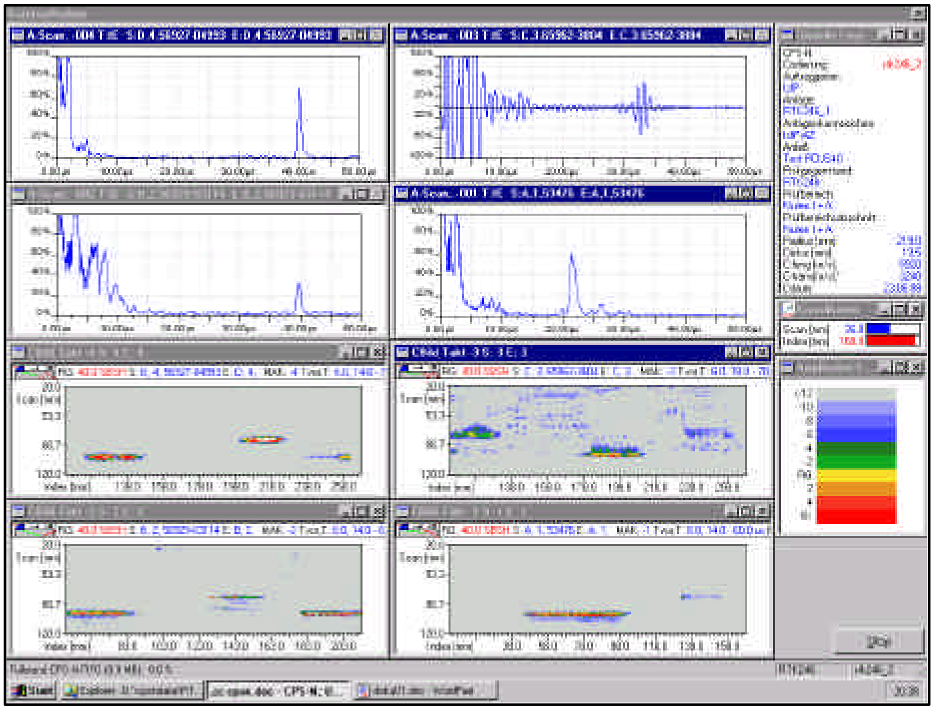

Figure 12: CPS-N™ Online Display of A-scan and C-scan Images

Analysis of the acquired ultrasonic data is performed using A-scan, B-scan, C-scan and D-scan displays; composite top, side, and end view images (CBD-scan) help the user during data analysis. In addition, the SAFT module provides further analysis capabilities. If required, the CPS-N™ software can be customized to virtually any specific requirements.

For the ultrasonic testing of components having complicated geometric conditions, the PCUS 40 system can be combined with Phased Array front end units to control piezoelectric search units [14]. To examine anisotropic materials with horizontally polarized shear waves (SH-waves) [15], an EMAT Phased Array front end is also available.

Eddy Current Inspection in a Lifetime Extension Strategy

According to the German nuclear power safety guidelines, the internal stainless (austenitic) steel cladding of the nuclear pressure vessel is assumed a protective coating for the ferrite pressure vessel steel only to avoid corrosion. Therefore, the cladding (e.g., material properties and thickness) has never been given due consideration to contribute to the strength and/or toughness in design and fracture mechanical considerations. With respect to ISI, only the adhesion (bonding) between the clad and the base material (using longitudinal waves with normal incidence) must be inspected and documented. The clad-volume does not require ultrasonic inspections, but UT is applied for the detection of sub-clad flaws using a dual-element transmit/receive search unit that insonifies the material with longitudinal waves at 70 degree incidence and at a focal distance of 30 mm.

Considering the aspects of component lifetime extension, the development and validation of new NDT techniques that can additionally contribute to the standard techniques with diverse information for the interpretation of potential non-conformities is of interest. Currently, lifetime extension in Germany, compared to other countries, is in general not a topical task.

However, the pressure vessel of the oldest pressurized water reactor (400 MW, two loops) was under discussion for further licensing. Mainly under the aspects of an assumed advanced neutron degradation of a near-core circumferential weld (belt-line region) construction-welded with increased copper content electrodes, the risk of embrittlement-fracture of the weld was discussed. Because of the specific situation the clad near this weld was inspected, in accordance with the special license conditions and state-of-the art, during each outage using an enhanced multi-frequency eddy current technique. This technique, operating with frequency components at 20kHz or higher, was used to detect surface-breaking flaws. An optimized mixing algorithm [16] was applied to suppress disturbing signals caused by coil lift-off at the rough and uneven clad surface and by local δ-ferrite changes. By applying fracture mechanical approaches it was demonstrated that embrittlement-fracture can be excluded when considering the contribution of the clad to the overall strength and ductility. In order to secure such an approach, NDT techniques capable of documenting the integrity of the clad (e.g., the detection of embedded flaws in the clad volume or at the clad-to-base material) have to be validated.

Research and Validation Program

According to the state-of-the-art, the eddy current technique discussed above is only sensitive for surface breaking flaws. The emphasis of the proposed research was on the extension of the eddy current technology for the detection and characterization of the previously mentioned concealed discontinuities in the clad volume. The clad-to-base material interface and the adjacent base material should be inspected using enhanced UT. Due to the acoustical properties of clad, the detectability of small flaws using ultrasound is a well-known problem and the classification of indications as planar flaws (crack-like) or volumetric flaws is generally possible with certain restrictions. The optimization of a low [17], multi-frequency eddy current technique that can bridge the detectability gap was proposed. In contrast to the above-mentioned ultrasonic difficulties when inspecting stainless steel (austenitic) welds, the proposed eddy current technique has its benefits due to obvious physical reasons. The characterization of indications is possible when combining classified flaw type with an estimation of the flaw size. Critical flaws, such as planar (crack-like) flaws originating at the clad-to-base material interface and growing into the clad and/or the base material under fatigue loads and sub-clad cracking, can be easily discerned from flaws in the clad-volume caused during the manufacturing process.

IZFP developed a system based on the low frequency eddy current technique [17]. Complemented by the above-mentioned high-frequency technique, the total frequency spectrum available to eddy current testing is covered; therefore, an all-inclusive and detailed NDT assessment of the clad condition is possible [18].

Special features of this inspection system are:

- **high signal dynamic (> 85 dB) and high long-range stability for the detection of small measurement effects in a strongly disturbed environment**
- **strong computing power by utilization of an integrated DSP (digital signal processor)**
- **powerful signal processing algorithm**

The eddy current electronics are contained in a dedicated housing (black box) connected to a PC, which is used for data acquisition, data display, data analysis, and documentation. The two main components are the eddy current analog-board and the DSP-board. The DSP-board can process up to four eddy current analog-boards for time-parallel inspection with four frequencies. The inspection parameter set-up and the transfer of the inspection signals to the DSP-board and from the DSP-board to the PC are performed via a serial interface. The block diagram of the eddy current system is provided in Figure 13.

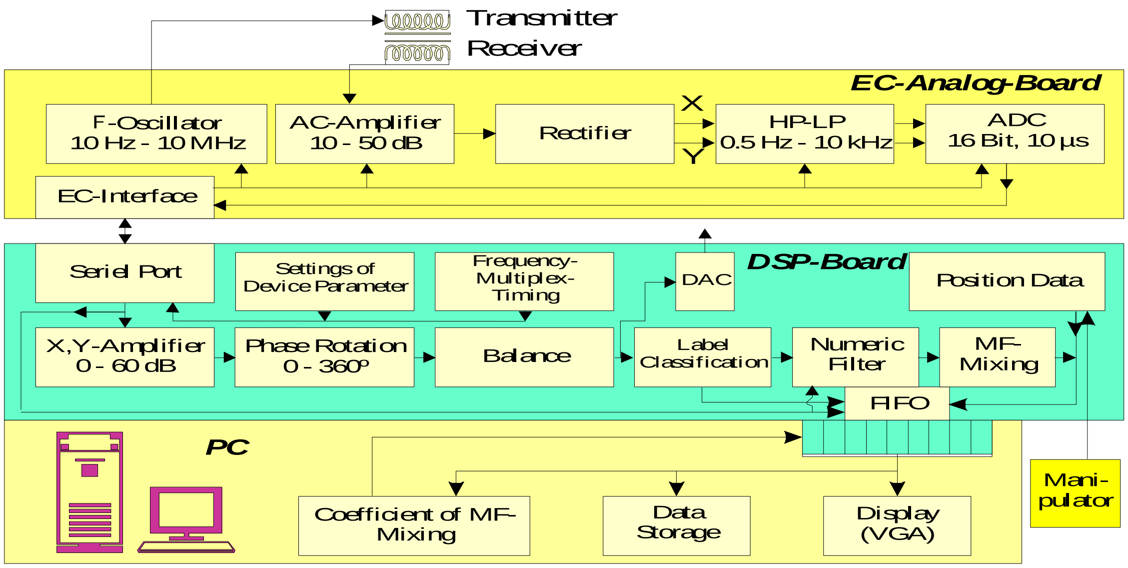

Figure 13: Block Diagram of the Multi-frequency System, Analog and DSP-board

The basic concept is to numerically control most of the system functions using the software in the DSP to minimize the hardware cost. The applied signal processing software is based on multi-regression analysis (e.g., a least square fit) using polynomials up to the third power as the basic function. The available algorithms can be interpreted as a numerical filter for different inspection tasks. The objective of the signal processing is to suppress disturbing signals and the quantitative evaluation of target functions, e.g., the characterization of type and size of the flaws. The calibration of the inspection system requires well-defined calibration blocks and test blocks, representing the complete set of relevant influence parameters and their possible changes of the actual inspection situation. Figure 14 presents the system.

Figure 14: PC-based Multi-frequency Eddy Current System

Results Obtained from Calibration Blocks and Test Specimen

The inspection of claddings is affected by many influencing parameters, such as surface breaking flaws, surface profile, δ-ferrite content, clad thickness, volumetric flaws, lack-of-bond, and sub-clad cracking. These many different influences make signal processing very difficult; however, comprehensive information pertaining to the condition of the clad can be filtered if suitable software is available.

The following presents actual inspection results obtained using three frequencies (3-frequency technique) simultaneously. Figure 15 shows the results after evaluation of the input data with a numerical filter, optimized for the prediction of the lift-off between the eddy current sensor and the surface of the inspected clad. All other (above-mentioned) influence parameters are suppressed (filtered). A higher frequency combination and an absolute coil are applied (50kHz, 280kHz, 600kHz). With the sensor placed on the surface, the color-coded C-scan image on the left side of Figure 15 represents nearly a direct image of the waviness of the scanned surface. The grooves of the different weld-paths are clearly indicated including ground-out (repair) areas. The amplitude images (center of Figure 15) present cross-sectional A-scan type displays of the eddy current amplitude in vertical (top) and horizontal (bottom) directions as indicated by the cursor line on the C-scan display. The corresponding lift-off values (in mm) are shown on the scale to the left of the A-scan images.

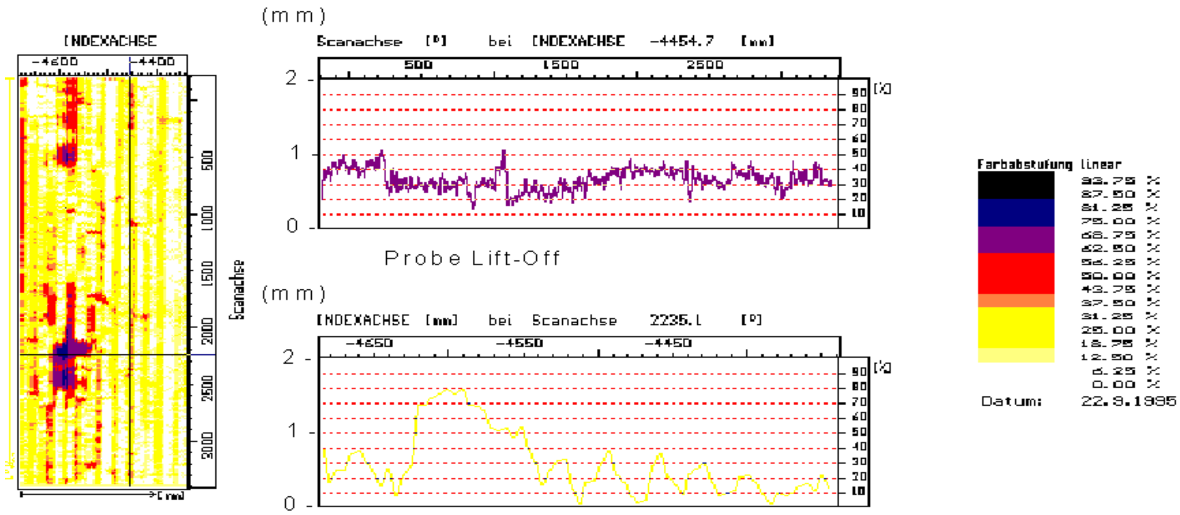

Figure 15: Surface Profiling

Using the same frequency mix and coil combination, other special optimized filter coefficients of the numerical filter can be used for C-scan presentations of the spatial distribution of the δ-ferrite content and to display surface-connected flaws. The system provides for the detectability of a 1mm deep planar flaw independent from flaw orientation (length = 15mm, which is the effective transmitter coil diameter). The thickness of the cladding can be determined using an absolute coil at lower frequency settings of 500Hz, 2.8kHz, and 5kHz. Depending on sufficient signal-to-noise ratios, thickness changes within 0.5mm can be resolved from clad-thickness ranging from 6mm to 12mm.

To characterize concealed (embedded) discontinuities, special low frequency (500Hz, 2.8kHz, and 5kHz) differential coils are applied. Figure 16 presents analysis results using the numerical filter for the detection of volumetric flaws contained in the clad.

The C-scan reveals three side-drilled holes (ø ≥ 3 mm) 2mm, 3mm, 4mm, and 6mm below the inspection surface. The amplitude presentation in Figure 16 shows the amplitudes of the indications representing remaining ligaments, e.g., the remaining wall thickness above side-drilled-holes of 2mm, 3mm, 4mm, and 6mm, respectively. For the detection and analysis of embedded planar flaws (height ≥ 3 mm) oriented perpendicular to the surface, such as lack-of-fusion between individual weld-paths in the volume of the clad or sub-clad planar flaws, specially optimized filter coefficients are available. Planar flaws concealed in the volume of the clad (thickness = 12 mm) with a remaining ligament of 9mm and sub-clad planar flaws with 12mm remaining ligament (clad thickness) can be reliably detected. Due to the local (stepwise) increase of electric conductivity of the clad through the clad-to-base material interface into the ferrite base material, the inspection procedure profits from the current density enhancement that produces a high signal-to-noise ratio for the detection of planar flaws reaching the base material-to-clad interface.

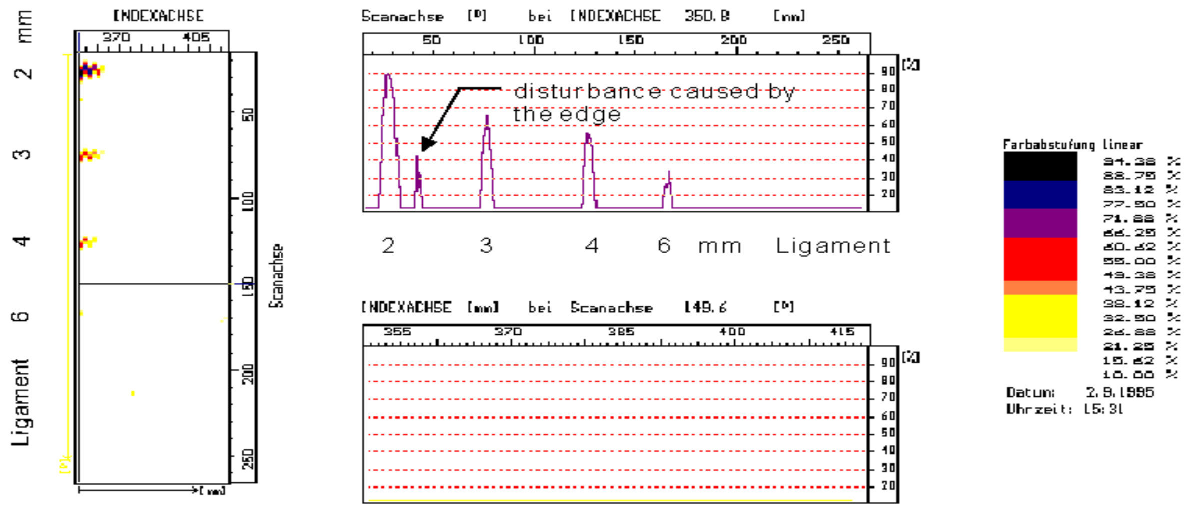

Figure 16: Detection of Flaws in the Clad Volume of an RPV

Experiences from ISI in Nuclear Power Plants

The described system was used in two German nuclear power plant outages in spring and fall of 1995. One essential result is the gained knowledge that the set of calibration and test blocks represents only a relatively small subset of possible clad characteristics of real pressure vessels. Distinct local differences can be detected, especially in repair locations. Furthermore, relatively large values for lift-off and coil-tilt must be considered near welding grooves. It was found that even when calibration of the numerical filter functions using plant-specific test specimens (representing the plant-specific clad material and deposit process) were conducted and indications were detected, recorded, and documented in accordance with the specification, these indications and their influences were not always represented in the calibration or the test blocks.

Therefore, the development of specially designed software was stimulated, extending the test block calibration by using additional calibration signals from the actual pressure vessel cladding. The data evaluation software is applied off-line after collecting the data. In the first step, the filter coefficients obtained from the calibration of the test blocks are applied to the actual pressure vessel data. Only the indications that correspond to type and maximum extent of the available signals acquired from the test blocks can be analyzed. All other signals have to be treated (analyzed) as non-relevant signals. This fact reveals the inherent problem of techniques requiring calibration procedures. There is the need to perform reliable equivalence and conformance tests, comparing the disturbing conditions from the actual pressure vessel clad to the proposed calibration blocks. If the conformance is insufficient—which in reality is always the case when a clad is inspected for the first time—the calibration data set must be expanded (extension of the calibration data base) by using actual (i.e., real) disturbing data from the inspected vessel. However, the adequacy of the algorithm for flaw detection, classification, and sizing has to be reviewed and verified in a reliability test on the calibration block again. In general, the amplitude heights used to determine the recording threshold have to be verified and/or newly defined. Following the procedures mentioned above, including system performance demonstrations, is the safe way to build confidence in the inspection results.

Conclusions

Ultrasonic plug-in boards were developed based on highly integrated electronic components. The PCUS 10/11 pulser/receiver board provides all of the analog and digital circuits required on a single ¾ length ISA (or full-size PCI) board, rendering a complete test instrument when combined with IZFP's PCUSware2™ software for manual ultrasonic inspections.

Special software features provide simple and easy to use tools to merge inspection data and results into any Quality Control system. To perform single-channel automated inspections, particularly flaw analysis with SAFT, the PCUS 10/11 system is used in conjunction with the CPS-SAFT™ software package.

The modular electronic components of the PCUS 40 system allow configuring compact and economical multi-channel ultrasonic systems for inspections in industrial plants, as well as configurations for process-integrated testing systems in steel industries. The PCUS 40 system, using the CPS-N™ software, allows recording of the complete RF-wave form, and thus provides all the information required for a detailed description of ultrasonic indications and material flaws. If high-speed data acquisition with a large number of ultrasonic channels is required, the PCUS 40 system permits data reduction using data reduction algorithms. If required, the CPS-N™ software can be customized to virtually any customer-specific requirements.

A multi-frequency eddy current inspection system was designed to assess the integrity of reactor pressure vessel clad. Comprehensive and diverse information in addition to the conventional NDT techniques was attained. The application of the above-mentioned techniques at a German power plant has contributed to the decision of the authorities to restart operation after a long shut-down time.

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