AUTOMATED ULTRASONIC SYSTEMS DEVELOPMENT TECHNOLOGY
FOR THE WELDED JOINTS AND MAIN METAL INSPECTION

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Introduction

Since 1990 year Scientific and Production Center of Non-Destructive Testing (SPC) ECHO+ have been developed automated ultrasonic testing (AUT) systems. Accumulated its experience company can offer technology of the operative and flexible reacting upon modern requests of the ultrasonic diagnostics market equipment and services.

Three-dimensional flaws images with high resolution were the first developments primary intent. It could give the maximal exact information about flaws sizes, localization and type. This goal defined main engineering solutions of the first AUT AUGUR series system and it could be achieved on exploiting NPP.

The Fourier Transformation SAFT method was used for the data processing [1] for the high quality images reception while inspection data post processing. Full valued application of this method, except for other, required using specialized probes (with wide directivity diagram) and accurate scanning. For the data acquisition were used the six channeled data logging device and local scanner providing the accurate positioning of probes group in inspected volume with size 200x200 mm. The scanner and the system direction computer (operator place) could be delivered from each other on the 300 m distance. Therefore the system included the speaking device, providing connection between two operators who sets scanner and system operator.

Further system development for operational NPP was in the increase of channels quantity, methods of UT data acquisition and data acquisition rate, increase of specialized scanners quantity and increase of inspected volume to the total welded joint’s volume inspection, improving of the data processing methods and software services [2]. For the thirteen years period (up to 2003 year) five generations of the AUT Augur systems for NPP were changed.

Later have been developed the automated systems based on the AUGUR systems last generation for welded joints inspection of the main gas pipelines, rails, systems for the external and internal pipes base metal inspection, stationary systems for the freight car wheel pairs’ inspection, system for the inspection of under overlays welded joints of the large diameter welded tee with overlays. Inspected objects differences demanded various architectural and structural decisions development.

The complex of the sixth systems generation, being based on technology of data acquisition using phased arrays, is the last direction of developments. This complex is the line of devices providing the data acquisition, both with the use of the automated scanners and with the mechanized devices with a manual drive.

Our developments’ evolution is aimed on the two basic tasks solution – inspection procedure simplification (facilitation and acceleration of data acquisition) and maximally possible informing of inspection results (more information about flaws). Till recently high quality of one’s task solution was frequently accompanied by the degradation of other’s solution. However, phased arrays (PA) technology appearance, development of data processing calculating methods allowed creating the systems which are able to solve successfully both tasks and to offer at the market wide and completed spectrum of AUT tasks solution. Such decisions complex will go about further.

Augur system features

Main units of AUT AUGUR mobile system

In a base case multi channel AUGUR mobile system, aimed on some type stationary object inspection, consists of: system unit, external unit, scanner with electronic unit, connection cables and piezoelectric probes set. Additionally in the system complement can be: automatic coupling liquid supply system, speaking devices for operators' connection (one operator is on the inspected object with a scanner, other – operates the system from a computer), additional computer for data processing and storage (database server).

System unit is a computer flaw detector with analog-digital combined tract and circuit providing the programmatic scanner operation and channels switching of ultrasonic unit. Operator controls the system – data record, processing and AUT information imaging – using a computer of system unit with software. The most widespread system unit is an industrial computer with the built-in system modules on the corps of which sockets are placed for connecting cables and speaking device. The system unit also can be the electronic unit, connected with an external computer through the standard USB interface, supplying from the power supplies 12 volt or 220 volt. In a Fig. 1 are resulted variants of system units for various inspection problems.

The converter's analog-digital module into the system unit provides the echo signals, which incomes on a cable from the electronic unit of scanner, reception and gain, their digitalization, digital processing and memorizing in buffer storage for subsequent data communication in a computer, probing signal formation as a two polar impulse with the regulate duration and amplitude. On the same printing board the commands transmission and forming from computer is carried out for the scanner' drives control, commands forming for the preliminary gain control and channels switching of scanner electronic block, and also additionally commands reception and transmission on a successive channel, in accordance with exchange protocol, determined standard RS-485. Structurally the analog-digital module is executed as one printing board set in the standard slot of industrial computer.

The external unit is the electronic unit placed near the scanner which forms on its exit necessary pulse pressure and currents. It ensures the scanner's step electric motors operation and the scanner functioning on considerable distance from the system unit without relative weight and dimensions of a connecting cable increase.

Fig. 1. System units. At the left – the system unit on the base of the industrial computer, in the centre – the system unit constructed as a portable box with tablet computer or notebook, on the right – the system unit for use in difficult environmental conditions with the notebook connected to it.

Scanners for AUGUR systems and other AUT systems

The set of scanners among which, except scanners for typical objects (for example, girth and longitudinal welded joints of pipelines) are also specialized scanners is developed for work as a part of AUGUR system. For the automated two-dimensional scanning of pipelines with external diameter from

426 mm scanner SC.426T is used. The scanner consists of a track motionlessly fixed on the inspected object, and the mobile scanner (Fig. 2) which provides probe moving along and cross section welded joint according to inspection methodology algorithm. The scanner can be used as for the girth (a girth track), and longitudinal (a longitudinal track) welded joints inspection. The typical length of a cross section scanning branch (a moving drive on an axis X) is 120 mm that provides the majority inspection problems solution. However for big thickness objects, as for example shaft of big diameter rotors, the different functioned reactors body, length of "branch" X increases to necessary size.

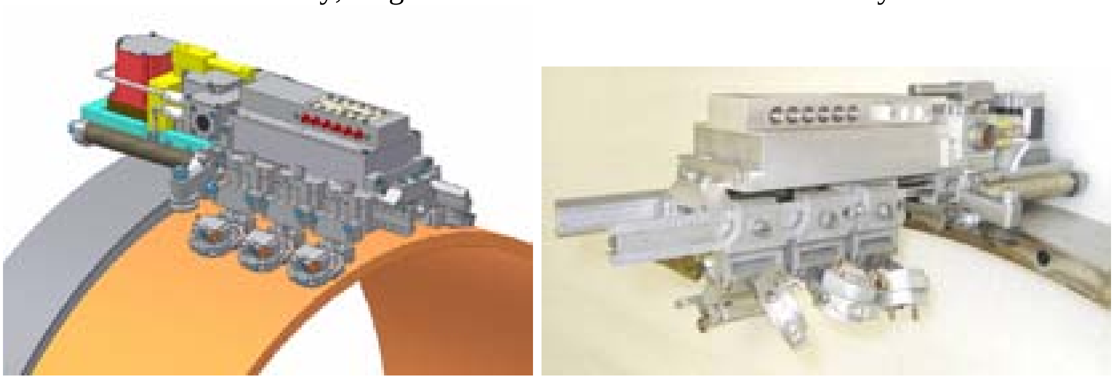

Fig. 2. Scanner SC.426T.

Scanners SC.325 and SC.219 (Fig. 3) with a chain drive for pipelines with diameter from 219 to 426 mm solve similar problem of two coordinate scanning of probes group or blocks. Scanner SC.219 (Fig. 3, on the right) consists of a track motionlessly fixed on inspected object, driving chain and the mobile scanner providing probes moving along and cross welded joint.

Fig. 3. Scanners for AUT of small diameter (from 219 to 426 mm) pipelines of girth welded joints.

Scanner SC.A5-OMT (Fig. 4) provides probes one-coordinate moving while the pipelines base metal AUT, and also girth and longitudinal pipelines welded joints with external diameter 500 mm and more. The scanner includes a drive X, probes pressing rail, probes pressings, the scanner electronics unit, the traversed path sensor and the set of tracks consisting of a longitudinal track on magnetic fastening and girth tracks. For each nominal pipeline's diameter the system is completed with a separate girth track.

Fig. 4. Scanner SK.A5-OMT.

One-coordinate scanners with the manual and mechanized drive are developed for exact probes positioning in conditions where the easy access of the operator to inspected object is provided. The manual scanner (Fig. 5, at the left) can be used in composition of flaw detectors using the phased arrays and supporting the ultrasonic data record. The mechanized scanner is used with the AUGUR systems system unit. This scanner consists of the small cart with magnetic wheels, the electronic unit, two probes pressings and connection cables.

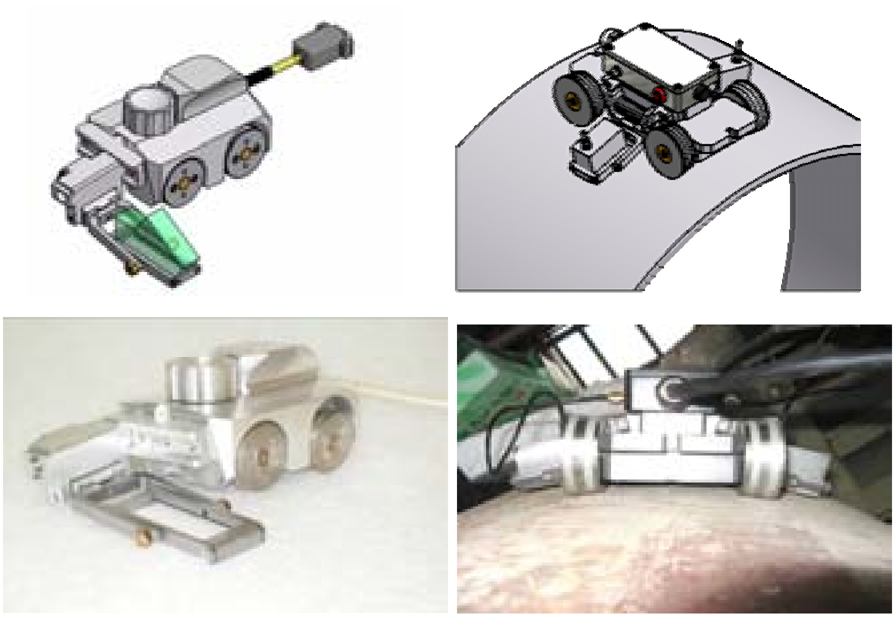

Fig. 5. One-coordinate scanners with manual (at the left) and mechanized (at the right) drives.

Series of specialized scanners SC.500 is developed for the inspection of girth welded joints of various pipelines nozzles welding to austenite pipeline Du500. In a Fig. 6 scanner SK.560 for the inspection of the main circulating pipeline welding to the conical bush of the body reactor VVER-440 nozzle is resulted. The scanner provides full girth synchronous scanning of eight probes along and cross welded joint axis on the conical bush surface. The specialized scanner from the same scanners series for the longitudinal welded joints inspection of pipelines elbows of the main circulating pipeline Du500 of reactor VVER-440 (a Fig. 7) provides simultaneous inspection of two longitudinal welded joints by two probes groups placed diametrically in a plane of the elbow cut.

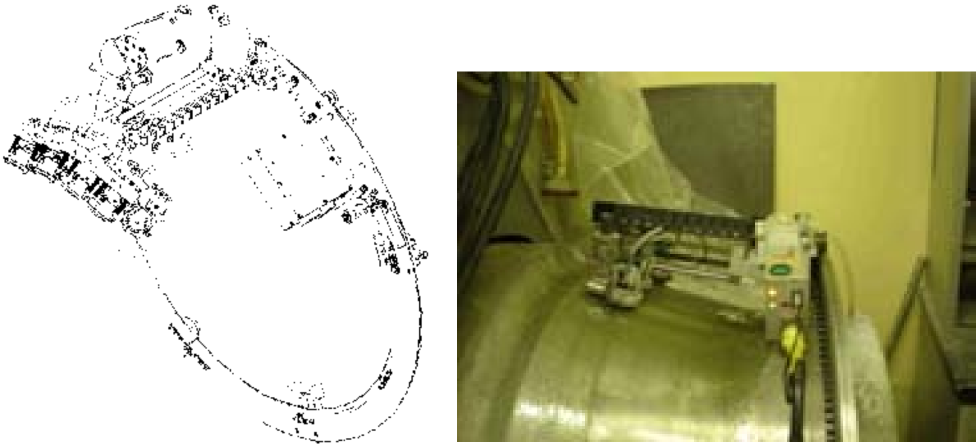

Fig. 6. Specialized scanner SC.560. The main circulating pipeline of reactor VVER-440. The scanner has a changeable angle of slope of "branch" X.

Fig. 7. Specialized scanner SC.590. On the right – the full-size pipe elbow stand simulator of the main circulating pipeline of reactor VVER-440.

Except scanners for AUGUR systems SPC «ECHO +» has developed and produces scanners for other ultrasonic testing systems. For example, for flaw detectors using phased arrays, such as Harfang X32, Omniscan MX and etc. scanners of T-300 model are developed for the inspection of austenite girth welded joints with nominal diameter 325 mm. The scanner provides simultaneous moving of four multi element probes on prisms around welded joints for one minute. In a Fig. 8 the general view of such scanner is shown. The simultaneous welded joints inspection is provided to detect longitudinal and cross section flaws.The scanner is used with the small electronic unit providing scanner supply and operation.

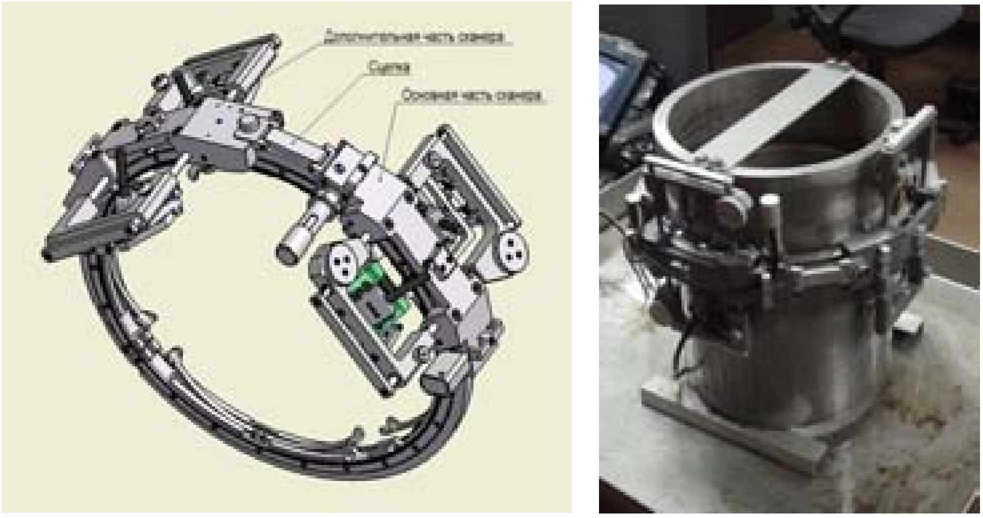

Fig. 8. Scanner T-300 for flaw detectors with phased arrays.

Scanner PRP-100 was also developed for one-dimensional scanning of latest ISONIC systems models (Sonotron NDT company). It provides the probes group and the electronic unit moving along girth welded joints with diameter more 152 mm on tracks which are used for automatic welding systems (Fig. 9) is. The scanner provides the optimum AUT organization during installation works.

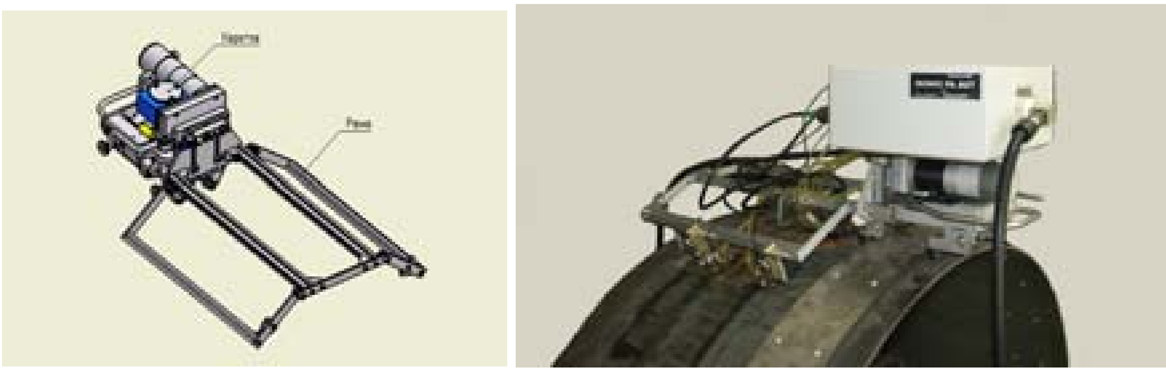

Fig. 9. Scanner PRP-100 with flaw detector established on it.

The software of AUGUR series systems

The software of AUGUR systems realizes the systems hardware operation and offers functionality defining by inspection methodologies – data acquisition, processing, imaging and tools for the data analysis. Software executes following basic functions which are defined by the AUT basic stages [3]:

- Piezoelectric probes calibration;
- Setting of methodical inspection parameters;
- Inspection;
- Processing of received AUT data;
- Data imaging and analysis, and AUT datasheets forming.

The additional utilities into the standard delivery set executes following functions:

- Editing of system users accounts;
- Data copying between AUGUR systems and servers;
- Design of three-dimensional sketches of inspected objects (schemes for imposing on flaws images);

- Defectogram construction with monitoring of possibility of defect progressing on years or for comparison of several AUT results.

Important feature of the AUGUR systems software is the database of the inspection results (DB) which is filled during all inspection object life. Powerful tools for synchronous viewing of data received in various times provide monitoring of the object state. The DB has the authorized access that allows to document all monitoring procedure stages with possibility of the following audit. Other major feature of AUGUR systems software is use of the client-server architecture that allows to create distributed workplaces with united server of the inspection data.

The AUGUR systems software is constructed by a modular principle and can be formed depending on solved inspection problem features and Customer requirements. The basic functions and features of some programs and their modules are described lower.

The program of probes calibration is intended for fast measurement of basic probes parameters before inspection. According to GOST 23702-90 and EN 12668-2-2002 the probe index, beam angle and directive diagram width, pulse and frequency characteristics, conditional sensitivity and others are defined. Probe's passport issues. The procedure and probes calibration algorithms are detailed in the article [4].

Programs of data acquisition (registration) for different AUGUR systems are arranged by the general principle. The operator specifies parameters of inspected object, loads methodical parameters to start the concrete object inspection, specifies the equipment parameters applied in the inspection and starts inspection process.

During the control program operates scanner movement and executes data acquisition according to the used methodology. During the inspection 100 % AUT data registers without any cutoffs that allow to meet requirements ASTM 2235-9 at replacement of the radio graphic inspection by the ultrasonic. Data during the inspection could be presented in demanded by the inspection methodology type – A - B - C - D-scans, map corrosion, TOFD. Indicators of acoustic contact quality and automatic alarm strobe about flaw detection could be included.

The data acquisition program allows simultaneously using great number of techniques with quantities of converters for one inspection cycle. The combination of widely used UT methods (echo–, echo–mirror, diffraction, mirror through transmission and others) with coherent (holographic) processing allows to receive high-quality three-dimensional flaws images on a limit of information saturation. Only these images could give exact information about flaws sizes and types.

In the program TCG is set for each channel according to individual DAC curves of used probes.

In a Fig. 10 the main window of the data analysis program with echo signals ready for the analysis (at the left) and the welded joints with thickness 55 mm flaws image (on the right) is shown. Scales (x, y, z, t), cuts on echo signals file, types on a data cube of the images, markers are shown. Distances in three-dimensional coordinates system could be measured using markers. Synchronization of marker position on all shown images allows to analyze the received from several channels data, for example during welded joint inspection with two beam angles or with double mode methodology [5].

Fig. 10. The main window of the data analysis program. Basic elements and data presentation variants are shown. At the left echo signals and A-scan are shown, on the right – three image sections of welded joint with thickness 55 mm are shown.

In the software are realized data processing algorithms, allowing to visualize flaws, to raise echo signals and images quality, to automate the data analysis process and the AUT conclusions creation. Algorithms of flaws revealing and sizing serve for the automation of defective areas recognition and definition of the flaws sizes and type. Algorithms are adjusted for the chosen inspected object and inspection procedure. Parameters adjustment and algorithms checking demands big sample of real or artificial defects data processing. Algorithms of automatic flaws sizing in austenite pipelines welded joints Du300 and flaws in the rails are most detailed.

The algorithm of automatic flaws detection and definition of the conditional sizes during the regular AUT could be adjusted according to requirements of the operating normative documentation (for example, PNAE Г-7-010-89, STO Gazprom 2-2.4-083-2006, ASME Code CASE 2235-09 etc.). Thus making decision about detected flaws inadmissibility could be accepted as automatically, and with operator participation. In a Fig. 11 the example of flaw revealing in the standard of a composite welded joint of the main circulating pipeline welding to reactor VVER-440 is shown.

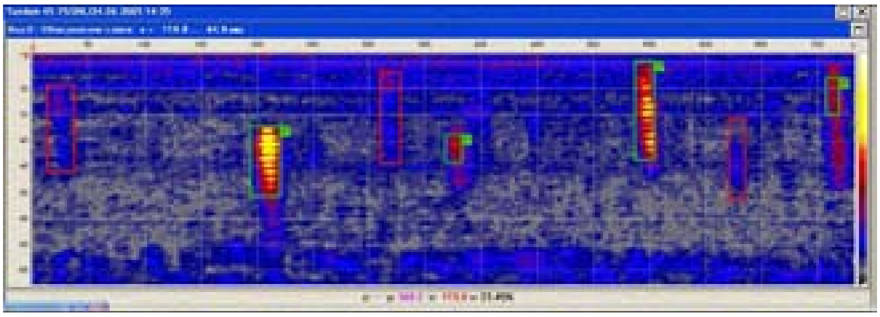

Fig. 11. Results of using the automatic contouring algorithm to the search AUT data in composite welded joint standard.

The automatic or semiautomatic sizing algorithms by measuring mode data are intended for real flaws parameters automation determination by coherent images. On Fig. 12 is shown example of automatic layerwise crack sizing with height to 12 mm in the pipelines Du300 welded joint.

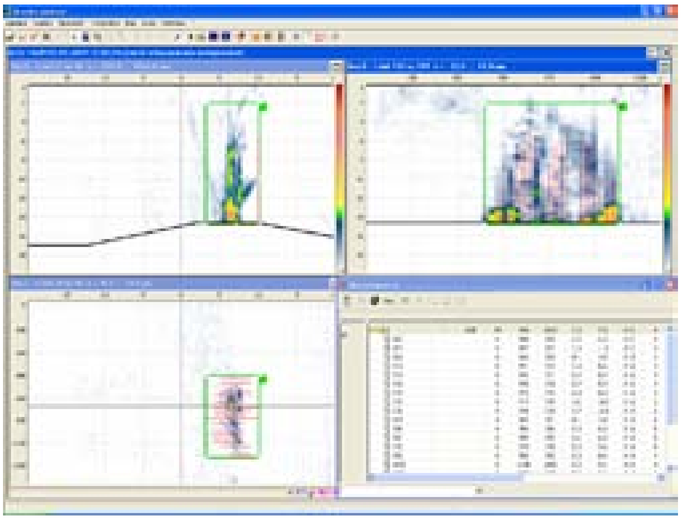

Fig. 12. Result of the automatic construction of layerwise crack profile with height to 12 mm in pipeline Du300 welded joint on the base of several images combining get by C-SAFT method.

In AUGUR system software is provided converter of the data files getting by other AUT systems including phased array flaw detectors Omniscan MX and Harfang X-32 with transformation in S-scan. Processing and software functionality could be used and for these data.

Program for construction of three-dimensional inspection object scratches (Fig. 13) allows the operator to combine on one image three-dimensional coherent image of internal object structure and contours of object strucrure. This possibility simplify the flaws coordinates determination against to the welded joint and other geometric reflectors, allows to specify the object bottom form and the welded joint chamfer by diffusive reflections.

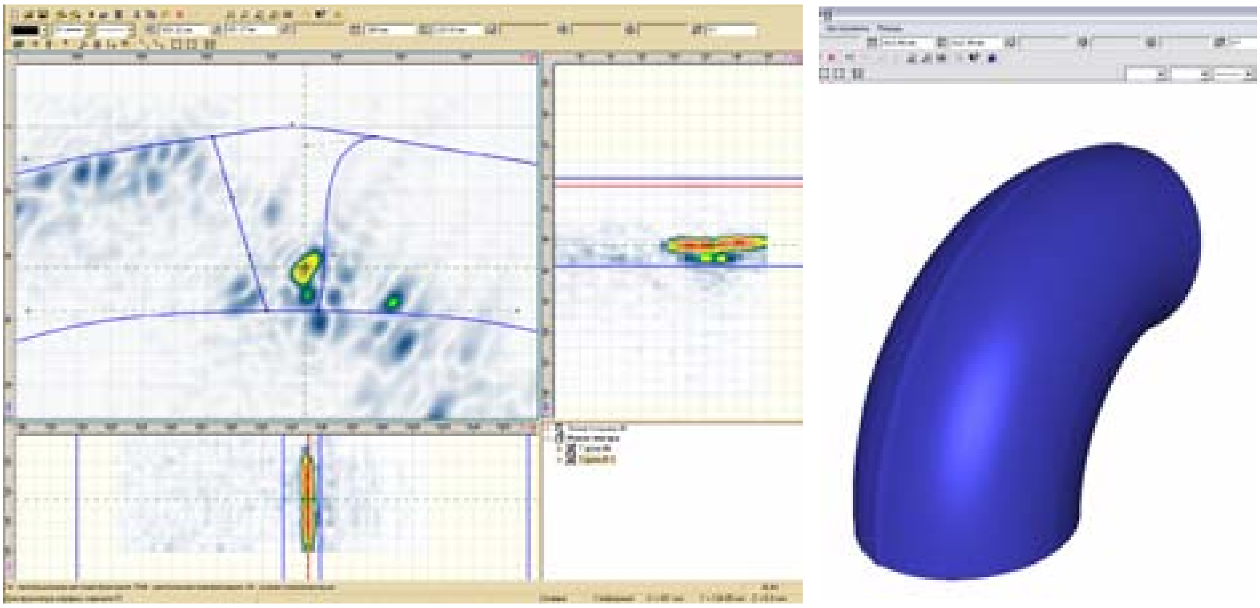

Fig. 13. Building the chamfer scratch of longitudinal welded joint of pipe Du500 elbow. The side drilled holes in the adjustment sample image is resulted, three-dimensional image of pipe elbow (a), the scratch constructed in program (b).

The Program for defectogram formation allows to present the flaws location map in the object in any chosen projections, the flaws images on three-dimensional inspection object image and as a result to add AUT conclusion by the flaws location demonstrable scheme.

Classification of AUT tasks and construction of the optimum inspection system

For formation of optimum hardware-software basement of the inspection it is offered two basic lines of AUT tasks classification in the modern NDT market – by the manner of data acquisition and by the manner of data processing for representation to the operator who forms the inspection datasheet. Other possible lines of AUT tasks classification (on accessibility to inspected object, climatic and other to inspection procedure conditions and so forth) has lesser influence on systems design and defines only technical decisions on concrete inspection system units.

By a manner of data acquisition inspection tasks divides on the inspection with inspected object moving relative to probes group (the inspection of longitudinal welds of pipes at factory, metal sheet on the rolling mill, rails inspection with flaw detector car….) and on the inspection when probes group movable "compulsorily" relative to inspected object by means of the scanning device. In the first case, the inspection system cannot control a movement of object, the entrance information on movement (speed of moving) is invariable and the basic for synchronization of inspection process. In most cases such inspection tasks has one-dimensional geometry (P1). In the second case the inspection system operates process of probes scanning of, moving them in one or several directions (A1, A2, A3). Movement control is conducted through motors with the active analysis of the information about trailer and other position gauges. The most known tasks for the second group of classification – the inspection of welded joints and the base metal of pipes and other equipment. Data acquisition is conducted only by the multichannel method which version is use of ultrasonic antenna arrays. A way of use of antenna arrays we will carry to classification by a manner of data processing.

By the manner of data processing it is possible to classify inspection tasks on (i) ones with a minimum processing level when under the chosen range and rejection level settings for each channel, the decision is ‘flaw / no flaw’ (Regular AUT), (ii) on tasks which are accompanied by automatic recognition of data acquisition problems (the analysis of coupling, tracing of sensitivity level of …) and inspection data postprocessing, i.e. when the operator obtains flaws images for the analysis (Analysis

AUT) and (iii) tasks with automatic decision-making with the received images to which the data batch-processing precedes, allowing to make it (Automated AUT).

Formulating in another way, it is possible to say that the manner of data acquisition and a manner of data processing define the basic distinctive features of a hardware and software parts of the inspection system.

For each crossing of two lines of this classification which, our way to opinion, covers the majority of modern AUT tasks, it is possible to define the equipment and software package providing by minimization of upgrade size the shortest way to creation of the demanded inspection system on the basis of AUGUR hardware-software platform. AUGUR-T system developed in 2009 for the operational inspection of tee-fittings welded with overlays for Gazprom is the example of realization of described approach.

AUGUT-T system for tee-fittings inspection

The basic distinctive requirements for developed system were: 1) revealing of defects in tee-fitting weld under the overlay with at access to object only from outer surface; 2) possibility of the inspection by means of one system of other welded joints and the base metal of tees; 3) accordance with requirements to equipment service conditions.

The decision of the given problem interestingly representing three variants from presented above classification. The task of weld under the overlay inspection covers by system with circular 2D-scanning (A2) on a branch pipe of a tee and the subsequent 3D-coherent data processing (Analysis AUT). A girth welds inspection task covers by the same scanning device with flaws accepting by amplitude and conventional length (Regular AUT). And the base tee metal inspection is spent by system with one-dimensional scanning (A1) also with flaws accepting by amplitude, using methodology of long range ultrasound (Regular AUT).

Weld under overlay inspection

Necessity of focusing with remote scanning for tee-weld under the strengthening overlay, is caused by that distance from a beam index to inspection area can reach 400 mm. The conventional pulse-echo inspection is almost impossible in such conditions because of presence of multiple rereflections, and also an essential sound divergence and attenuation conducting to radical decrease of resolution and the signal/noise relation (SNR).

For the weld under outlier inspection it is offered to use the possibilities of three-dimensional coherent processing by a projection method in spectral space (3D FT-SAFT) which isavailable in AUGUR software, giving the chance of UT fields focusing even at the big distance from inspected area. algorithm. It is possible with exact mechanical probes moving to synthesise the large aperture and, thereby, to increase considerably range of successful focusing area in comparison with modern systems based of the phased arrays. This allows to use effectively an ultrasonic method for distant welds inspection.

The analysis of conditions and an inspection procedure shows that the equipment solving this problem should use the standard electronic block on the basis of the industrial computer, scanner SC.426T, the set of probes with 2.5 MHz frequency and beam angle 70°. The basic feature of the software is presence of the module of 3D FT-SAFT and frontal holography coherent data processing.

Girth welds inspection

The girth welds inspection is carried out by conventional AUT techniques, with the scanner SC.426T; the electronic block on the basis of the industrial computer, the standard complete probes set. In the software applied not coherent data processing, allowing to carry out confident revealing of flaws according to codes.

Base metal inspection

The base metal inspection of pipe course and branch pipe of a tee has been solved by effect of waveguide distributions of ultrasonic waves in plates. For this purpose the one-dimensional automated or manual scanners of AUGUR system can be applied for moving of probes group. The electronic block is based on tablet laptop. The complete set of converters consists of two probes on frequency of 1.2 MHz with a beam angle 60°. The software includes modules of the analysis of the data, indemnifications of attenuation and dynamic TCG adjustment, automatic flaw area sizing, construction of a three-dimensional object draft, templates of the inspection datasheets.

The AUGUR-T system for tees inspection created on a platform passed necessary tests and with 2009 is actively used in ‘Gazprom’.

Conclusion

Presence of the developed basis of methodical, software and hardware solutions allows to offer a method of construction of AUT systems, based on the generalized sight at the majority of modern inspection tasks, and allowing to create systems with demanded parameters in the short terms.

Having in an arsenal the branched out set of scanners, electronic units and the software as a complete modules, it is possible to create AUT systems accelerataly, as much as possible considering parameters of inspected objects and the customer requirements.

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