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# ULTRASONIC PHASED-ARRAY TESTING OF FERRITIC WELDS IN CONVENTIONAL BOILER CONSTRUCTION

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***ABSTRACT***

*For the first time the ultrasonic testing method „Phased-Array" (UT-PA) was applied in an industrial scale in a conventional boiler in Germany. A detailed testing specification has been prepared. The sensitivity calibration method was the Time-Corrected-Gain (TCG) Method. Calibration blocks with two reference flaws were boiler tubes with the same material, heat treatment outside diameter and thickness as the real tested welds during the assembly. The reference flaws were thin rectangular notches with the following dimensions: depth 1mm, width 0.2 mm and length 6 mm. The dimensions of the machined notches have been measured by means of Computer Tomography (CT). Together with the plant operator, an independent inspection authority and the manufacturer the previously mentioned NDT method was qualified within an extensive qualification scenario. The qualification has been conducted on the artificial flaws of the calibration blocks as well on test welds with real flaws. The dimension of the real flaws have been also investigated and measured by means of CT. During the tests it was found that certain failure types e.g. radiating star cracking can be better detected by using the ultrasonic phased-array testing technique as by means of conventional RT. By using UT-PA it was possible to achieve quality assured test results based on EN standards for pressure equipments with a minimum wall thickness of 6.3 mm (ferritic materials). This testing method reduced the necessary time for the assembly substantially.*

***Key words**:* ultrasonic, phased-array, assembly, boiler, weld.

## 1. Introduction

Currently, non-destructive volume testing of circular weld seams on thin-walled tubes (wall thickness 6 to 8 mm) in boiler construction is exclusively performed by means of conventional RT testing with isotopes. Due to the necessary radiation protection measures, this results in restrictions regarding erection work at the construction site and thus allows test periods only during the night shift. A faster and more precise method is the UT-PA method. With UT-PA as

an imaging test method, error location and detectability are more precise than when using conventional ultrasonic testing.
This testing technique allows welding and testing work within 24 hours without restrictions. Prerequisite in this respect is the excellent coordination/organization of erection and testing work. To be able to achieve this objective, the site management and the responsible test supervision must work hand in hand.
This contribution will present the aforementioned test method and its application in real construction site conditions. For the first time, a large number of metallic welding connections were tested with this test method at a construction site in Germany. With the application of this test method, all participating parties (plant operating company, manufacturer, erection company and the independent testing agency) were able to realize major time savings.

## 2. Standards, codes and regulations and scope of testing

Prior to the introduction of harmonized standards in Europe, the standardization for pressure equipment had been essentially regulated on a national level. In worldwide international power plant construction, manufacturers had been able to introduce – depending on contract designs – the familiar national codes and regulations (e.g. German standards TRD or AD); frequently, regulations and technical delivery conditions valid for the place of installation of the pressure equipment had to be complied with additionally (e.g. Danish rules for welding work on piping systems).
With the introduction of the "New Concept“ (New Approach), the foundation was already laid on May 7, 1985 for a harmonization of the joint European internal market and – through the creation of interdisciplinary standards committees (CEN = European Standardization Committee) – the transfer of national technical rules to European standards was introduced.
For pressure equipment, there are today comprehensive standards available in Europe which frequently has already replaced, in new editions, the status of the initial editions which had often been flawed by many errors. The following provides an overview of the basic standards for pressure equipment:

- DIN EN 12952 Water tube boilers [3]
- DIN EN 12953 Large-scale water tube boilers [4]
- DIN EN 13445 Unfired pressure vessels [5]
- DIN EN 13480 Industrial piping [6]

The other applicable standards specified in these basic standards regulate e.g. the qualification of non-destructive test methods and their execution. Test scopes for non-destructive tests are principally regulated via the above-mentioned standards and are to be classified as minimum requirements.
In boiler construction according to EN 12952 [3], the extent of testing for typical pipe welds – e.g. for evaporator, superheater, economizer, etc. – has been specified at 10% minimum. Not taken into account is any scaling of the test scope due to special ambient welding conditions as well as processing requirements of new materials in boiler construction.
Based on the fact that in large-scale steam generator construction at today's standard boiler sizes, the extent of welding at the construction site will be, for the pressure part, within the range of approx. 35,000 welds for circular tube welds, extended test scenarios will essentially influence the erection flow by means of additional specifications.

To ensure a secured quality standard, the minimum standards of EN 12952 [3] are certainly no adequate basis, all the more so since the new materials require a higher test level due to the partly very narrow processing time frames for welding, especially for manual welding under erection conditions.
The subsequently presented state-of-the-art non-destructive testing techniques allow the boiler manufacturer the continuous integration of test scenarios into the erection flow. Tests can be made directly after execution of the erection; test results which are important for the erection progress are promptly available with the phased-array technique.

## 3. Qualification scenario

With regard to meeting the extent of testing on welding connections, not only the European harmonized product standards for pressure vessels – such as DIN EN 12952 [3] for water tube boilers – but also the hitherto existing national codes of rules such as TRD [1], AD-2000 [2] or the VGB guidelines provide for the application of the classical non-destructive test methods, such as the radiographic test according to DIN EN ISO 17636 [8] or the ultrasonic test according to DIN EN ISO 11666 / DIN EN ISO 17640 [9, 10].
Moreover, there are far-reaching restrictions for the application of the classical ultrasonic test on circular tube welds:

- In accordance with DIN EN 12952-6, ultrasonic testing is applicable without restrictions for ferritic materials as of wall thicknesses > 8 mm. For wall thicknesses < 8 mm, ultrasonic testing "is to be carried out according to written instructions for the test method by the manufacturer which is to ensure that the boiler safety will not be impaired“. [DIN EN 12952-6 para. 9.4.2.1, item 12]
- In this respect, the regulations of the VGB Guideline 501H [7] are yet more stringent in that ultrasonic testing for ferritic materials is only provided as of wall thicknesses of 15 mm.

Accordingly, the use of the test method UT-PA rendered a qualification indispensable to prove the suitability of this test method for the planned purpose of application, with the participation of all parties, i.e. plant operating company, manufacturer, erection company and the independent inspection authority. Qualification of the test method was effected following VGB Guideline 516 "Methodology for Proceeding in the Qualification of Non-Destructive Tests“[14].
Qualification of UT-PA was effected by the proof of detectability of not only artificially introduced defects in comparison bodies in accordance with E DIN EN ISO 13588 [11], but also for the first time on welds with real weld defects. For this, the dimensions of both the artificially introduced defects and the real weld defects were examined previously by computer tomography (CT images).
For ferritic materials in the range of dimensions from ∅ 48 x 6.3 mm to ∅ 61 x 8 mm, it could be proven that – in addition to the detectability of artificially introduced defects – real critical weld defects can be clearly detected, such as:

- Worm holes
- Lack of fusion on weld flanks
- Radial end crater cracks
- Transverse cracks

Moreover, it is to be emphasized that the types of defects "lack of fusion on weld flanks" and "radial end crater crack“ could not be detected by means of classical comparison radiographs according to DIN EN ISO 17636 [8].
As an additional qualification measure, it was agreed between the parties involved that, at the beginning of the testing activity, 100 welds per tube dimension are to be comparison tested not only by means of UT-PA but also by conventional radiography test. For the qualification of UT-PA, at least 95% correspondence in the test results of these two methods was required and demonstrated.
Subsequently, and as another quality-ensuring measure for the ongoing verification of the test results of UT-PA, a conventional radiography test accompanying construction was performed on 5% of the UT-PA tested welds.

## 4. Qualification of the test personnel

The employed test personnel was qualified and certified according to DIN EN 473 [12] in a relevant sector of the industry (UT level 2 with additional training on the phased array technique of ultrasonic testing).
In addition to general knowledge regarding the ultrasonic testing of welds, the personnel also had to be familiar with the phase-controlled array technique and demonstrate practical experience in using this testing technique. Special training of the personnel was to be conducted on characteristic parts with welded joints. This training should be documented [11].

## 5. Testing technique

In conventional ultrasonic testing, several probes with different stationary beam angles are used for one test assignment. A stationary beam angle also means stationary sound field characteristics. The more complicated the geometry of the component, the more probes of different types must be utilized. Accordingly, different test lengths (test runs) are also required.
The phased array technique offers the opportunity to control the individual elements of the probe by means of suitable electronics and thereby change the sound field depending on the application. One phased array probe replaces several conventional probes.
One phased array probe consists of an ultrasonic quartz crystal which is cut into several strips. The phased array probe is thus subdivided into several individual elements. Each element is able to send and receive. Controlling electronics enables panning and focusing of the sound field.

## 6. Advantages of the UT-PA testing technique vs. conventional testing technique

The following table shows the advantages of the phased array technique versus the conventional ultrasonic testing technique under actual marginal conditions:

Table 2: Advantages of the phased array technique

| ***MARGINAL CONDITIONS*** | ***ADVANTAGES FOR THE TEST*** |
|---|---|
| *Many test functions with corresponding test assignments* | *Reduction of the number of probes* |
| *Complex test geometry* | *Adjustment of the beam angle to the test geometry*<br>*Only one test probe for the required beam angles* |
| *Components with difficult access* | *Small dimensions of the test probe system* |
| *Restricted scan area* | *Small probe system, reduction of test length for weld tests, i.e. savings in material.* |
| *Short test periods* | *Reduction of the number of test runs* |

Additionally, the imaging phased array technique enables state-of-the-art and complete documentation of test results: A-, B-, B-, C- S images of displays, test parameters, etc.

## 7. Practical implementation

### *7.1 Equipment*

The portable phased array ultrasonic inspection device Phasor XS$^{TM}$ was used – manufacturer: GE Measurement & Control in Hürth, Germany – which is at the same time a conventional industry-standard inspection device. It has a rated and rugged design for use in industrial environments. The device has a colour display for real-time presentations of B-scans and sector scans with or without the A-scan of the selected beam. Possible are full screen display and storage of all screen contents (sector scans, A-scans, B-scans), measuring values and the parameters of current device settings. Generation of images and logs in JPEG format and storage are effected on SD memory card [13].

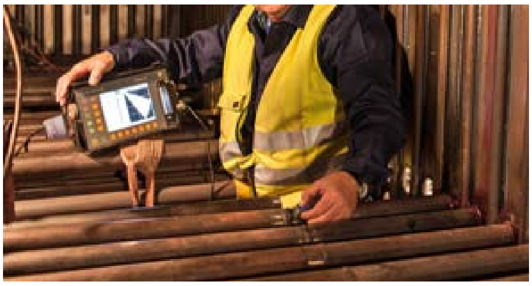
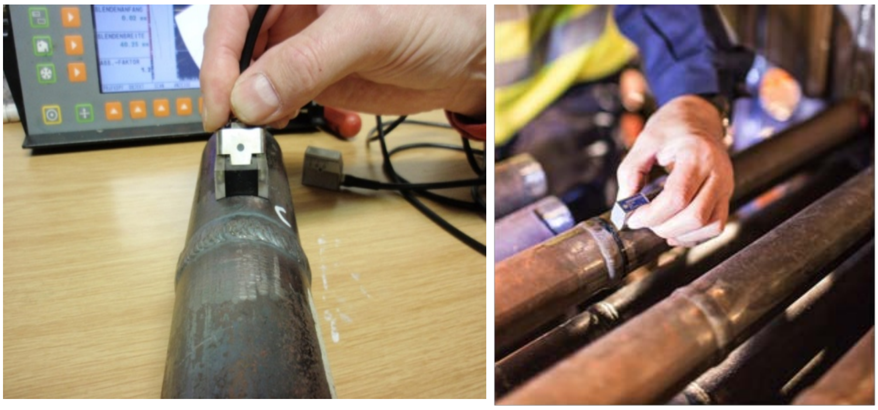


Fig. 1: Portable Phased Array Ultrasonic Flaw Detector Phasor XS$^{TM}$

### *7.2 Probes*

Probes with transverse waves were used. Both the so-called "Scribeline probes“and the MWB4PA16 probes were used (manufacturer: GE), both with 16 elements. The rated design type MWB prevails under construction site conditions.
The probes are adjusted to curved inspection surfaces according to DIN EN ISO 17640 [10]. The gap between inspection surface and probe shoe may not exceed 0.5 mm.



a Scribeline probe b MWB4PA16

Fig. 2: Phased array angle probes

Phased array angle probes with a frequency of 4 and 5 MHz have been used. The angle scan was performed between angle start 40° and angle end 70°.

### *7.3 Volume to be inspected*

The inspection volume comprises the weld and the basic material on both sides of the weld over a width of at least 10 mm and the entire width of the heat influencing zone.
The inspection was carried out at a fixed distance to the weld on both sides. The distance and the number of distances were calculated as a function of weld preparation and wall thickness before the inspection to ensure 100% coverage of the inspection volume.

### *7.4 Calibration block*

The calibration block was produced from the same material (with the same heat treatment, if necessary) as well as the same diameter and wall thickness as the inspection object.
The calibration block was used both for the distance adjustment and also for the sensitivity adjustment according to the time-corrected gain (TCG) method.
Reference reflectors were rectangular notches with a depth of 1 mm and a width of 0.2 mm in accordance with DIN EN ISO 13588 [11]. The length of the notches is 6 mm. The rectangular notches were made by means of spark erosion. The required dimensions were confirmed by means of CT measurements (see figure below).

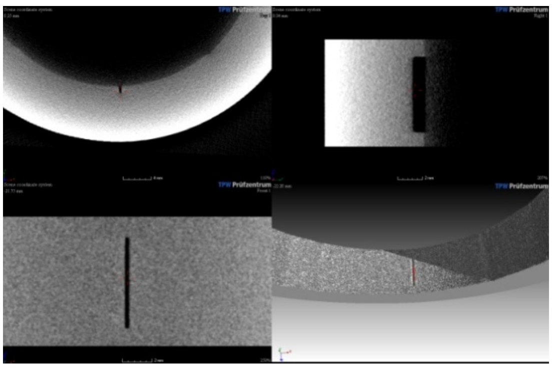
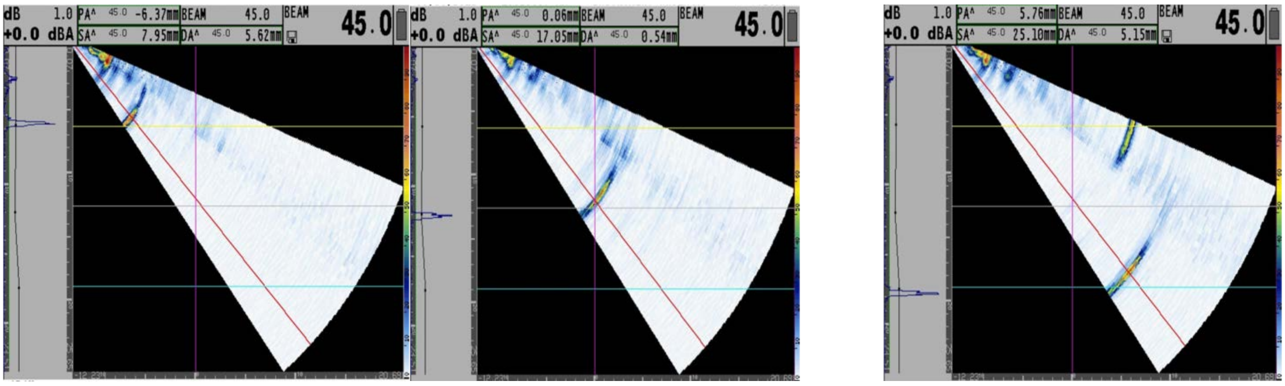


Fig. 3: CT image of a rectangular notche

### *7.5 Sensitivity adjustment*

The sensitivity adjustment was effected according to the time-corrected gain (TCG) method (time-dependent gain, depth compensation). The swept gain compensates for the natural decrease in echo amplitude with increasing distance. Swept gain must compensate both for the natural amplitude reduction due to the distance laws and sound attenuation as well as the change of the echo amplitude due to the beam angle. For this, the echo amplitude of every reference reflector must be recorded with every angle. The TCG curve was recorded at 80% screen height of the echo amplitude for every reference reflector (inside and outside notches). Three (3) points were recorded; item a, b, c in the figure below.




a b c

Fig. 4: Recording of the TCG curve

## 8. Results

The stipulated qualification measure was successfully completed. The comparison test by means of UT-PA and conventional radiography technique (RT) which was required prior to the beginning of the inspection activities on 100 welds of the component to be tested showed 97% conformity of these inspection methods.

Also successfully completed was the conventional RT accompanying construction and performed on 5% of the UT-PA inspected welds as a concluding quality-assuring measure. Correspondence was realized of inspection results of 100% between UT-PA and the conventional RT.

Moreover, by means of UT-PA, inadmissible welding defects were detected which could not be found by the conventional RT. One example for it is an end crater in the root which was optimally hit with a beam angle of 59° as figure below shows.

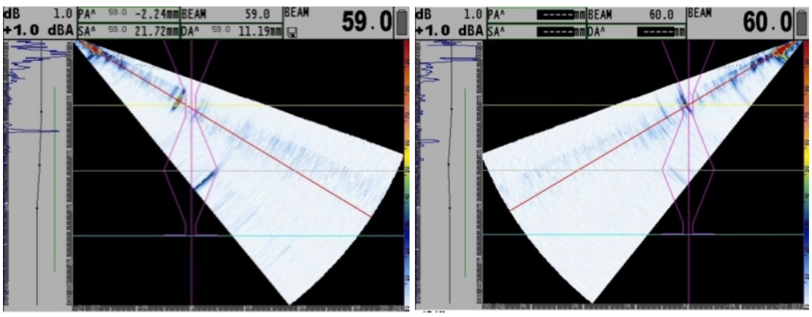



Fig. 5: Result by means of UT-PA

## 9. Conclusions

Within the scope of the qualification measure, the equivalency of the test results or, respectively, even a better fault detectability could be detected in terms of the above described innovative inspection method versus the hitherto existing conventional inspection techniques.
The practical implementation of this inspection method showed, with regard to the erection progress, a major potential for the reduction of inspection and erection times. In particular, the possibility of parallel execution of erection and inspection activities without time delays and mutual impairments realized essential gains in time.
Only the formalisms regarding missing or, respectively, unprogressively standardization present – at the current point in time – stumbling blocks for the large-scale use of these innovative test or inspection techniques. In this respect, updating and adjustment to the currently available state of the inspection technique are especially required for the European product standards for pressure vessels, such as EN 12952 [3] for steam boiler plants as well as EN 13480 for industrial piping and EN 13445 for pressure vessels.
The industry – both power plant operating companies and boiler manufacturers – must provide new impetus to the standards bodies to be able to establish the application of these inspection methods in the foreseeable future in boiler construction.

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