Automated ultrasonic tube-to-tube sheet weld scanning

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Abstract

This paper describes an advantageous ultrasonic technique for in-depth examination of tube-to-tube sheet welds in heat exchangers in different chemical processing plants, such as oil refineries, ammonia production plants and power plants.

Heat exchangers are critical components in many chemical processing plants. Their safe and reliable operation is an important issue for the operators. Currently, inspection of the tube-to-tube sheet welds in the heat exchangers is normally limited to various methods for surface inspection, while defects inside the welds remain undiscovered, which could compromise safety and could lead to failure and production stops.

To overcome this issue, FORCE Technology has developed an automated ultrasonic solution, which is capable of finding small embedded defects in the welds, is time efficient and provides detailed documentation of the inspected welds. This paper describes our solution and how we apply it.

Introduction

Inspection of tube-to-tube sheet welds are traditionally limited to visual, liquid penetrant and hydrogen leak testing. All these techniques only provide information about the surface condition of the inspected welds, such as surface cracks or other surface breaking discontinuities. The mentioned inspection techniques are not able to detect any internal weld defects such as lack of fusion or cluster porosity. Internal defects are crucial for weld integrity.

FORCE Technology has developed an alternative technique based on standard ultrasonic examination principles, which is capable of detecting them. The technique offers a lot of benefits for our customers and significantly increases the level of confidence they have in the examined heat exchangers. The technique is very fast, thus minimising downtime and provides full scanning of the welded volume.

Therefore, defects such as lack of fusion, inclusions or clustered porosity are easily detectable. The technique makes it possible to save detailed data for each particular weld, including precise dimensioning and positioning of detected defects inside the weld. The data can either be used for on-site reporting or, if needed, at a later stage. The equipment is easily transportable and does not require any safety preparations prior to testing, except for those required by the customer.
The technique is applicable for tube sheets in shell and tube heat exchangers. In some industries, this is the most popular type of heat exchangers. This type is also often used for high pressure applications. In a heat exchanger, heat from a hot fluid is transferred to a colder fluid, without mixing the fluids. One fluid flows through the tubes of the exchanger, while the other flows outside the tubes. Heat is transferred through the tubes’ material.

In order to maximise efficiency, heat exchangers of this type have a very large number of small diameter tubes, welded to the tube sheet. Fluid must not leak from the welds and, therefore, they need to be examined individually.

Heat exchangers can be made of different materials, all of which must have good thermal conductivity, good corrosion resistance and good resistance to very high temperatures.

Typically, different kinds of metal alloys are used in the production of heat exchangers, e.g. different kinds of steel (carbon steel, stainless steel, duplex), copper, titanium or nickel alloys, which gives excellent possibilities for ultrasonic inspection.
Ultrasonic NDT technique

The technique is making use of normal ultrasonic testing principles, but is applied with a specially designed scanner. It has the ability to scan the weld for internal indications in the full weld length, a 100% circumferential area and to size eventual indications. Internal indications such as lack of fusion, cluster porosity, inclusions and cracks are easily detectable.

The ultrasonic probe is positioned in the scanner’s hollow shaft and inserted into the inspected tube in the heat exchanger. The probe is rotated and translated axially simultaneously, thus performing a screw spiral movement. Inspection starts and stops a couple of millimetres before and after the weld, respectively.

A centring mechanism is keeping the inspection head centred in the tube. The specially designed scanner enables fast and accurate inspection of the weld. Inspection rate is between 60 and 90 welds per hour. Below the weld inspection principle is illustrated.
Automated data collection

Data collection is based on our automated ultrasonic inspection system, called P-scan. The system was first developed by FORCE Technology in the 1970s and has since been under constant development and improvement. The system can be applied in many areas and its further development is based on regular use and accumulated field experience.

Furthermore, we have developed a wide range of scanners, based on the P-scan system, adaptable to specific applications within different industries. Essentially, the P-scan is a computer-based ultrasonic inspection system for automated, mechanical or manual inspection of structures, welds and assembly of components.

The P-scan system has documentation and storage facilities for all data related to each inspection operation, and include visualisations of the inspection results in the form of high quality images of the material volume examined.

The P-scan system can provide different kinds of information. It has an A-scan, B-scan, C-scan, T-scan (thickness measurement) and TOFD (time-of-flight diffraction) mode. Furthermore, the system provides projection images of the object under examination. With the three projection images, called Top View, Side View and End View, any imperfection which have been detected are automatically shown at their correct 3D location. The system’s excellent traceability and documentation possibilities is very valuable for the operator and owner.

The tube-to-tube sheet scanner

Our tube-to-tube sheet scanner, named AHS-1, is a handheld unit, which either can be operated by the scanner operator or remotely from a laptop. The scanner basically consists of a motor, a shaft with an ultrasonic transducer and a keypad for local scanner control.

A centring mechanism is positioned at the end of the shaft, just in front of the ultrasonic probe. The shaft is hollow and contains cables for the transducer and a hose for water supply, as water is used as couplant between transducer and inner tube wall. The motor rotates and translates the shaft together with the transducer.

The scanner can be equipped with different probes, depending on the expected type of defect. Zero degree probes are typically used for detection of lack of fusion or cluster porosity, while angled probes are used for detection of cracks in the welds.

Inspection rate depends largely on the inner diameter of the inspected tube and is larger for small diameters and lower for large diameters. One-inch tubes are typically scanned with one rotation per second, i.e. a weld with a leg length of 5mm is being scanned in approximately 10 seconds.

The scanner is calibrated so that the position of the artificial defects in the mock-up is well defined, enabling positioning and sizing of potential defects in the actual heat exchanger welds.
**Calibration of the system**

Prior to inspection, the system has to be calibrated on a mock-up. The mock-up consists of 3-5 tubes in a tube sheet of identical design, as the heat exchanger that is to be examined. Full geometrical identity of diameters, thicknesses, positions and welding parameters should be ensured. Artificial defects are introduced in the mock-up welds, however, one of the welds must be kept without any welding defects.

Depending on the requirements, the artificial defects can be side drilled flat bottom holes or lack of fusion defects prepared during welding of the tube in the mock-up. As the scanner needs to be prepared to fit the actual tube geometry, the mock-up must be send to us in sufficient time before the actual testing.

The screenshot below displays a calibration scanning with 2 artificial lack of fusion defects. Defect 1 is 5mm in length, corresponding to circumferential extent of 13 degrees and Defect 2 is 10mm in length, equal to 26 degrees. Defect 2 is located in depth of 4.1mm measured from the tube inner wall. The signals to the left are from the tube back wall, prior to the weld.
Fast-rate inspection

The technique has good versatility and adaptability to various tube dimensions, from 12mm in internal diameter. It finds various types of weld defects and weld leg-length can be determined as well. Maximum scanning length is up to 80mm in standard scanner setup. An important requirement is that the inner surface of the tubes must be clean, free of scale, corrosion or other impurities.

As the equipment needs both power and water supply, normal safety and security measures for such cases apply, but no additional measures are required during inspection. The equipment is easily portable, which makes it easy to reach customers anywhere in the world.

During a 10-hour shift, around 600-800 welds are examined and a preliminary report stating any severe findings will be issued prior to the inspection team leaving from the site. Such high inspection rate significantly reduces down-time of the system and, combined with the high quality of data and documentation, provide a clear advantage over the more traditional inspection methods.

Conclusions

FORCE Technology's tube-to-tube sheet weld scanner provides fast and accurate detailed data on the condition of the welds in the inspected tube sheet and thus represents a better solution than alternative traditional inspection techniques.

The technique has been successfully applied for tube-to-tube sheet weld inspection on a number of projects worldwide. For years, FORCE Technology has been on the front edge of innovation in many fields, including NDT education and inspection. Our tube-to-tube sheet weld scanner is a prove of that.

Further information
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