Abstract

The present economic climate is focusing downstream Oil Companies to maximize the use of their production assets.

The major driver for this has been the reduction in maintenance period with the emphasis on increasing activities which can be carried out when the plant is on stream. Inspection on stream has many advantages for the operator, the more obvious being that there is no requirement to shut their plant down. Other gains to be made are that there can be a better planning for any subsequent remedial action before any planned shutdown.

This paper will discuss the progress made by TÜV Rheinland Sonovation into the application of conventional and Automated Ultrasonic Techniques leading to the present capability of inspection at 900 degrees Fahrenheit (480°C).

Explanations will be given on how this was achieved with the attendant considerations on Health and Safety, application problems with the required calculations. In addition several case studies will be presented.

Keywords: High Temperature, Ultrasonic, TOFD, Phased Array, Corrosion Mapping

Introduction

TÜV Rheinland Sonovation has been operating as a privately owned company for several years during which, amongst many other innovative developments, it has been progressing Ultrasonic High Temperature methods for testing of heavy walled components. Recently, the shares of the company have been acquired by TÜV Rheinland whereby TÜV Rheinland Sonovation became the Global TÜV Rheinland NDT Competence Centre.

The financial ramifications of having to shut plant down for inspection to examine critical pressurised components can be significant. To reduce downtime and optimise shutdown planning, TÜV Rheinland Sonovation started the development of Ultrasonic High Temperature methods nearly 20 years ago. An early application was the monitoring of a weld section from which a defect, detected during a routine shutdown inspection was removed by grinding. The monitoring was initially envisaged as repeat intrusive inspections by Magnetic Particle Testing until a final repair involving local heat treatment could be effected during a next planned shutdown. TÜV Rheinland Sonovation proposed the monitoring to be carried...
out from the outside of the steam drum during operation. The steam drum had an operating temperature of around 200 °C which required the development of high temperature Ultrasonic Testing, as little was known at that time of the behaviour of ultrasound in steel at elevated temperatures, let alone the behaviour of ultrasound in the wedge material in front of the ultrasonic probe. Other considerations were the influence of heat on the actual sensitivity at those temperatures in relation to the noise generated in the wedge and the material tested.

**Development Work**

Initially TÜV Rheinland Sonovation made an experimental mock up heated by means of induction cables. The following picture (FIGURE 1) shows the set up at the low temperature range of the development work.

![Initial Test Plate Setup](image)

**FIGURE 1** INITIAL TESTPLATE SETUP

From the initial tests it became apparent quite quickly, that main influencing factors were coupling, cooling of the probe array, the actual ultrasonic angle being launched into the steel, scanning mechanism and the material of the transducer wedges.

The coupling problem was solved by the use of high temperature lubricant, whilst expensive, offered an efficient coupling medium. To arrive at this solution, a test program was carried out with many different commercially available coupling media lubricants and other substances that were procured. Results were sometimes quite different from the specification delivered with the coupling medium to the extent that one of these couplant samples caught fire at a temperature far below the highest application temperature specified by the manufacturer!

Calculation and practical experiments proved the actual inspection angle being offered by the transducer wedges at different angles and temperatures.

The following picture (FIGURE 2) sees development work at relatively low temperatures as a means to show the effect of angle and sensitivity.
What was discovered at an early stage is that it is not possible for every situation to be suitable for inspection at elevated temperatures. The geometry and thickness of the component, the actual working temperature during the inspection, the smallest defect to be detected, the accuracy that should be achieved and several other factors determine the success rate of each particular inspection, which makes most inspections unique.

All findings during the development work were carefully documented and led to procedures and work instructions for such inspections which helps to streamline inspections in this field in general and is absolutely indispensable for each individual inspection.

It was found during the development trajectory that to employ fully automated scanning technique was problematical due to the effect of temperature on electric motors. It was decided to apply semi automated methods for scanning with the facility of digital feedback.
FIGURE 3 HT MEASUREMENT ON SITE

For corrosion mapping development work done during the same period, (Error! Reference source not found.) there was little problem with regard to the scanning mechanism, as the TÜV Rheinland Sonovation Video Tracking system could be applied as this only leaves the transducer in contact with the surface under inspection.

FIGURE 4 SCHEMATIC CORROSION MAPPING SETUP

An important factor in the successful projects was the validation of the theoretical and practical development in close to real set ups in the TÜV Rheinland Sonovation laboratories.

Validation
Validation should be carried out at with a similar material composition and at the expected temperature encountered during inspection. This work, often carried out under the supervision of Clients, gives them the confidence that an effective, acceptable inspection can be carried out. At the same time, clients become familiar with the application and can help optimising the working circumstances. These circumstances greatly influence the quality and safety during the test at elevated temperature and with this the success factor for the complete inspection.

Further development work

The successful early applications of High Temperature Ultrasonic Testing pushed the further development and later practical application of this technology. The temperature boundary at which testing could take place increased, more and more geometries could be covered and damage mechanisms that could be detected and sometimes sized increased. By the middle of the first decade of this century, the TÜV Rheinland Sonovation R&D team was expanding which lead to the introduction of ScanPlan® which increased the possibilities to utilise modelling of more complex geometries. The highest temperature at which inspections were performed was reaching the 400 °C mark and further development of a simulation package and improved hard- and software tooling was embarked upon to increase reliability and applicability.

High temperature complex geometry application

At this time, there was an enquiry from a major oil company to examine complex geometry weldments in steam headers. Headers in a sister refinery had a problem that had caused a failure, resulting in a significant period of unplanned shutdown. TÜV Rheinland Sonovation was approached by the plant owner to enquire whether it was feasible to examine this weld at some 500 °C.

The aims of the inspection were as follows
- To be able to apply ultrasonic inspection at temperatures up to 480 degrees C
- To apply these techniques in a safe manner
- To be able to apply these techniques in an accurate and repeatable manner.

To enable this, it was necessary
- To minimize the time spent at the inspection area,
- To quantify Temperature influences
- To quantify and minimize the influence of as many variables as possible.

TÜV Rheinland Sonovation stated, based upon the development work done and practical experience gathered up to this point, this would not be possible without a significant amount of preparation work, consisting of modelling, procedure development, testing on known defects and validation. Not only was this a very high temperature test, but also in a complex geometry which, without a proper approach as proven successful in previous years would not lead to the outcome needed. The Oil Company agreed to assist financially throughout this program of work.

The work was started by producing mock-ups of the geometries to be examined. Part of a header of the sister plant containing a real defect was built into a mock-up for later validation.
purposes. Making use of the previous experience and improved tooling such as simulation that was developed by in collaboration with a local university, TÜV Rheinland Sonovation managed to arrive at the first draft procedure for the inspection within weeks after starting the project. Further practical tests and validation of the procedure lead to the conclusion that a Phased Array inspection was feasible at temperatures of up to around 425 °C and a TOFD inspection was successful within the required parameters up to around 475 °C!

Within a few months after the initial enquiry the site work was started and several headers were successfully inspected with the fully validated procedure. The exercise led to a reliable insight in the actual condition of the headers and with that to a reliable risk profile of the plant on which a well-founded decision could be based, not to replace any of the headers but one, for verification purposes. As a result, the shutdown was reduced to a normal duration without the necessity of replacing several expensive components. The total project led to a cost saving of several millions of Euros for the plant owner.

![FIGURE 5 HT SITE INSPECTION SITUATION](image)

Examples of other successful applications

The following table shows a typical range of applications using various techniques

<table>
<thead>
<tr>
<th>Client</th>
<th>Application</th>
<th>Technique</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Station</td>
<td>Steam Drum</td>
<td>Longitudinal Seam defect monitoring</td>
<td>Tofd</td>
</tr>
<tr>
<td>Power Station</td>
<td>Piping System</td>
<td>In service defect detection</td>
<td>Tofd</td>
</tr>
<tr>
<td>Refinery</td>
<td>piping and vessels</td>
<td>Accurate monitoring</td>
<td>corrosion</td>
</tr>
<tr>
<td>Offshore</td>
<td>platform</td>
<td>Accurate monitoring</td>
<td>corrosion</td>
</tr>
<tr>
<td>Power Station</td>
<td>piping</td>
<td>Fabrication inspection of partially filled welds</td>
<td>Tofd</td>
</tr>
</tbody>
</table>
Chemical plant piping systems  Hot tap inspections  Tofd  150-250 ºC
Chemical plant vessel  In service defect detection  Tofd  295 ºC
Refinery piping and vessels  Accurate monitoring  corrosion  Pulse Echo  100-200 ºC
Offshore piping systems  Weld root monitoring  Pulse Echo  80-100 ºC
Chemical Vessels  Defect monitoring  Tofd  400 ºC
Chemical plant Piping systems  In service defect detection  Tofd  400 ºC
Chemical plant Piping systems  Defect monitoring  Tofd  150 ºC
Chemical plant pipe to header Weldolet  Defect detection and monitoring  Tofd  485 ºC
Low temperature vessels  Fabrication inspection of partially filled welds  150-200 ºC

**Application on Fabrication Welds**

There are certain circumstances when knowledge of the initial weld runs of fabrication welds can be vital as any subsequent repair can be either impracticable or indeed expensive. This picture (FIGURE 6) shows a typical intermediate inspection carried out at elevated temperature.

This particular inspection was carried out at pre heat temperature on weld of a thickness of 120mm

![FIGURE 6 HT INSPECTION VALIDATION BLOCKS FOR PARTLY WELDED WELDS](image)

In addition to the advantage of knowing the quality of the initial weld roots it had advantages in this particular inspection where maintain geometrical tolerances were essential. Significant repair work at this stage would have compromised this.

**SAFETY IMPLICATIONS**
The most important factor for applying ultrasonic inspection is of course safety. This applied throughout the development stages and when high temperature inspections were being applied in the laboratory and certainly on site. Special procedures were put in place to ensure the safety of the staff in general and the engineers working on the project in particular. For site work it is essential to liaise carefully with the Plant Engineers and Safety officers to ensure a smooth and safe operation.

Important factors to be considered are as follows

- The extent of lagging to be removed to minimize staff contact with the surface.
- The positioning of scaffolding to ensure easy uncluttered access and egress at the inspection area.
- The use of three inspection technicians, one operating the scanning mechanism, another operating the instrumentation and the third acting guard on the technician operation the scanning mechanism.
- The use of protective clothing is obviously essential and although TÜV Rheinland Sonovation has their own in house safety equipments, these must be cleared with the client’s representatives.
- Good inspection planning and procedures are required to minimize inspection times for personnel and equipment.

Plant owners now often adopt TÜV Rheinland Sonovation’s proven safety procedures.

CONCLUSIONS

TÜV Rheinland Sonovation have now shown that Ultrasonic Inspection can be carried out at High Temperatures in many situations, the following table is a brief description of the inspection temperatures and techniques we have applied to date.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Application</th>
<th>Temperature Limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOFD</td>
<td>Defect Detection</td>
<td>480 °C</td>
</tr>
<tr>
<td>TOFD</td>
<td>Defect Monitoring</td>
<td>480 °C</td>
</tr>
<tr>
<td>Phased Array</td>
<td>Detection and Sizing</td>
<td>450 °C</td>
</tr>
<tr>
<td>Corrosion Mapping</td>
<td>Corrosion Assessment</td>
<td>350 °C</td>
</tr>
<tr>
<td>Spot Checking</td>
<td>Thickness Testing</td>
<td>Over 400 °C</td>
</tr>
</tbody>
</table>

TÜV Rheinland Sonovation has now successfully applied ultrasonic inspection at elevated temperatures in many circumstances and in many different applications and techniques, Work will continue to increase the temperature limitations shown.

Although this technology is obviously more expensive to apply than advanced Automated Inspection at ambient temperature it has shown to offer clients significant cost savings as an alternative to shutting plant down for conventional inspection.