Corrosion monitoring with tangential radiography and limited view computed tomography

Uwe Ewert, Martin Tschaikner, Stefan Hohendorf, Carsten Bellon, Misty I. Haith, Peter Huthwaite, and Michael J. S. Lowe

Citation: AIP Conference Proceedings 1706, 110003 (2016); doi: 10.1063/1.4940574
View online: http://dx.doi.org/10.1063/1.4940574
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/1706?ver=pdfcov
Published by the AIP Publishing

Articles you may be interested in
Thermal stability of curved ray tomography for corrosion monitoring
AIP Conf. Proc. 1581, 324 (2014); 10.1063/1.4864837

Simultaneous segmentation and reconstruction: A level set method approach for limited view computed tomography
Med. Phys. 37, 2329 (2010); 10.1118/1.3397463

Quantitative Performance Assessment of Computed Radiography for Corrosion Detection in Process Pipes
AIP Conf. Proc. 894, 1266 (2007); 10.1063/1.2718111

A computed tomography implementation of multiple-image radiography
Med. Phys. 33, 278 (2006); 10.1118/1.2150788

Reconstructions in limited-view thermoacoustic tomography
Med. Phys. 31, 724 (2004); 10.1118/1.1644531
Corrosion Monitoring with Tangential Radiography and Limited View Computed Tomography

Uwe Ewert\textsuperscript{1a)}, Martin Tschaikner\textsuperscript{1}, Stefan Hohendorf\textsuperscript{1}, Carsten Bellon\textsuperscript{1}, Misty I. Haith\textsuperscript{2b}, Peter Huthwaite\textsuperscript{2}, Michael J.S. Lowe\textsuperscript{2}

\textsuperscript{1}BAM Federal Institute for Materials Research and Testing, Berlin, Germany
\textsuperscript{2}Imperial College, Department of Mechanical Engineering, London, United Kingdom

\textsuperscript{a)}Corresponding authors: uwe.ewert@bam.de
\textsuperscript{b)}misty.haith09@imperial.ac.uk

Abstract. Accurate and reliable detection of subsea pipeline corrosion is required in order to verify the integrity of the pipeline. A laboratory trial was conducted with a representative pipe sample. The accurate measurement of the wall thickness and corrosion was performed with high energy X-rays and a digital detector array. A 7.5 MV betatron was used to penetrate a stepped pipe and a welded test pipe of 3 m length and 327 mm outer diameter, with different artificial corrosion areas in the 24 mm thick steel wall. The radiographs were taken with a 40 x 40 cm\textsuperscript{2} digital detector array, which was not large enough to cover the complete pipe diameter after magnification. A C-arm based geometry was tested to evaluate the potential for automated inspection in field. The primary goal was the accurate measurement of wall thickness conforming to the standard. The same geometry was used to explore the ability of a C-arm based scanner in asymmetric mode for computed tomography (CT) measurement, taking projections covering only two thirds of the pipe diameter. The technique was optimized with the modelling software aRTist. A full volume of the pipe was reconstructed and the CT data set was used for reverse engineering, providing a CAD file for further aRTist simulations to explore the technique for subsea inspections.

INTRODUCTION

Accurate and reliable detection of pipeline corrosion is required in order to verify integrity of pipelines in the petrochemical industry. The radiographic inspection of corrosion and the measurement of wall thickness loss have been standardized in EN 16407, part 1 and 2: 2014 [1, 2]. For thick-walled pipes with large diameters, tangential radiographic inspection can only be applied with high energy radiography. Tangential radiographic inspection is a suitable method measuring accurately the wall thicknesses of pipe walls in reference to comparators [1]. Double wall radiographic inspection with evaluation of the intensity of indications is less accurate for thickness measurements than tangential radiographic inspection and it is not the best choice for the prediction of pipe life. For preparation of the experiments and its evaluation, a step pipe was manufactured. The planning of experiments was performed with the RT simulation software aRTist [3]. Wall thickness limits were estimated for tangential X-ray inspection with 7.5 MV and the final experiments were done with a mock-up test pipe.

DETERMINATION OF WALL THICKNESS WITH TANGENTIAL RADIOGRAPHY

Standardized Techniques and Its Limits

The European standard EN 16407 part 1 describes the radiographic wall thickness measurement of pipelines. Figure 1 shows the typical setup for tangential radiography. The radiation source is selected depending on the maximum material thickness to penetrate in the tangential direction. The standard [1] provides guidance for the...
selection of source energy. The method is limited to a maximum wall thickness depending on the pipe diameter. Figure 2 shows the wall thickness limits and diameters for different source energies. Additionally, the limit for the 7.5 MV betatron [4] has been added. The maximum penetrable wall thickness for 355 mm diameter steel pipes amounts to about 30 mm in air. The related inspection conditions and limits for subsea conditions will differ. This was investigated in [5].

![Diagram of radiographic inspection setup](EN_16407-1)

**FIGURE 1.** Tangential Radiographic Inspection Set-up (top) and digital radiograph with line profile (bottom)

The accuracy of the wall thickness determination depends on the calibration of the software evaluation tool, the detector pixel size and the image unsharpness. More details can be obtained from [6].

**Computed Tomography Transform of Profile Functions**

Computed tomography (CT) was explored as tool for improving the measurement accuracy of wall thickness measurements from single acquired profile functions [7, 8]. A measured profile function is considered as one of hundreds of identical slice projections. In this method, the same measured projection is used instead of hundreds of separate angular projections as required for CT reconstruction.
Figure 3 shows the scheme of the algorithm which is based on a reconstruction from a single projection, considering symmetry assumptions and the selection of the final transformed profile in the direction of measurement. The reconstruction is comparable to an inverse Abel transform. It is well known that ring artefacts are expected in the reconstruction due to noise correlation. Consequently, an increase of noise is visible in the area of the reconstructed wall profile after CT transform. The result is widely independent of the image unsharpness. Therefore, the measurement can be performed with reduced distance of source and object in relation to the standard requirements [1]. The reduction of the source to detector distance (SSD) yields an increase of radiation intensity at the detector and reduced noise in the profile. The reduced SDD can also be used for reduction of exposure time. Figure 3d shows wall profiles with increasing unsharpness. The profiles become blurred but the inflection points of the profiles are in a stable position. Suitable results were obtained even if the unsharpness is in the order of the wall thickness. This is especially an advantage for subsea exposures to reduce the influence of the thickness of penetrated water around the pipe. It is also a suitable technique for pipe inspection with limited access.

**Limited View Computed Tomography**

For preparation of the experiments, step pipes (Fig. 4) were manufactured earlier to validate the accuracy of the wall thickness measurements with the BAM software tool ISee [9], which is used for measurement of the thickness in field as well as for training of RT personnel in digital industrial radiography (RT-D). The step pipes were used to perform experiments within air and water [10]. Computer Aided Designs (CAD) were generated and the modelling tool aRTist [3] was optimized for accurate measurements of the step pipes in air and water [5].

The inspection of large pipe components with subsea automated RT inspection technology is basically designed to visualize corrosion in double wall geometry with the source and detector positioned along the pipe diameter [11]. For more accurate measurement of corrosion depth and remaining wall thickness the tangential testing geometry is required. The C-arm setup of source and detector is modified in a way that the source and detector are mounted for tangential penetration along the pipe wall as shown in Fig. 5. Time efficient measurements, geometric limitations and available digital detector array dimensions should be considered for 100% measurement of the circumference.
If the detector acquires only about ½ of the projected image due to its limited size, it is called “half beam” geometry (See Fig. 5). Limited view CT with half beam geometry was considered as the best solution for effective and accurate measurements. Figure 5 shows the recommended and tested geometry. The betatron and detector are mounted asymmetrically on a C-arm. The system is rotated around the pipe by 360°. A CAD model of the step pipe was used for radiographic simulation in order to estimate measurement errors. For simplification the C-arm setup was not moved.
but the mock-up pipe and step pipe were rotated in the simulation and laboratory trials. Two exposure geometries were tested:

1st A large detector is used which covers the tangential projection of wall and the pipe center (see Fig. 6 left).
2nd A small detector is used which covers the tangential projection of the wall only (see Fig. 6 right).

**FIGURE 5.** Tangential radiograph of a step pipe with flat bottom holes and scheme of a possible mobile inspection setup

The 2nd exposure geometry, small detector, corresponds to the real available detector size. No digital detector arrays (DDA) are in use with a larger size than 400 x 400 mm². Figure 7 shows the measurement set up. A betatron with a potential of 7.5 MV was used to permit the tangential penetration of the test pipe of 3 m length and 327 mm outer diameter. See also the graph in figure 2 for energy selection. The test pipe was positioned on a turntable and secured by a chain and a crane to avoid the risk of a fall. The electronics of the detector (XRD 1621 AN16) were shielded by 25 mm of tungsten. The pipe was positioned for tangential projection of one wall. Both walls could not be projected simultaneously.

The reconstruction was performed with VGStudio MAX 2.2.6, and exclusively with half beam projections whereby the central beam through the pipe center was outside of the detector area. In the laboratory the complete projections (full beam) could be measured if the detector is shifted to obtain a projection of the complete pipe diameter. The stitched image is equivalent to a projection taken with a larger effective detector size. This was not considered for subsea applications because the additional time required for the full beam geometry would reduce the potential for mobile and time effective CT. Figure 8a shows the result of the surface reconstruction. The wall thickness is color coded. The nominal wall thickness is coded in green. The weld root and cap is coded in blue since the thickness exceeds the nominal thickness of the base material. Corrosion is coded in red since the remaining wall thickness falls under the acceptable size. Figure 8b presents a reconstructed cross section at a selected position. The corrosion depth almost reaches the full wall thickness and the pipe needs to be replaced.
FIGURE 6. Schemes of mobile pipe inspection with large and small DDA. Cone artefacts appear if the radiographic projection does not cover the central pipe area.

FIGURE 7. Radiographic inspection setup in BAM HEXYLab for half beam CT of a test pipe of 3 m length and 327 mm outer diameter, with different artificial corrosion areas in the 24 mm thick steel wall and a weight of about 350 kg.
Corrosion in thick walled and large diameter pipes can be detected and measured with high energy radiography in tangential inspection mode (T RT). A CT based transform was applied for reduction of the SDD in tangential inspection mode. The accuracy of wall thickness measurements is higher for tangential inspection than for double wall inspection (DW RT). The mobile CT radiation geometry and surface reconstruction for step pipes was optimized by modelling with the software package aRTist.

A 7.5 MV betatron was used for CT measurement of a pipe sample with 327 mm outer diameter, 24 mm wall thickness and 2 m length in tangential inspection mode. The pipe was mounted on a turntable and inspected with a 40x40 cm DDA in asymmetric projection mode over 360° and acquiring about one half of the radiographic pipe projections (half beam geometry). The same procedure can be applied for wall thickness measurements in field using a C-arm based mobile manipulation system followed by tomographic volume reconstruction (3D). All corrosion types can be visualized and their dimensions can be measured.

ACKNOWLEDGEMENT

We thank B. Redmer and U. Zscherpel for valuable discussions and support. We thank BP for support of the project.

REFERENCES


