13th IMEKO TC10 Workshop on Technical Diagnostics
Advanced measurement tools in technical diagnostics for systems' reliability and safety
June 26-27, 2014, Warsaw, Poland

Thickness measurements of corroded district heating pipelines with utilization of Structured Light Technique.

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Abstract- In this paper we present application of the Structured Light Illumination method for measurements of thickness of corroded district heating pipelines. The presented methodology allowed determination of the depth of pitting corrosion centres on both inner and outer sides and in each point of the pipe. Obtained data was consequently utilized for statistical analysis of corrosion growth process. The conclusions about the pitting corrosion process, as well as possible development of the presented methodology are discussed in conclusions.

I. Introduction

Corrosion is an issue in almost all fields of industry. Despite the increasingly sophisticated methods of anti-corrosion protection, corrosion defects, nicks or cavities are one of the most common causes of failures or limitations of exploitation parameters of devices or installations [1]. District heating network is exposed to electrochemical corrosion processes on both sides of the pipe. The inner corrosion is caused by the medium that transmits heat (ie. water flawing inside the pipeline) and the outer corrosion occurs due to ground waters, which leak into the outer side of the pipeline. Corrosion processes lead to material losses and consequently alter mechanical properties of pipelines. A general corrosion is characterized by relatively uniform distribution of material loss on the surface and slow pace of growth and thus it can be easily studied or diagnosed [2]. Much bigger effort is required when dealing with a pitting corrosion as distribution of defects in that case is non-uniform on the surface [2]. The problem is especially emphasised in district heating pipelines, where a pitting corrosion can growth thousand times faster than a general corrosion.

Evaluation of the material losses caused by corrosion processes is currently carried out by visual inspection or by measurements of a wall thickness (ie. with ultrasounds techniques [3]). By visual inspection it is not possible to identify the reasons of failure: if corrosion processes lead to leakage, crack and if they occurred on inner or outer side of the pipeline. The conventional ultrasound technique, on the other hand, enables pointwise measurement of the thickness and thus its usability is limited. In most cases it is required to find points with the deepest cavity (the biggest material loss). Data acquired with conventional ultrasound technique provides rather information about averaged corrosion depth than the actual state of the pipe. More advanced, scanning techniques provide full-field information, but the measurement process is hindered in the case of pipes with small diameters.

The main aim of the work was to introduce an alternative method for assessment of impact of corrosion processes on district heating pipelines, by measurements of residual wall thickness of pipes fragments.

A good alternative for currently used techniques are optical methods of measurements, which combine full-field information with relatively simple and automatic measurement process. Full-field optical methods of measurements are also scalable and can be used for small as well as for bigger objects. In recent years, applicability of optical methods of measurements in different fields of industry is growing. Example applications of Digital Image Correlation method, Structured Light method or thermography can be found in scientific literature [4,5,6,7]. The mentioned applications also concern heat and power generating industry. Among the mentioned methods, the most suitable for full-field shape measurements with good accuracy (which is the case in presented paper) is structured light method.

II. Methodology

The aim of the experiment was to determine the thickness of corroded pipes over their entire surface. Each pipe was cut in half along its axis before the experiment. The measurement of each samples was separated into two stages. During the first stage, a sample was scanned using the structured light method in order to obtain a 3D shape. The second stage of the measurement involved a numerical processing of the obtained point cloud.

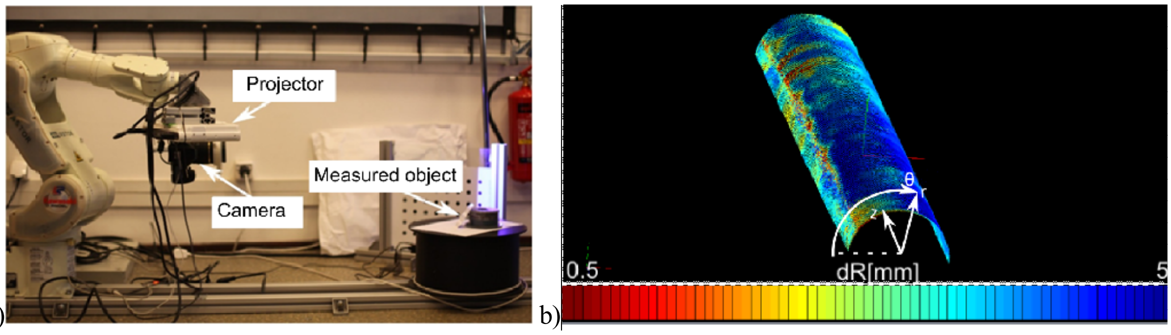

Figure 1 a) Typical structured light measurement system, b) point cloud of the pipe sample in cylindrical coordinate system; in colours value of 'R' coordinate is coded.

A. Structured Light Method

Structured light illumination methods are a wide group of methods for 3D shape measurements of objects [8]. In principle a measured 3D object is illuminated with a computer-generated pattern by a digital projector. The linear fringe pattern, projected on the object, appears distorted due to the shape of the object. A digital camera records a sequence of distorted patterns and in a course of data analysis, depth is retrieved. In the most common technique a combination of a set of phase shifted, sinusoidal fringes and Gray codes are projected on the measured object. This combination enables measurements of step-like objects. Important technical parameters of measuring devices (projector and camera) are: resolution (defines accuracy of measurements), contrast (influences the signal-to-noise ratio), depth of focus (defines dimensions of the measurement volume and linearity of greyscale). The projector and the detector have to be rigidly connected and the measured object need to be present in the field of views of both devices. Example measurement setup is presented in Figure 1a.
In the case of presented measurements, in order to obtain full, 3-D representation of the measured object, it was necessary to perform a series of measurements from different directions (at least 8). In order to merge point clouds obtained from each measurement, a set of spherical markers has been applied to each sample. The final output of each measurement is a point cloud, which represented the sample (see Figure 1b). The basic accuracy of the system used for the measurements was *0.1mm* in the *0.5m x 0.5m* field of view.

B. Point cloud processing

In the second stage of measurements, point clouds were subjected to numerical processing. Procedure for each sample was exactly the same. In the first step, a cylinder has been fitted to the obtained point cloud using an iterative algorithm [9]. The axis of the fitted cylinder has been selected as the axis of the new, cylindrical coordinate system (Figure 1b). Next, inner and outer surfaces of the sample have been separated from each other. The thickness in each point of the sample has been calculated as a distance between points on inner and outer surface of the point cloud (difference of R coordinate between points with the same Z and ϕ coordinates). Data processing path is presented schematically in Figure 2.

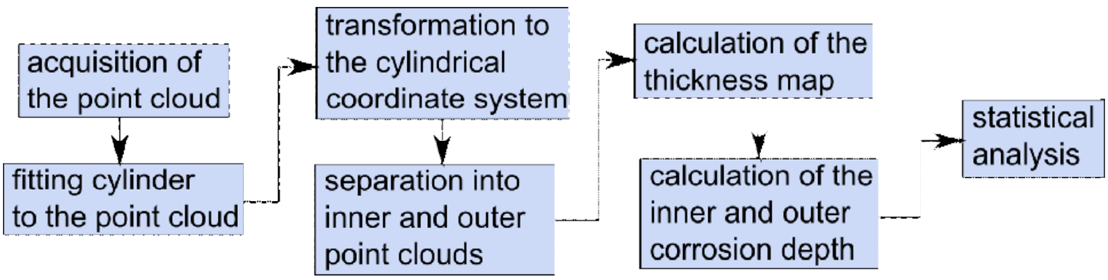

Figure 2 Flow chart of the point cloud processing.

Obtained thickness maps of all samples have been consequently used for statistical analysis of the corrosion process.

III. Example measurement results

In Figure 3 the photo of outer side of upper and lower parts of the measured sample are presented. The nominal thickness of the sample (in the healthy part of the sample) was 3.6mm. In Figure 3 one can observe perforation of the lower part of the pipe. Results of statistical analysis of the sample are presented in Table 1. The inner and outer corrosion values have been calculated as differences between nominal inner and outer radius respectively. The nominal radii have been taken from a healthy part of the sample.

Figure 3 Outer side of the upper and lower part of the pipe; red circle indicates perforation of the sample.

Table 1 Results of statistical analysis of thickness of the sample

	Upper half	Lower half
Maximum thickness (mm)	3.60	3.60
Average thickness (mm)	3.16	3.08
Average loss	12%	14%
Minimum thickness (mm)	1.97	0
Maximum loss	45%	100%
90% of surface has thickness > (mm)	2.76	2.51
95% of surface has thickness > (mm)	2.63	2.29

Data in Table 1 indicates, that the lower part of the sample is corroded more than the upper part. It also shows, that perforation occurred in the lower part of the sample.
In the next step, results of thickness measurements have been presented in thickness maps. In order to facilitate interpretation, the results are visualised as a cylindrical surface mapped onto a plane (Fig. 4). Magenta colour in the presented maps indicates points which were masked out and removed from statistical analysis. In these points, the measured thickness exceed the assumed nominal thickness of the sample. It could be caused by measurement errors or artifacts on the surface of the measured sample.

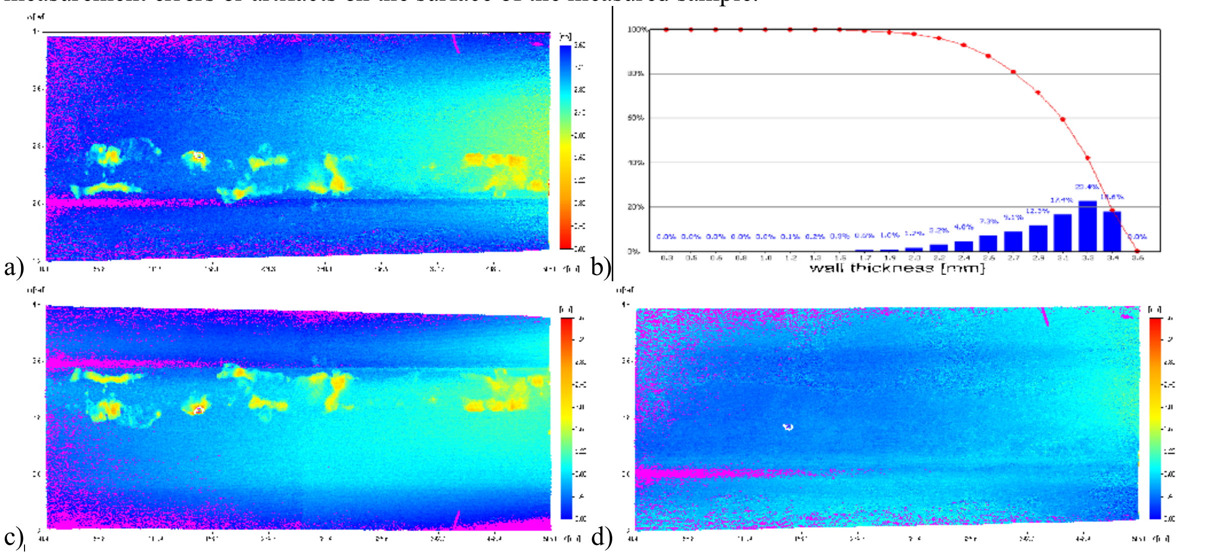

Figure 4 a) Thickness map of the measured object transformed into cylindrical coordinates, b) histogram of the thickness, c) inner corrosion map in cylindrical coordinates and d) outer corrosion map in cylindrical coordinates.

In presented thickness maps, one can observe how and in which regions the corrosion process growth the most. The corrosion centres are located along the axis on the inner surface of the measured sample (Fig. 4a). A small perforation has been detected in the central part of the sample.

IV. Conclusions

It has been shown, the structured light method is feasible for analysis of corrosion process in district heating pipelines. Total of 18 samples have been studied. All samples came from the Warsaw district-heating network. The diameters of measured samples varied from DN 50 to DN 1100 [mm] and nominal wall thickness varied from 3.6mm to 11mm. The exploitation age of the samples varied from 2 to 50 years. The samples were collected during the failure recovery process. The results have been used for qualitatively assessment of the corrosion process, but also some general conclusions have been drawn:

- It has been confirmed that in 90% of the measured samples, a pitting corrosion on the outer side of a pipe was a main caused of a failure.
- In samples of pipelines placed in service before 1995, pitting corrosion of the inner side of the pipes was also observed. This was caused by a poor quality of water in those years.

- Optical measurements showed severe internal corrosion localised along the axis of the pipe in the area of longitudinal seam. This indicates manufacturing faults.

In respect to the measurement method it has to be indicated that local deformations of the samples could distort the obtained results. This is because a cylinder is fitted to all data points obtained from the scanning. One of the main tasks in the future works is to develop a filtration method, which would automatically remove deformed regions of the sample from statistical analysis. It can be carried out with well-known numerical tools such as RANSAC algorithm.

In the next step it is planned to utilize results of precise measurements of depths of corrosion centres for estimation of lifetime of the pipelines. This can be done on the basis of guidelines developed by American Society of Mechanical Engineers (ASME) [10] and appropriate statistical tools.

Acknowledgments

Financial support from the statutory funds of Warsaw University of Technology and support of the employees of the Heat-Tech Center Dalkia Warszawa S.A. in planning the measurements are gratefully acknowledged.

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