Institut für Mathematik
Fakultät II – Mathematik und Naturwissenschaften
Technische Universität Berlin

Internship Report

MSc Scientific Computing

Institution: Federal Institute for Materials Research and Testing (BAM)

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Contents

1 BAM

1.1 Overview

The Bundesanstalt für Materialforschung und -prüfung (BAM) is a senior scientific and technical Federal institute with responsibility to the Federal Ministry for Economic Affairs and Climate Action. It tests, researches and advises to protect people, the environment and material goods. BAM's roles and responsibilities include:

- further development of safety in technology and chemistry
- implementation and evaluation of physical and chemical tests of materials and facilities, including the preparation of reference processes and reference materials
- promotion of knowledge and technology transfer within the BAM's areas of work
- cooperation in the development of statutory regulations, for example concerning the setting of safety standards and limits
- advice to the Federal Government, industry, and national and international organisations in the fields of material technology and chemistry.

1.2 Division 8.4: Acoustic and Electromagnetic Methods

The use of acoustic and electromagnetic methods in the development, validation and application of non-destructive testing methods (NDT) as well as the human factor analysis in NDT constitutes the focus of the Acoustic and Electromagnetic Methods division. We detect surface-level and hidden inconsistencies, defects and material changes before damage develops. Studies are conducted in the laboratory, in the production facility, or while components and machinery are in operation. The current main projects include:

- Mechanized and imaging ultrasonic testing
  - using phased arrays in contact testing
  - high-resolution in immersion testing
  - contactless using airborne ultrasonic waves and laser
- Use of guided waves for structural health monitoring (SHM)
- Mechanised and imaging electromagnetic testing with Eddy current and magnetic flux leakage
- Simulation and modelling of test assignments

Figure 1: BAM site in Lichterfelde, Berlin

2 The Project: MRO 2.0

2.1 Overview

The aim of the project MRO 2.0 - Maintenance, Repair Overhaul is to develop new technologies for maintenance and repair activities which simultaneously mean an upgrade, i.e. an improvement in the properties of the component. Improved properties in turn lead to higher efficiency and lower emissions.

2.2 The role of Ultrasonic Testing

The method explored to create 3D models involves submerging a gas turbine blade in water and utilizing an ultrasonic robot arm to perform measurements at predetermined points. The robot follows a preprogrammed path to ensure comprehensive coverage of the blade's surface at right angles. Ultrasonic waves emitted by the robot's transducers penetrate the blade, interact with internal features, and generate signals. These signals are subsequently processed using Time-of-Flight Diffraction (TOFD) and Total Focusing Method (TFM) techniques to convert them into ultrasonic images. To extract the surface location information, handcrafted image processing techniques are applied. Finally, a coordinate transformation is employed to combine the surfaces of each ultrasonic image, resulting in the creation of a three-dimensional model of the turbine blade as a point cloud. This methodology provides a systematic approach for ultrasonic imaging, facilitating the assessment of structural integrity and maintenance practices of gas turbine blades.

2.3 My responsibility

Development of algorithms for feature recognition from ultrasonic test data:

- Extraction of 2D surface contours from ultrasound reconstruction images
- Composition of the surface contours in 3D as point clouds using Euler angles
- Evaluation of the quality of the algorithms by comparison with reference data sets
- Development of evaluation algorithms for certain properties of the reconstructed surfaces (e.g. inclination)
- Investigating the feasibility of deep learning in this context

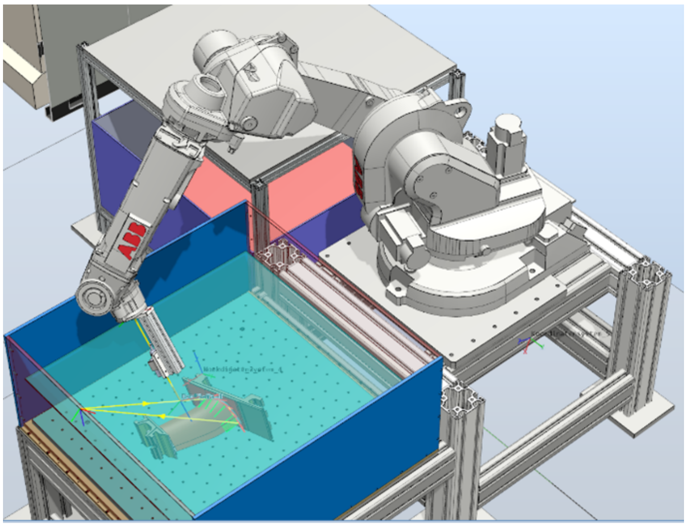

Figure 2: The experimental setup

3 My Contributions

Provided with a series of ultrasound images representing the inner and outer surface of a gas tubrine blade, I developed specialized image processing algorithms to extract the signal from the noise, using reference optical scans to check errors.

3.1 Outer Surface Extraction

After calculation of the first stage images, the outer surface's position and shape are extracted. For that, an individual algorithm has been developed using different image processing tools. The algorithm takes the TFM images and the pixel's x and z coordinates as input and, for each image, returns a point cloud with surface points identified. The algorithm involves the following steps for each TFM image associated to a measurement position:

- A K-means clustering is performed on the image to identify the regions with the highest probability of containing the surface.
- A cubic polynomial is fit to the z-coordinates of the maximum amplitude points for each x-coordinate associated to the highest mean cluster.

- The polynomial fit is then evaluated for the pixel's x-values to provide a local point cloud in the probe coordinate system.
- Additionally, absolute amplitude values are extracted with help of the z-direction envelope of the image.

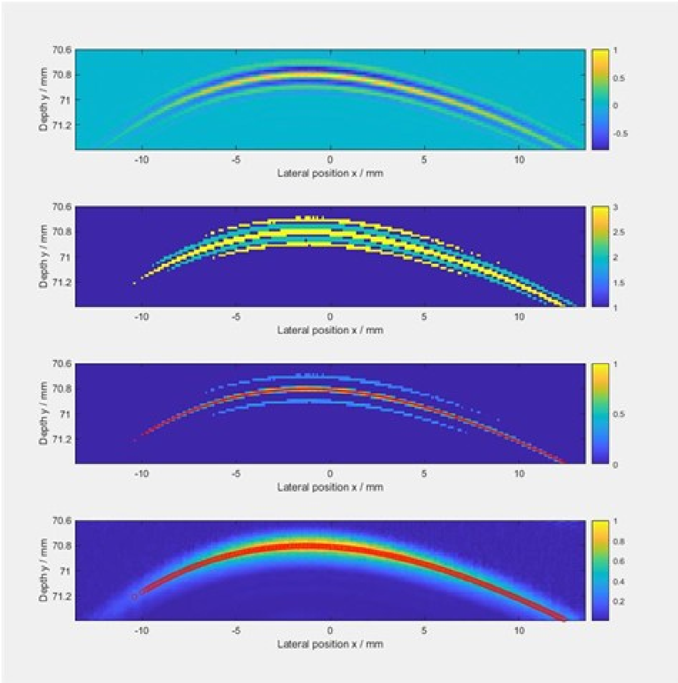

Figure 3: Surface extraction process for example image: a) raw TFM image b) mask obtained by k-means clustering with three regions c) masked and normalized TFM image with cubic fit at column maxima (red line) d) z-direction envelope of TFM image with amplitudes evaluated at positions of cubic fit (red circles)

3.2 Inner Surface Extraction

On the second set of TFM images, once again a surface identification is performed, this time for the inner surface. Since the outer and inner surfaces have different characteristics, a different algorithm must be used. The back wall identification algorithm involves the following steps:

- A K-means clustering is used on the TFM image's z-direction envelope (Figure 4 a) to identify the regions with the highest probability of containing a back wall surface (Figure 4 b).
- A Gaussian Process Regression (GPR) is performed to fit a piecewise-Gaussian curve to the z-coordinate of the minimum amplitude point for each column of the TFM image (Figure 4 c). Choosing the minimum instead of the maximum amplitude is based on the fact that the back wall echo is always inverted in phase.
- Finally, the GPR curve is masked with the k-means regions selected in the first step and the coordinates evaluated to return a back wall point cloud (Figure 4 d). To avoid extracting outliers, points, that deviate from a moving average more than a certain amount are filtered out.

3.3 Transformation to 3D

After all of the local surfaces have been identified, they are transformed into a 3D global coordinate system and the wall thickness and structure are analyzed. This includes visual inspection and comparison with reference optical scans.

4 Results and Further Work

In this project, we have shown how an automated ultrasonic NDT system for the evaluation of wall thickness for complex-shaped parts can be realized. In summary, the possibilities and flexibility of a robot arm were combined with modern ultrasound imaging and data processing methods to achieve a locally resolved mapping of the tested part's wall thickness. Compared to the manual, pointwise method frequently used in turbine blade and vane thickness evaluation, this is a big step towards higher efficiency and reliability, which is important as digitalized testing is the basis of modern maintenance processes. On two turbine vanes, a total of 20 scans were performed, five for the

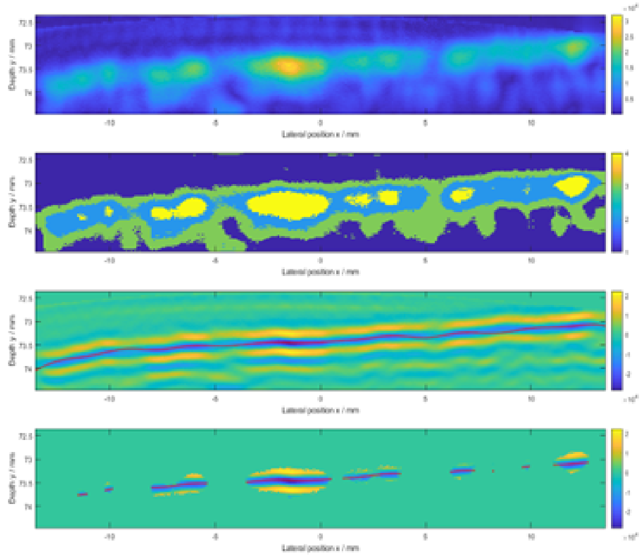

Figure 4: Inner surface extraction process for example image: a) z-direction envelope of second-stage TFM image b) mask obtained by k-means clustering of a) with four regions c) raw second-stage TFM image with Gaussian process regression fit (red line) for column minima d) image and fit from c), masked with highest region from b)

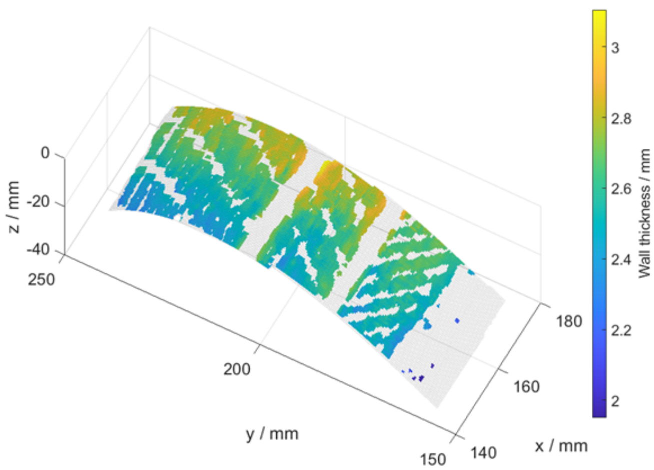

Figure 5: Representation of wall thickness mapping

suction and pressure side each. From these scans, outer and inner geometries have been reconstructed and the wall thickness values determined locally. The reconstructed results have been compared to reference data in alignment and accuracy of determined wall thickness. The constructed wall thickness values deviated from the reference wall thicknesses between 0.05 mm and 0.1 mm on average, with a standard deviation of 0.06 mm to 0.16 mm. In the future, we hope to develop faster TFM algorithms as this is the main computational cost of the process and develop point cloud processing algorithms to analyze the surfaces directly in 3D.