# MIDPOINT DETECTION AND MESH OPTIMISATION FOR FORWARD EDDY CURRENT TOMOGRAPHY TRANSFORMATION


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## 1. Introduction

Eddy current tomography is under heavy development method for 3 – dimensional non-destructive testing of ferromagnetic elements [1, 2, 3]. It is based on law of magnetic induction, where in tested object eddy current are inducted by exciting coil. By Lenz law opposite magnetic field is created by eddy currents, thus, depending on eddy current distribution in tested element, disturbances on magnetic flux density occur. Those disturbances can be measured by many sensors, such as SQID sensors [4], fluxgate sensors [5], Hall effect based sensors [6] or by simple inductive coil. Utilisation of inductive coil allows measurement of phase shift between exciting and measured signal as well as value of inducted signal amplitude.

Previously presented eddy current tomography setup for cylindrical elements [2] is based on two-coil system, where tested element is linearly moved between coil and fully rotated around its axis in each linear step. During measurement, data about signal amplitude and phase shift are simultaneously measured for each position of tested element. Exemplary measurement results are presented in figure 1.

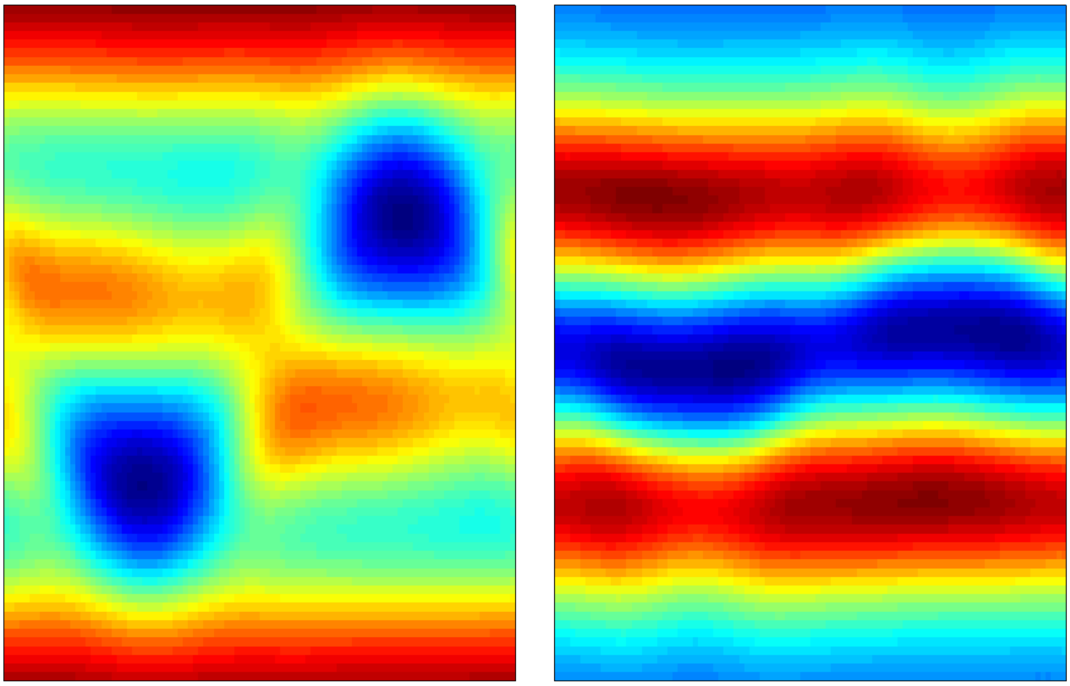

Fig.1: *Exemplary results from eddy current tomography setup. Amplitude data (right) and phase data (left) are both presented in linear movement function (y axis) and rotation (x axis)*

After measurements shape of tested element is reconstructed (inverse tomography transformation). This issue is the biggest problem in development of eddy current tomography. Many methods of inverse transformation have been previously reported – most of them were basing on edge finite-element method [3,7]. Newly proposed approach is also based on finite-element method but in different way. Effective ways of FEM -based forward tomography transformation (simulation of measurement results with known shape of tested element) was previously reported [8]. On that base inverse transformation can be applied by conducting many steps of forward transformation for different simulated object shape and comparison with measurement results. This approach requires execution of many forward transformations, so in order to achieve satisfactory results in acceptable time some optimisation of transformation is required.

Previously mentioned test stand provides results for 87 steps of linear movement and 100 rotation steps for each linear position which requires nearly 9000 calculations of forward transformation. This results with considerable computation time – even with utilization of parallel computing on 48 core computational station. Despite that some unacceptable numerical noises were discovered [8]. In this paper method based on midpoint detection and mesh optimisation for overcoming those problems is presented.

## 2. Measurement results analyse – midpoint

As presented in figure 1 results of phase shift measurement and amplitude measurement differ from each other. On the other hand some kind of symmetry with respect to the point is clearly visible in both graphs. This results from tomography setup geometry – tested object is moved between exiting and measurement coils and is rotated around its axis. In situation as presented on figure 2 objects influence on magnetic field disturbances as well as measured signals should be identical.

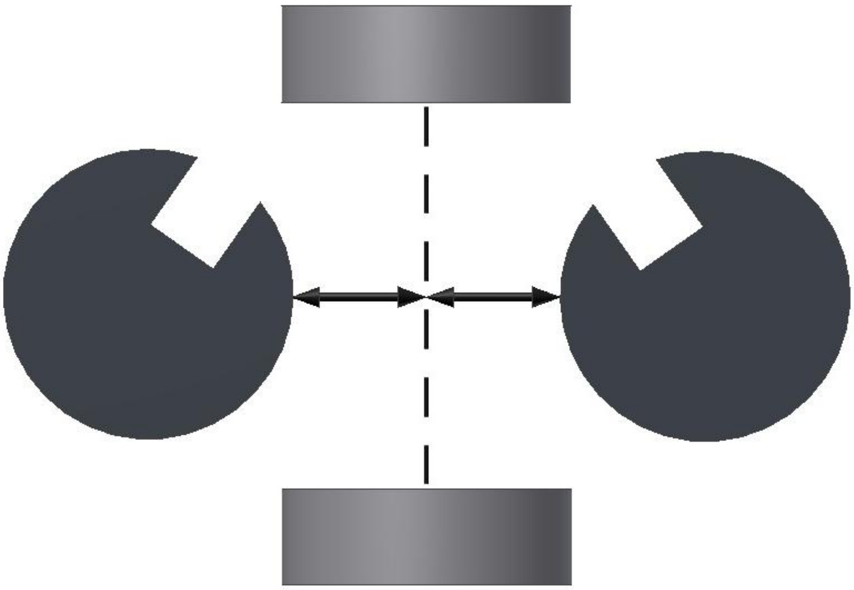

Fig.2: *Visual explanation of results symmetry. Tested element is presented in two position. Second position is reflection of first with respect to the coils main axis.*

As one can see in figure 2 results should be linearly symmetrical, but results presented in figure 1 are obviously symmetrical with respect to the point. This results from methodology of results presentation, where x and y axes represent respectively element rotation and linear movement.

As presented in figure 2 the same measurement results are acquired when both linear and rotation position are symmetrical to some axes. Intersection of those axes is the midpoint of measurement results.

That knowledge combined with proper identification of the midpoint can reduce twice required number of calculations. Since the results are symmetrical with respect to the point, there is no need for calculation of the reflected data.

## 3. Measurement results analyse – mesh optimisation

As mentioned before [1, 8] steps between measurement points are short. Also measurement data as presented in figure 1 shows, only in few point high values of local derivatives occur. Thus satisfactory data can be numerically interpolated only from few points. This results with significantly lower computation time – when combined with proper midpoint detection, forward tomography transformation requires calculations only in 80 points and proper data interpolation. This results with more than 100 faster calculations. Despite that, influence of previously mentioned problem with numerical noise during simulation [8] can be worked around.

## 4. Algorithm description

For midpoint detection simple brute force algorithm was applied. Data were rotated around points near the half of the data array and mean square error between each rotation and original data was calculated. Point with minimal MSE is the searched midpoint. Typical value of mean square error for rotation around optimised midpoint does not exceed 0,002 for normalized input data.

For optimisation of point selection for data interpolation discretely linear algorithm was applied. Firstly initial array of indexes is randomly generated. Corresponding points from measurement data are selected and results are interpolated by two-dimensional spline interpolation algorithm. Then square error between original and interpolated data is calculated as a quality factor. Afterwards in separate steps each index is modified (by increment or decrement of its numerical value) and operations of interpolation and quality calculation occur. Algorithm executes until single change of mesh provides better data reconstruction. This results with a risk associated with getting stuck inside local minimum and not founding globally optimal results. To minimalize that risk algorithm executes 20 times, with different (randomly generated) initial state. Algorithm is implemented in open software Octave and its computation time on typical PC computer is around 15 minutes.

## 5. Exemplary results discussion

Exemplary results are presented in figure 3. On left part measurement results trimmed to midpoint are presented. Mean square error between data reflected around the point and input measurement data equals 0,0017 which confirms proper midpoint selection.

In the central position results of mesh optimisation are presented. Results of data interpolation from optimised mesh are presented on the right. Maximal difference between interpolated and initial data equals 1,55 %, where mean square error equals 0,018 %.

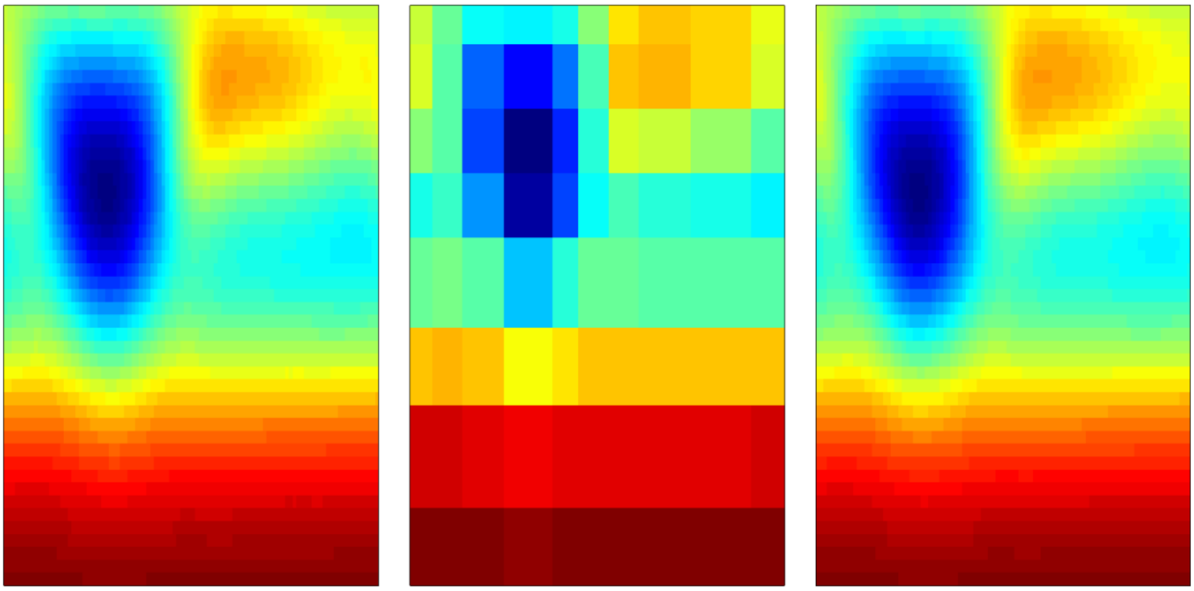

Fig.3: *Exemplary results of described algorithm. Comparison of input data (left), points optimised for interpolation (centre) and interpolated results (right) present high efficiency of data reconstruction.*

## 6. Conclusion

Presented methods of optimisation provide extremely effective reduction of computation time required for FEM – based forward eddy current tomography transformation. Thereby completely new idea for inverse tomography transformation can be applied with acceptable calculation time.

This will allow further development of environmental friendly, effective technique for non-destructive testing of ferromagnetic materials.

**References:**


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