

## Assessing the Influence of Crack Geometry on Inductive Thermography Response in Ferromagnetic Steel

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### Abstract

Inductive thermography is used to investigate surface and near-surface cracks through electromagnetic excitation and infrared thermal measurements. This work focuses on crack characterization, analysing how crack geometry affect the thermal response and the extracted thermographic features, with particular attention to phase signals obtained through FFT-based lock-in processing.

Repeated experiments were carried out in different labs under different excitation and infrared camera conditions on calibration samples containing simulated open cracks with varying geometries, in order to evaluate the robustness of the extracted thermal features for crack characterization. In parallel, finite element simulations (FEM) were performed to support the interpretation of the experimental thermal behaviour.

### 1. Introduction

In recent years, inductive thermography has become a powerful non-destructive technique for the inspection of conductive materials and the detection of surface and near-surface cracks [1-3]. Ferromagnetic steels are particularly suitable for this method due to their high magnetic permeability, which enhances the interaction between the induced eddy currents and the defect region. The presence of an open crack locally modifies the current distribution and produces a characteristic thermal response that can be measured by an infrared camera [4].

Although several studies have demonstrated the effectiveness of inductive thermography for crack detection [1-8], the characterisation of crack geometry remains a more challenging task, mainly discussed in terms of simulations. It is in fact a challenge to reproduce a crack with a particular and complex geometry as in case of real mechanical components, and so have master specimens for calibration [4]. In particular, the influence of crack depth and inclination angle on the measured thermal response must be better understood in order to distinguish between different defect configurations. In fact, usually, the thermographic evaluation of cracks is performed by analysing the profile extracted along the centre of the defect, where parameters such as phase contrast and related asymmetry are commonly used for crack detection and assessment [1-5]. For this reason, this work focuses on the extraction and analysis of novel specific thermal features sensitive to crack geometry, with particular attention to phase information obtained through FFT-based lock-in processing [2].

Experimental tests were carried out on calibration samples containing open cracks with different depths and inclination angles. Repeated measurements were performed using two different experimental setups, varying both excitation conditions and infrared camera configurations, in order to evaluate the robustness and repeatability of the extracted thermal features. Finite element simulations were also performed to support the interpretation of the experimental results and to extend the investigated crack configurations. The combined experimental and numerical approach aims to improve the understanding of the relationship between open crack geometry and thermographic response, contributing to a more reliable characterisation of defects by inductive thermography.

### 2. Methods and results

A S355J2 calibration specimen manufactured according to DIN 54193:2018-02 was investigated using two different inductive thermography setups, referred to as the Bari and Leoben configurations. The specimen contains open EDM cracks 10 mm long with two different depths (0.5 mm and 1 mm) and several inclination angles (75°, 60°, 45°, 15°), aimed at analysing the influence of crack geometry on the thermographic response.

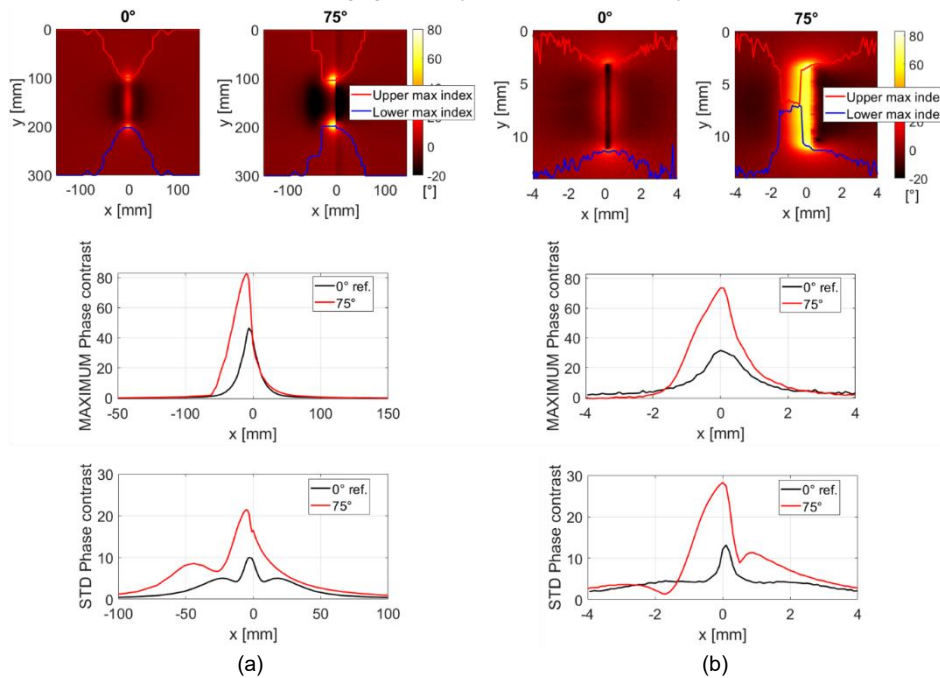
After a preliminary experimental campaign that employed different coil geometries and excitation modalities, including pulsed and lock-in thermography with different pulse duration, both setups employed Helmholtz coils and a lock-in excitation based on three consecutive pulses, each with an excitation duration of 200 ms. The Bari setup operated at 200 kHz and 4.2 kW using a FLIR X6540sc MWIR camera at 250 Hz, while the Leoben setup used 140



kHz and 8 kW with a MWIR IrCam Velox 1310SM camera with a frame rate of 190 Hz. In both configurations a spatial resolution of about 0.1 mm/pixels has been reached.

The phase signals obtained through FFT-based lock-in processing were analysed to evaluate the sensitivity and robustness of the extracted thermal features with respect to crack depth and inclination angle under different experimental conditions. Finite element simulations (FEM) already validated in [3] in case of ferromagnetic steel were also performed changing the boundary conditions, excitation parameters, specimen and crack geometry to support the interpretation of the experimental results and extracted thermal features sensitive to the crack morphology.

Both numerical and experimental phase maps were processed using the same feature-extraction procedure. After subtracting a reference value obtained from a sound region, phase-contrast maps were generated and the 75° crack configuration was compared with the 0° reference. Maximum phase contrast values were extracted separately from the upper and lower regions of the images to identify the thermal tips around the crack. The results show that crack inclination significantly affects the phase-contrast distribution: while the 0° crack produces a nearly symmetric response, the 75° crack generates a higher and more asymmetric signal with displaced thermal tips. This trend is observed in both simulations and experiments, although the experimental results exhibit a stronger asymmetry and higher phase-signal variability. The discrepancies are mainly attributed to the simplified representation of crack opening, geometry, and local boundary conditions in the FEM model.



**Figure 1.** Comparison between FEM (a) and experimental (b) phase-contrast results for angle cracks (0° ref. vs 75°).

## Conclusions and outlooks

The results demonstrate that crack inclination significantly influences the phase-contrast distribution in inductive thermography. Compared with the 0° reference, the 75° crack produces a more asymmetric and spatially distributed response. The extracted features, particularly maximum phase contrast and profile standard deviation, proved sensitive to crack orientation and showed consistent trends across different experimental setups. Overall, the study confirms the robustness of phase-based thermal features for crack characterization. Future work will extend the analysis to additional crack angles and depths to develop quantitative indicators for a more objective and reliable assessment of open cracks.

## References

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