Article

# Using square wave inductive thermography techniques to monitor the dynamic growth of cracks in steel welded structures

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**Abstract:** Monitoring crack growth is essential for maintaining steel structures subjected to cyclic loading, such as bridges, cranes, offshore platforms, and wind energy towers. A reliable crack detection method ensures the timely identification of crack initiation and propagation in critical structural components, allowing for necessary repairs or restorations before they cause service interruptions, accidents, or structural failures. This paper presents a real-time crack detection system based on inductive thermography to monitor crack growth in an SM490 steel welded specimen under cyclic loading. The system operates by generating eddy currents, which induce localized heating at the crack tips. This temperature increase is captured using an infrared (IR) camera, and the analysis of IR images enables precise identification of crack location and growth in real time. Additionally, the system is highly efficient, with a low power consumption of only 200 W, making it a practical and effective solution for on-site crack monitoring. These characteristics emphasize its strong potential for non-destructive testing (NDT) applications.

**Keywords:** Crack growth; Crack length; Crack detection; Monitoring; Real time; Active thermography

## 1. Introduction

Detecting cracks in steel structures subjected to cyclic loading is critical for maintenance and safety, especially to prevent fatigue-related failures that initiate and propagate through crack growth. Traditional non-destructive testing (NDT) methods face challenges when applied to large steel structures like bridges, offshore structures or wind energy towers, such as limited accessibility, environmental conditions, and the presence of protective coatings.

A NDT method based on infrared active thermography, introduces an external heating source to perform crack detection. Particularly, in this research, the authors use induction heating to generate eddy currents in the welded steel specimen under study. Cracks interfere with eddy currents flow and heat distribution, making them visible in infrared images. This technique, however, traditionally requires large power supplies and cooling systems, and generates high temperatures in the coil, making it unsuitable for large or elevated structures.

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To overcome these limitations, the authors developed a miniaturized active thermography system using a square wave AC voltage generated from DC via the S2S[1] Hi Speed Wave Induction Unit, see Figure 1. This new setup reduces energy consumption and suppresses coil temperature rise, enhancing usability in practical field applications [1]. The system has been already tested to detect crack in different structural steel specimens and to compare the experimental results with FEM simulations, see [2].

In conclusion, the square wave induction-based thermography system effectively detects and monitors surface cracks in steel, even beneath coatings. It offers a compact, energy-efficient alternative suitable for field application in structural health monitoring.

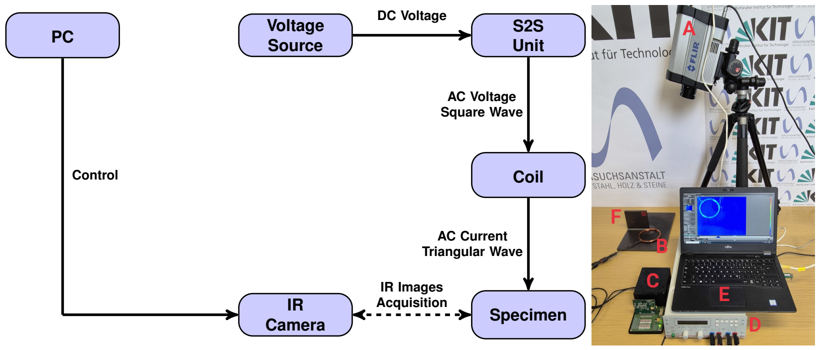


**Figure 1.** Experimental setup. (**a**)Structure. (**b**) Equipment. A: IR camera, B: coil, C: S2S unit, D: voltage supply, E: PC and F: steel specimen.

## 2. Experimental methodology

To assess the effectiveness of the proposed NDT system for real-time monitoring of crack growth, a steel welded specimen with an anti-corrosive coating was subjected to cyclic loading. This process aimed to initiate cracks at the weld toe. In this study, crack initiation encompasses both nucleation and micro-crack propagation phases, as referenced in [3]. Following initiation, cyclic loading was continued to promote crack growth along the horizontal plate on both sides of the weld toe. At predefined cycle intervals, the loading was halted to allow for crack detection and length measurement using infrared (IR) imaging and microscopy.

### *2.1. Steel specimen*

In this study, an SM4902[2] steel specimen featuring a longitudinal stiffener welded with a convex fillet was tested. The region prone to fatigue crack initiation and propagation, including the weld toe, was covered with an anti-corrosion coating. To monitor the applied stress, strain gauges were installed on both sides of the specimen at the same longitudinal location as the weld toe. Additionally, black paint was applied to enhance the surface reflectivity of the specimen.

### *2.2. Cyclic loading and crack initiation and growth*

An eccentric motor was used to apply cyclic bending loads to a steel specimen, generating resonant vibrations with a stress ratio of 0 and a loading frequency of 18.1 Hz. The maximum stress reached 80 MPa, and strain gauges placed away from stress concentration zones measured the applied stress. Cracks initiated and grew along the weld toe after 30,000 cycles. Crack growth was monitored at eleven intervals, starting at 30,000 cycles and

1 Square to Shark
2 Japanese steel, whose grade is equivalent to S355J2 European steel.

continuing every 50,000 cycles from 100,000 to 550,000 cycles. IR and microscopic imaging were used to measure crack length and track crack tip positions.

## 3. Crack path and length

From the IR and microscopic images obtained during the fatigue test, the crack growth rate and length can be established.

### 3.1. IR images

The crack propagation path can be visualized by plotting the coordinates of crack tips identified in the IR images.

The growth and progression of left and right cracks are illustrated in the IR images in Figure 2. Figure 2(a) displays the final detection of the left crack, after N=550,000 cycles, with a detailed view of the crack region in Figure 2(c). Similarly, Figure 2(b) captures the final detection of the right crack, and its corresponding zoomed region in Figure 2(d). The black points indicate the detected crack tips and trace the entire crack growth path over the course of the experiment.

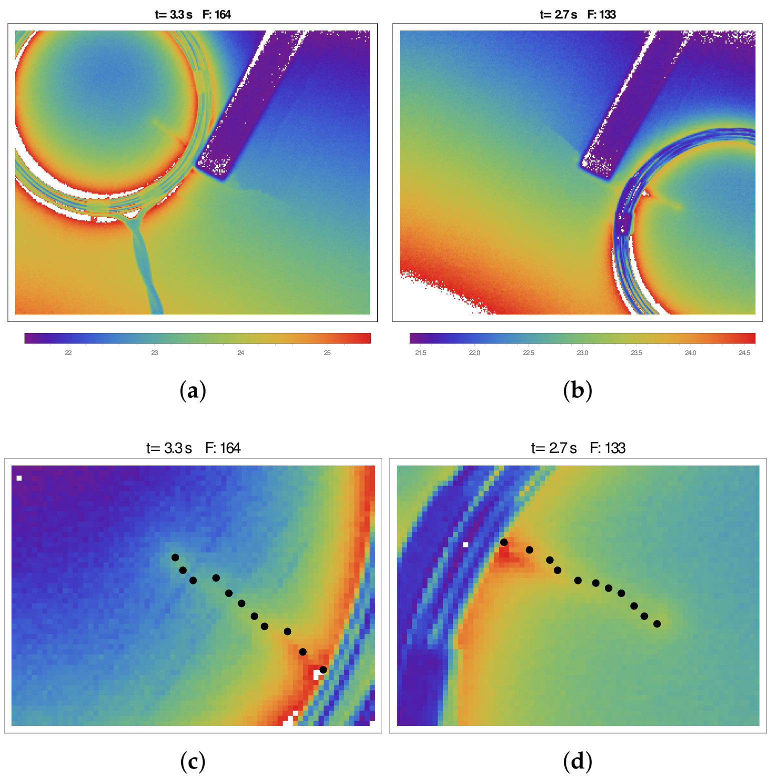


**Figure 2.** Cracks after $N = 550\,000$ loading cycles. (**a**)Left crack. (**b**) Left crack propagation. (**c**) Right crack. (**d**) Right crack propagation.

From the IR images, the crack lengths can also be estimated. Laboratory calibration determined that 79.64 pixels correspond to 40 mm, meaning one pixel is equivalent to approximately 0.502 mm.

### 3.2. Microscopic images

During the fatigue test, digital microscopic images of the cracks were captured simultaneously with the IR images, see Figure 3.

Based on these microscopic images, the left crack was measured at 17.71 mm, showing a difference of 1.61 mm compared to the length estimated from the IR images. The right crack measured 16.33 mm, differing by 1.28 mm from the IR-based estimate.

These results demonstrate that the IR method provides a reliable and significantly faster alternative for measuring crack length, with only minor discrepancies compared to microscopic measurements.

### 3.3. Crack growth rate

Using the IR images, the evolution of crack length as a function of loading cycles was calculated for both cracks and is presented in Figure 4. As shown, the growth of both cracks is nearly linear and follows a similar trajectory. Based on this observation, the crack growth rate is estimated to be approximately 3.50 mm per 100,000 cycles.

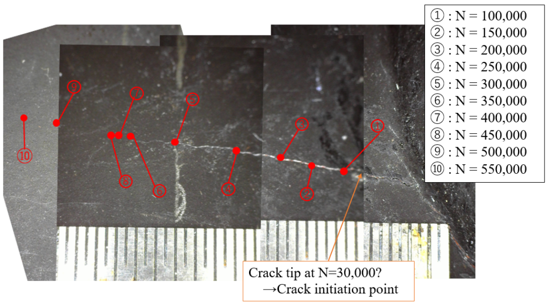


**Figure 3.** Left crack length evolution during the cyclic loading.

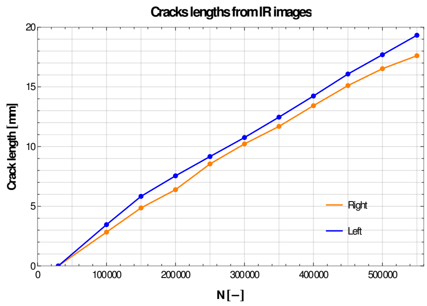


**Figure 4.** Crack length evolution of both cracks during the cyclic loading.

## 4. Conclusions

The proposed methodology offers a promising and reliable alternative for detecting cracks and monitoring their growth in steel structures subjected to cyclic loading. The results obtained are comparable to those achieved using a microscope, indicating that the system can be adapted for on-site and real-time testing

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