Ultrasound excited thermography of load bearing members used in constructional steelwork

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Abstract

In nondestructive testing of structural elements ultrasound excited thermography offers various fields of application. The most practical experience with sonic IR imaging is available in testing of CFRP or similar types of composite materials. The idea of ultrasound excitation of structural members is to generate elastic waves that propagate inside the investigated structure. In case of internal failures like cracks or delaminations there is a chance to reach a state of oscillation in which boundary faces move relatively to each other. For steel members friction and plasticity have to be considered as the most relevant dissipative effects leading to heat generation [1]. With typical noise equivalent temperature differences (NETD) of about 20 mK or lower todays cooled infrared camera systems easily detect smallest temperature variations on the component's surface and offer new possibilities of nondestructive testing. The methods were not transferred to massive steel members used in constructional steelwork so far. Tests on a 3 m long hot-rolled steel truss weighing more than 300 kg demonstrated that crack detection is possible but also showed the known problems with IR imaging of metal structures.

During ultrasound excitation of CFRP components it has been reported of standing wave patterns. This problem illustrates the following fundamental aspects of sonic IR imaging.

- Beside structural imperfections that lead to locally increased energy dissipation the damping of the base material itself is sufficient to be detectable as dissipative heat generation patterns according to the excited vibrational mode. Defect detection can be difficult or impossible if the failure's position matches a nodal point of the oscillating structure. Focussing on steel members with a thickness above 8 mm no standing wave patterns were recognized during IR imaging.

- In contrast to carbon fibre reinforced polymer components with a typical thickness of a few mm which have been often examined the success of crack detection in steel members is heavily dependent on the ultrasound excitation frequency. This is clarified by comparing thermo-acoustic spectra of samples made of CFRP and steel [2]. While the CFRP sample shows its failures nearly at the whole excitation frequency range, the steel sample's elevated thermal answer at crack locations is found only at a few narrow frequency bands. It is assumed that in case of steel structures only the excitation of eigenfrequencies leads to energy dissipation in cracked areas. The global eigenmode but especially the oscillating behaviour of the crack faces themselves is probably one of the most critical factors for an efficient crack detection using IR thermography.

The principal effects that lead to heat generation in cracks are not fully understood. The steel plate shown in figure 1 has a 15 mm long crack at the notch. It was examined using an ultrasound excitation device in the range of 15 to 25 kHz. Many frequencies were found at which the crack faces could be clearly identified by means of a cooled FLIR Phoenix IR camera. Figure 2. a) and b) show grey level images converted into colour scale in which the crack is visible at the top side and along the plate thickness. Only one single excitation frequency during a frequency sweep allowed the detection of the crack tip shown in figure 2. c). It can be assumed that in this case cyclic plasticity at the crack tip is the prevailing effect. The first aim is to identify the reasons for the principally different crack visualizations. Therefore the corresponding vibrational modes have to be identified.

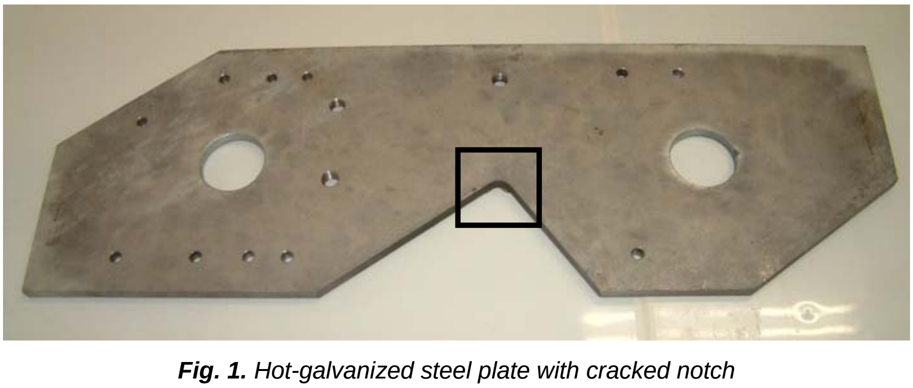

Fig. 1. *Hot-galvanized steel plate with cracked notch*

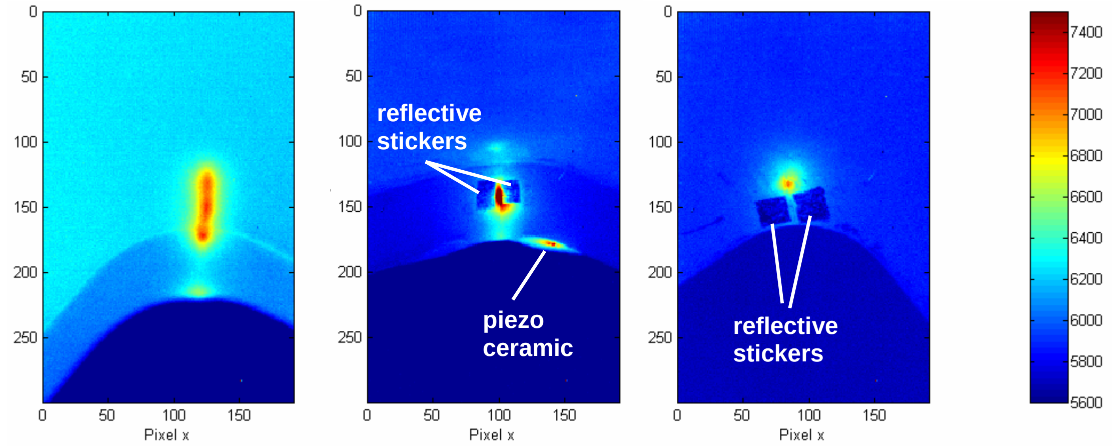

Fig. 2. *IR images taken at different excitation frequencies (grey levels in colour scale)*
a) Visible crack in top side view
b) Visible crack along thickness direction
c) Visible crack tip

A finite element modal analysis of the steel plate in figure 1. proves that all three crack modes I-III can occur in the investigated frequency range. By means of a fibre-optic interferometer used as differential measuring vibrometer the out-of-plane oscillation of the crack faces was investigated at varying excitation frequency. Therefore two points on top of the steel plate at both sides of the crack were equipped with reflective stickers to ensure a high resolution measurement of mode III movement of the crack faces. Figure 3. a) shows the velocity amplitude vs. excitation frequency plot for the right crack face in figure 2. in the range from 20-23 kHz. Frequencies leading to crack detection are marked with a dot. The differential velocity amplitude of both measured points on the plate is shown in Figure 3. b).

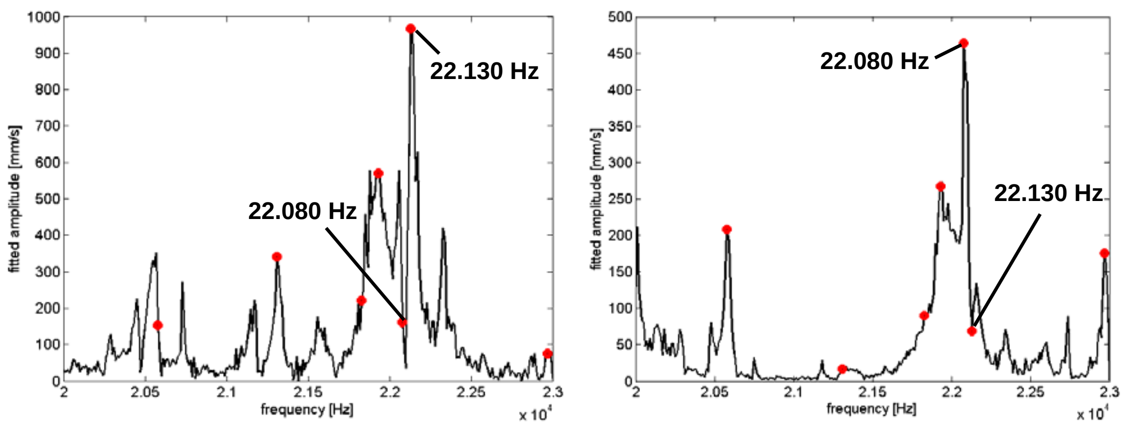

Fig. 3. *Velocity amplitude vs. excitation frequency plots*
a) Velocity amplitude of the right measuring point in figure 2.
b) Differential velocity amplitude of both measuring points in figure 2.

Comparing figure 3. a) with b) and focussing on the marked frequency 22.080 Hz which leads to crack face detection it can be recognized that the velocity amplitude of the single measurement is quite low. However, the differential velocity amplitude is very high and indicates a strong mode III movement of the crack faces. It can be assumed that in this case friction of the crack faces is the dominating effect leading to heat generation. Looking at the frequency 22.130 Hz it is notable that the measured point on the right side of the crack oscillates with a high velocity and thus with a large displacement amplitude. The differential velocity measuring at 22.130 Hz demonstrates that both crack faces do not perform strong relative displacements according to mode III movement proved by a rather low differential velocity amplitude. Nevertheless this excitation frequency was the only one found in the investigated range that led to the detection of the crack tip shown in figure 2. c). From the results of the mode III vibrometer measurement it is assumed that at this frequency a regular bending mode shape occurs in which both crack faces move parallel to each other without typical mode III phase shift.

REFERENCES

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