Va io Mea emen Technologie (Tempe at e/St e /Fatig e/C ack) ith Highl P eci e Inf a ed The mog aph and Thei Application †

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Abstract:

Effective diagnostic technology of defects such as steel structures and machine parts has been developed by detecting a minute temperature change using highly precise infrared thermography, including the application of a thermoelasticity heat generation method to crack diagnosis and stress measurement. Also JFE Steel Group applied a supersonic wave excitation method to the crack diagnosis and we achieved various effective deterioration diagnoses in iron and steel manufacturing facilities. Some selected technologies have been currently applied to measurement business of JFE Steel Group.

1. Introduction

The JFE Steel Group is developing various measurement technologies utilizing highly precise infrared thermography as one effort to establish ef f cient diagnostic technologies. Highly precise, high speed measurement of extremely minute temperature changes by infrared thermography has become possible as a result of higher performance in infrared devices and measurement equipment and progress in signal processing technology. As a result, infrared thermography has evolved into a powerful diagnostic and measurement tool with a wide range of applications, not limited to conventional temperature measurement but extending to nondestructive inspections of stress, crack diagnosis, etc., and diverse examples of application have been reported[1)].

This paper introduces the principles of three techniques, i.e., the thermoelasticity heat generation method, the ultrasonic excitation method, and the thermo-wave method, as examples of measurement technologies using infrared thermography and their applications, development and application to high ef f ciency diagnosis of deterioration in steel works equipment, and development and application in the measurement business of the JFE Steel Group.

2. Crack Diagnosis and Stress Measurement Applying Thermoelasticity Heat Generation Method

2.1 Principle of Thermoelasticity Heat Generation Method[1)]

The temperature of a gas decreases when adiabatic expansion occurs, and conversely, its temperature increases under adiabatic compression. In solids, a similar phenomenon is known to occur as a result of sudden stress. This is generally called the thermoelasticity effect. In metals and other homogeneous materials, [illegible]

$\Delta\sigma$ is the change in the sum of principal stresses,

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T is absolute temperature, and K is the thermoelastic coefficient. The thermoelastic coefficient is a char-

between the two crack tips was virtually zero, showing that neither compression nor tension acted on that area. This is because the crack opening is not mechanically constrained except at the crack tip and strain does not act in the area.

Next, Fig. 8 shows the time-series stress change mea-sured by infrared thermography. It can be understood that stresses from 30 MPa to approximately 80 MPa acted on the sound part (reference area in Fig. 6) when the crack trolley passed over the measurement area 3 times. The stress under the 80% loading condition in WKLV WHVW ZDV FDOFXODWHG E\ ¿QLWH HOHPHQW method (FEM) analysis, showing that it is possible to measure stress with good accuracy. On the other hand, large stresses from 100 MPa to 180 MPa acted on the crack tip due to stress concentration. In the stress curve for the crack tip, two peaks were detected in each pass. This shows that stress reached its maximum in the instant when the two wheels of the crab trolley passed over the crack tip.

As described above, it is possible to obtain the crack OHQJWK IURP GLPHQVLRQDO GDWD DQG VWUHVV ÀXFWXDWLRQV from time-series change data.

Figure 9 shows the results of improvement of the S/N ratio using the self reference lock-in method described LQ 6HFWLRQ 7KH VWUHVV ÀXFWXDWLRQ RI WKH UHIHUHQFH DUHD in Fig. 6 (a) was used as the reference signal. The S/N ratio improved remarkably, and it was also possible to detect crack tip heat generation at the tip of the triangu-lar rib.

As shown by this explanation, the possibility of remote crack diagnosis of a crane structure by the ther-PRHODVWLFLW\ KHDW JHQHUDWLRQ PHWKRG ZDV FRQ¿UPHG. WXDWLRQV RI WKH IRUFH ZDV YHUL¿ planned for the future.

2.4 Stress Measurement Applying Thermoelasticity Heat Generation Method

This section introduces an example of stress distribu-tion measurement of multi-stage spot welds using the thermoelasticity heat generation method as an example of development and application in measurement busi-ness of JFE Steel Group. Figure 10 (a) shows a stress distribution image of a spot weld. Fig. 10 (b) shows WKH VWUHVV SUR¿OHV RQ OLQHV ƒ, „ and … in (a). At the HQWUDQFH VLGH RI VSRW ZHOGLQJ¡â of tensile stress follow line ƒ, but at welding line „ of the 2nd stage spot welding arranged at the exit side of WKH ¿UVW VWDJH ÀXFWXDWLRQV RI F lowed with the phases (peaks and valleys) reversed from those in line ƒ. If the two sheets are pulled upward and downward, rotary bending force is generated in the sur-face of the sheet, along the line „, the surface of the welded sheet is mainly subjected to compression, and tensile stress is mainly generated on the back surface of the other sheet. In line …, which is at a distance from

the weld, a slight load deviation can be observed on the right side, but the generated stress is mild and homogeneous. As this example demonstrates, complex phenomena such as the division of stresses between sheets in spot welding, friction between the sheets, etc. can be observed by 2-dimensional images.

3. Crack Diagnosis Using Ultrasonic Excitation Method

3.1 Basic Principle of Ultrasonic Excitation Method

With the thermoelasticity heat generation method explained in Chapter 2, it is necessary to apply external stress to the object of inspection. This section introduces an example of the development and application of an ultrasonic excitation method[7] as a crack diagnosis method for equipment in a static condition, such as rolls when lines are not in operation. In this method, ultrasonic vibration is irradiated on the object of measurement so as to generate frictional heat at the crack surface, and minute temperature changes are measured by infrared thermography.

3.2 Results of Laboratory Crack Detection Tests

A test specimen was prepared by introducing an artificial crack (length: 10 mm, depth: 5 mm) in a flat plate (100 mm × 200 mm), and the relationship between crack heat generation and the press load of the ultrasonic horn and the amplitude of the irradiated ultrasonic wave was investigated. The frequency of the irradiated ultrasonic wave was 19.5 kHz. As shown in **Fig. 11**, temperature rise (crack heat generation) increases when the press load of the ultrasonic horn is increased. This is estimated to be because contact between the horn and the specimen surface is improved, and irradiation loss of the ultrasonic vibration is reduced. From **Fig. 12**, temperature rise also increases when the amplitude of the irradiated vibration is increased. This is estimated to occur because the vibration amplitude of the crack surface increases, and as a result, frictional heat generation at the crack surface is increased.

Next, the effect of grease contamination on crack detection capacity was evaluated, as grease is an issue when this technology is applied at actual worksites. Detection tests were performed with test specimens coated with various film thicknesses of mechanical grease. **Figure 13** shows the results. Witho1-16004Cp-12(w)-13(s)-1