Predicting the Dynamic Stress Concentration Factor Using the Stress Measuring Method Based on the Infrared Thermography

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Abstract

This paper applies thermography to analyze transient stress variation of a circular holed plate. In experiment, the finite element modal (FEM) analysis of the specimen was performed and the surface temperature measured by infrared camera is calculated to the stress of the nearby hole, based on thermoelastic equation. Stress distributions between 2nd and 3rd vibration mode are investigated with thermography and also dynamic stress concentration factors according to the change of vibration amplitude are estimated at resonance frequency.

1. Introduction

Structural components subjected to high frequency vibrations, such as those used in vibrating parts of gas turbine engines, are usually required to avoid resonance frequencies. Generally, the operating frequency is designed at more than resonance frequencies. When a vibrating structure starts or stops, the structure has to pass through a resonance frequency, which results in large stress concentration [1]. This paper applies thermography to analyze transient stress variation of a circular holed plate. In experiment, the finite element modal (FEM) analysis of the specimen was performed and the surface temperature measured by infrared camera is calculated to the stress of the nearby hole, based on thermoelastic equation. Stress distributions between 2nd and 3rd vibration mode are investigated with thermography and also dynamic stress concentration factors according to the change of vibration amplitude are estimated at resonance frequency.

2. Experimental setup

Under adiabatic and reversible conditions, a cyclically loaded, isotropic structure experience in-phase temperature variations that are proportional to the change in the sum of the principal stresses. Thermoelastic stress analysis (TSA) uses infrared thermography camera to measure the temperature variation of an object and relates these changes to the associated dynamic stress [2]. It is important that thermal parallel condition must be maintined during the test for the correct thermoelastic stress analysis. In this study, the thermal parallel condition is guaranteed on the specimen by repeatedly applying the constant frequency and also an adiabatic chamber is designed in order to keep constant surrounding temperature and constant emissivity. The cantilever specimen with circular hole is deformed to out-of-plane vibration by shaker. Material is stainless steel which has the thermoelastic coefficient of $4.33 \times 10^{-12}\,Pa^{-1}$. Thermoelastic stress is analyzed with infrared thermography camera with lock-in module [3]. The specimen is vibrated at designated amplitude and frequency with shaker, which is controlled by the function generator and measure. The resonant frequency and amplitude of specimen is measured by the accelerometer. The measured resonant frequency is compared with the modal analysis results of finite element analysis and measured acceleration is used to acquire the stress distribution in the finite element analysis. Finally, the stress concentration factor, acquired by the finite element analysis, is compared with stress concentration factor measured using the infrared thermography technology. Fig. 1(a) and 1(b) show the shape and boundary condition of specimen and schematic diagram of test system respectively.

(a) Boundary condition of specimen

(b) Schematic diagram of measurement system
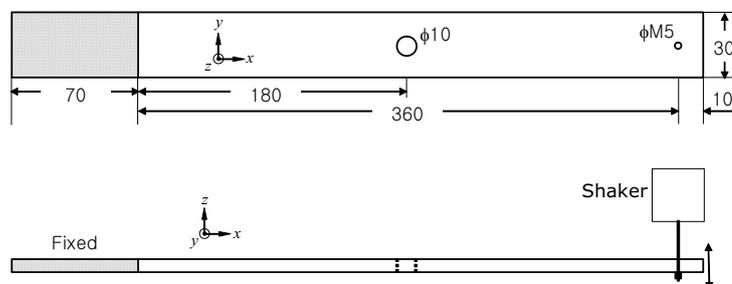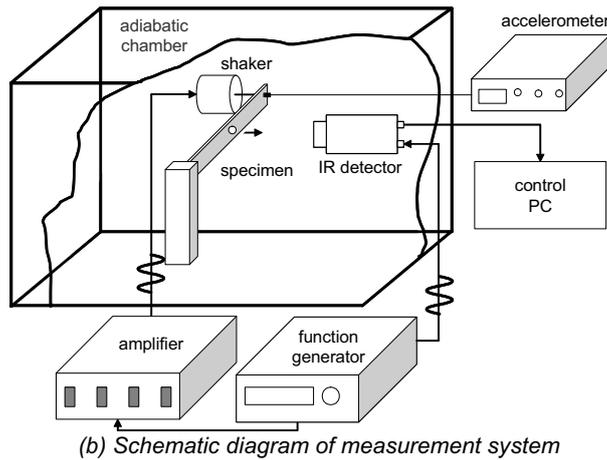
Fig. 1 *Experimental configuration*

3.   Results

3.1   FEM result

The resonant frequency, mode shape and stress distribution of test piece is acquired by performing the modal analysis using the commercial software (ANSYS, element shell 63). Fig. 2 shows the FEM results at the 2nd and 3rd resonant frequency, 39 Hz, which is compared with those of accelerometer. These results show that the biggest stress is measured around the round hole in the 2nd mode. Also, the results show that the nodal line is formed around the round hole in the mode 3 and stress is close to "0" and the biggest stress is measured at the fixed point (left end). The stress concentration factor obtained from the analysis results of the 2nd mode is compared with the acquired stress concentration factor with the infrared thermography test results. Fig. 3 shows the stress distribution in the form of proportion ($\sigma / \sigma_{\max}$) based on the maximum stress at each resonant frequency. The results show that the biggest stress is measured around the round hole in the mode 2. Also, the results show that the nodal line is formed around the round hole in the mode 3 and stress is close to "0" and the biggest stress is measured at the fixed point. The analysis results show that the highest stress concentration is measured in the mode 2, so we acquire the stress concentration factor based on the analysis results of mode 2 and then compare the acquired stress concentration factor with the infrared thermography test results.
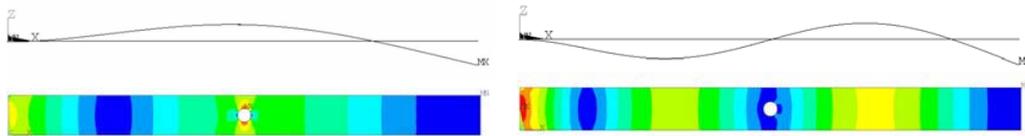
(a) 2nd mode (FEM: 39 Hz, Accelerometer: 35 Hz)   *(b) 3rd mode (FEM: 109 Hz, Accelerometer: 94 Hz)*

Fig. 2. *Vibration mode shape (upper) and stress distribution (down) by FEM*
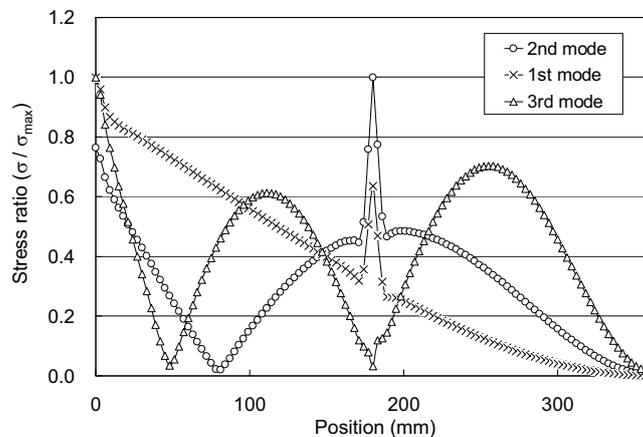
Fig. 3. *Stress ratio at each resonance frequency by FEM*

3.2 Thermography result

The infrared thermography test is conducted to measure the stress distribution resulted from the change of amplitude. According to Fig. 4, surface temperature is raised to 1.5 K and the thermal conduction can be neglected after about 200 sec. At this time, stress is measured with thermography system and Temperature fluctuation, ΔT is 0.4 K, which is equal to 296 MPa by classical theory. Figure 5 shows the results measured by comparing the stress distribution acquired using the IRT in the 2nd mode and FEM. This figure shows that the stress distribution is same around the round hole. Figure 7 shows the dynamic stress concentration factor resulted from the change of shaker amplitude at frequency of 40Hz, resonant frequency band. The excitation amplitude change measured using the acceleration indicates the accelerated value (g, m/s^2). The stress concentration factor is used to acquire the average stress in the areas of 195 ~ 210 mm and express the stress ratio for each location. The stress concentration factor acquired using the FEM is evaluated as 2.07 and measured as 1.75 ~ 1.92 in the infrared thermography test. The average of test results is evaluated or measured as 1.85. The error between infrared thermography test and FEM is evaluated as 10.6 %, which has good agreement.
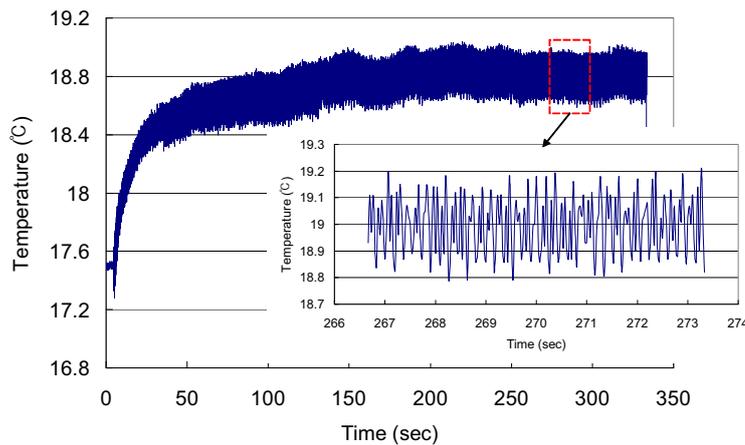
Fig. 4. *Temperature evolution at maximum stress point of 2nd vibration mode*

(a) Thermography result   *(b) FEM result*
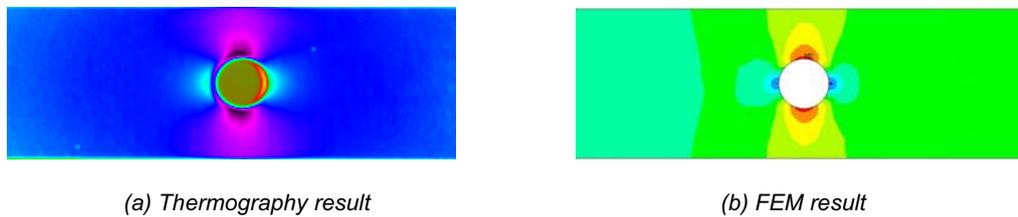
Fig. 5. *Comparison of stress map at the 2nd vibration mode*

(a)   *(b)*

(c)   *(d)*
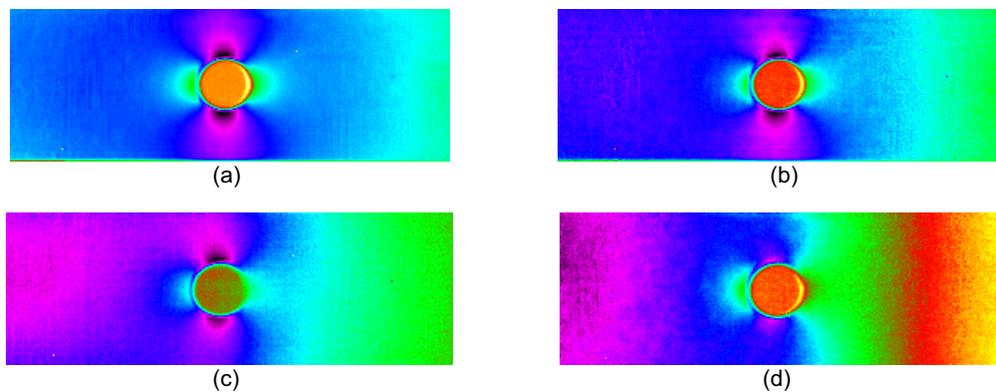
Fig. 6. *The change of stress distribution around the round hole according to change of frequency using the infrared thermography. (a) 40 Hz, (b) 50 Hz, (c) 60 Hz, (d) 70 Hz.*
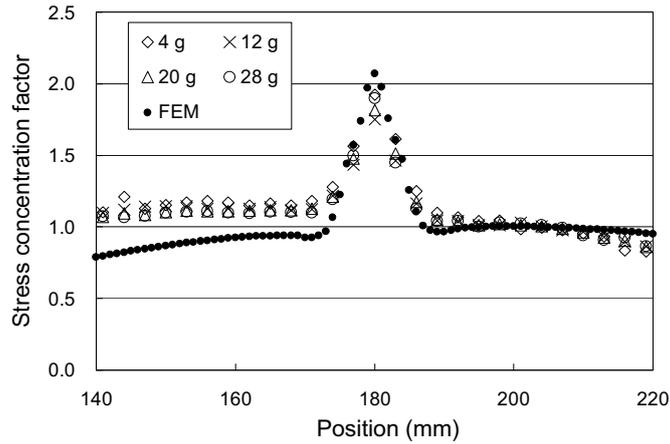
***Fig. 7.** Comparison of stress distribution in 2nd vibration mode*

4.   Conclusions

In this paper, we measure the stress distribution of structure designed in the form of cantilever under the transient condition using the infrared thermography and predict the dynamic stress concentration factor based on the stress distribution. In the test, test results shows the change of stress distribution resulted from the frequency change measured in the resonant modes 2nd and 3rd. Stress concentration factor resulted from the change of amplitude at frequency of 40 Hz is estimated and then the value is compared with results of finite element analysis. The relative measuring error is measured as 10.6 % because the spatial resolution of detection device is so limited and experimental system does not completely meet the thermal parallel condition of specimen. The many advantages of infrared thermography such as non contact, whole field, insensitivity of environmental vibration enables its user to measure the stress of small and micro structure, without shape limitation.

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