

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

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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.

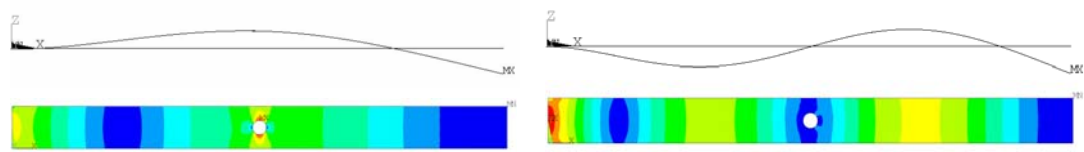
2. Applied theory and experimental setup

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 maintained 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 $4.33 \times 10^{-12} \text{ Pa}^{-1}$. 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.

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). The Fig. 1 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.



(a) 2nd mode (FEM: 39 Hz, Accelerometer: 35 Hz) (b) 3rd mode (FEM: 109 Hz, Accelerometer: 94 Hz)

Fig. 1. Vibration mode shape (upper) and stress distribution (down) by FEM

3.2 Thermography result

The infrared thermography test is conducted to measure the stress distribution resulted from the change of amplitude. The Fig. 2 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. The Fig. 3 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.

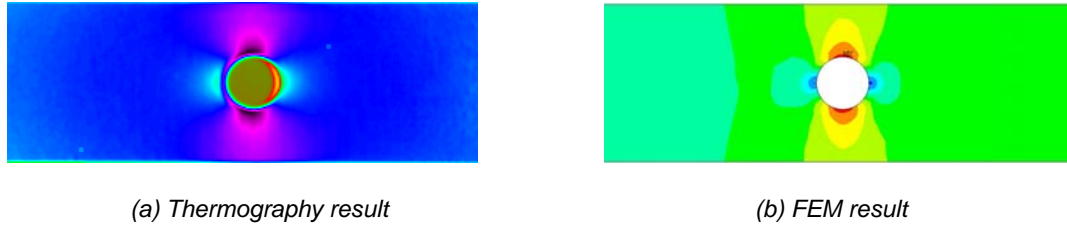


Fig. 2 Comparison of stress map at the 2nd vibration mode

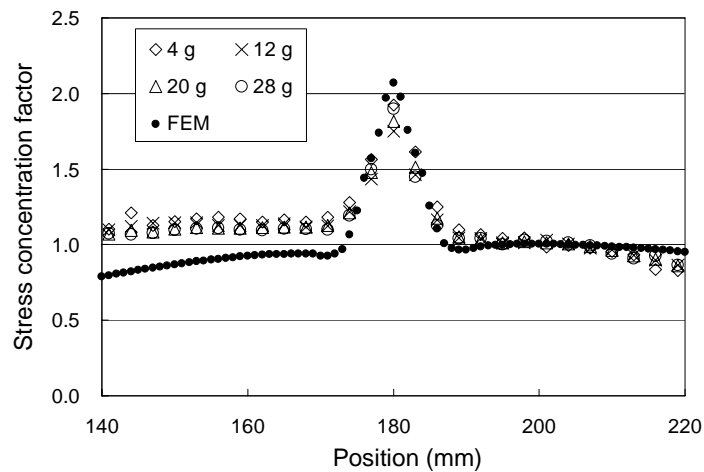


Fig. 3 Comparison of Stress map in 2nd vibration mode

4. Conclusions

In this paper, the dynamic stress concentration factor of cantilever beam with circular hole under cyclic vibration is estimated by the infrared thermography and is compared with the result of finite element analysis. The relative measuring error is evaluated as 10.6 %, which is derived from the spatial resolution of camera and heat loss such as thermal conduction. The infrared thermography, the advantage of non-contact measurement, enables its user to directly measure the stress, regardless of the geometric complex of object. It is expected to be widely used when analyzing the small structure,

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