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Active thermographic imaging with a moving line-focus laser beam
移動する線状レーザーを用いたアクティブ・サーモグラフィ映像法

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1. Introduction

Active-thermographic inspection, in which modulated, pulse, or moving laser beam heats up samples, has become more and more important in industrial applications.[1-3] Real-time thermographic technique is highly applicable to for nondestructive inspection (NDI) applications. Moving heat-source method, which has an advantage in spatial resolution. However, has disadvantage because the extremely fast movement of heat source is required for inspection of materials with high thermal conductivity (metals).

Recently the authors group performed the experiments by a thermo-tracer with real-time response and analyzed its time-domain response of the temperature of specimen surface.[4]

2. Experimental Apparatus and Specimen

The experimental setup is shown in Fig. 1. For a heat source, second harmonics of Nd-YAG diode laser-pumped solid-state laser (DPSSL) with wavelength of 532nm was used. Its beam was expanded with a concave lens and a pair of convex lens. A collimated beam was incident into a right-angle prism and a plano-convex lens both attached to a moving slider. As a slider, linear-motor slider (ORIENTAL MOTOR, EZ limo) with a moving speed of with a span of 100 mm was used. A thermal image was observed by a thermo-tracer (NEC San-ei, TH 9100) with a temperature resolution of 0.06K was used. The thermal image was recorded by a personal computer (PC) connected with a IEEE 1394 bus. The real-time (30 flames/sec) thermal response was recorded by a PC. The specimens used in this experiment were stainless steel (SUS304) of a cuboid shape with a size of 25mm x 40mm x 4mm$^{t.}$ The specimen surface was coated by black-body paint with an absorbance of 0.94. Inside of the specimen, rectangular slits with a width of x = 10mm and depths of y = 0.5, 1.0, and 1.5 mm were fabricated along the focused laser beam. Simulated defect was set to align with a line-focus laser beam.

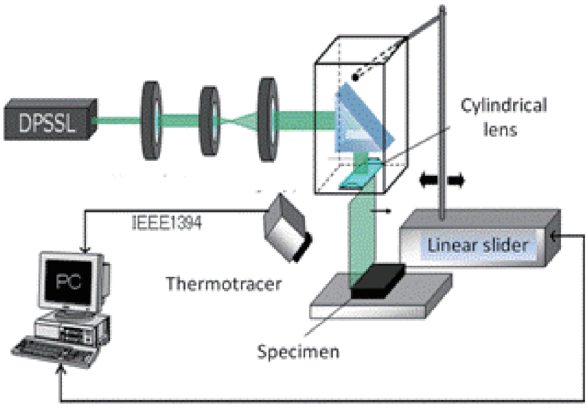

Fig. 1 Basic experimental setup

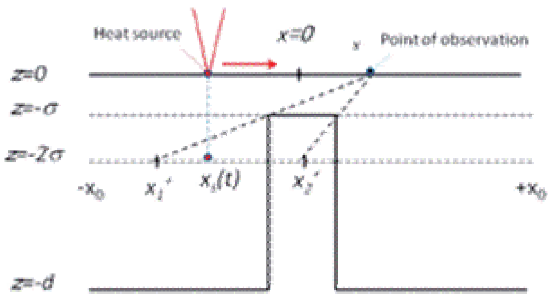

Fig. 2 Model for calculation

3. Experimental Result and Discussions

Fig. 2 shows a theoretical model for the thermal wave reflection. Here z = σ and z = d denote the locations of top and bottom surfaces of the undersurface defect, respectively.

Fig.3 (a) shows temporal variation of the surface temperature in SUS304 specimen obtained for laser power 224mW, and the slider velocity

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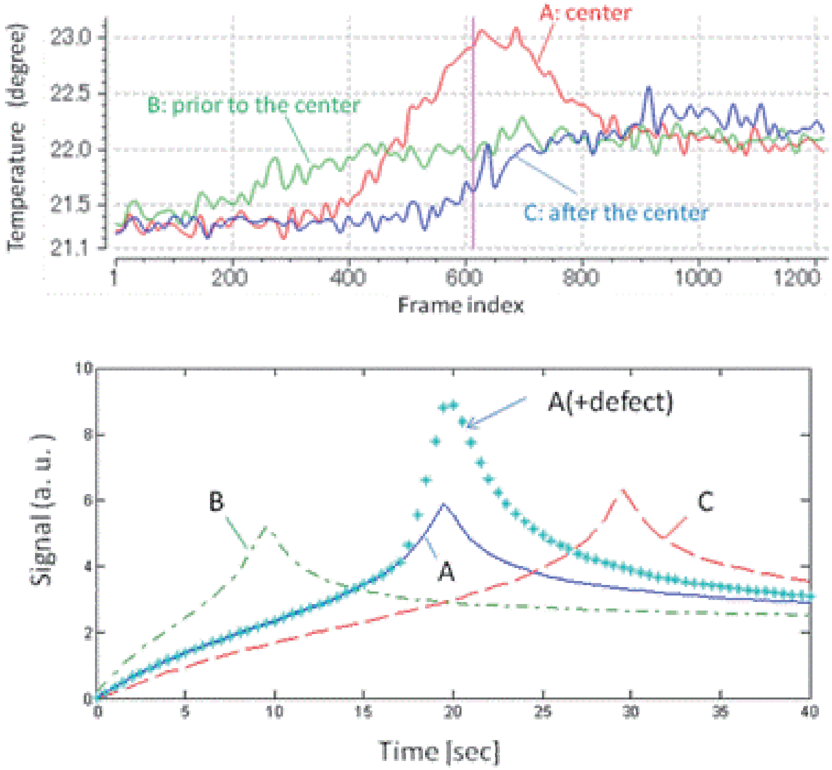

Fig. 3 (a) Obtained waveform of the surface temperature variation in SUS304 specimen (upper), (b) calculated thermal waveform (lower)

1mm/s. for the internal defect depth of 0.5mm. Figure shows apparent photothermal signal increase at the center (red) of the defect caused by the reflection of heat flow at the shallower internal defect interface.

The thermal wave reflection was analyzed with the above theoretical model, and the temperature signal was described by the incomplete Gamma functions. [4)]

Using thermal properties for SUS 304 (18 Cr-8 Ni alloy) specimen: density $\rho = 7920$ [kg/m^3], specific heat c = 0.499 [kJ/(kg·K)] and thermal conductivity $\kappa = 16.0$ [W/(m·K)], its thermal diffusivity is obtained as $\alpha = 4.04$ [mm^2/sec].

The waveform at the center for the same condition for Fig. 3 (a) was calculated with the theory and shown in Fig. 3 (b). Solid and broken curves represent surface temperature variation with and without the internal defect, respectively. The theoretical analysis agreed with the experimental data qualitatively.

4. Conclusion

Experimental results show photothermal radiometric apparent signal increase for the case of specimen with undersurface defect. It is interpreted to be caused by the reflection of heat flow at the internal defect boundary.

The present study has the ability to bring out the new degree of freedom in NDI by thermography with scanning. This scheme also has an advantage to adjust moving velocity change to specimens and to utilize the time-domain control by laser light pulse width or frequency modulation for NDI of materials with high thermal conductivities such as metals.

References

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