DEVELOPMENT OF A NEW NONDESTRUCTIVE INSPECTION SYSTEM FOR CASTING DEFECTS IN ENGINE CYLINDER BY PULSE HEATING INFRARED THERMOGRAPHY

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Abstract

In this paper, a new inline nondestructive inspection (NDI) system for engine cylinder production process is proposed based on the pulse heating infrared thermography. Pulse heating was applied to the inner surface of the engine cylinder from xenon flash lamp tube inserted into engine cylinder. Panoramic infrared images of the transient temperature distribution on the inner surface of the cylinder were taken by the infrared thermography system using an omni-directional mirror. Experimental investigations were conducted using actual engine cylinder samples with artificial casting defects. It was found that the defects can be identified by the localized contrast change regions in thermal images, demonstrating the feasibility of the proposed NDI technique.

1. Introduction

Some failures of engine cylinders were caused by casting defects located beneath the inner surface of the engine cylinder. Development of a new nondestructive inspection (NDI) technique for these defects is required. Thermographic NDI techniques using pulse heating [1,2] have been receiving an increasing attention as one of the effective NDI techniques, because they were non-contact, remote testing, time- and cost-saving techniques. However it is difficult to apply the conventional thermographic NDI for the detection of casting defects located beneath the inner surface of engine cylinder, since it is almost impossible to observe directly the inner surface of engine cylinder by the infrared thermography. Further application of uniform pulse heating to the inner surface is difficult using a conventional xenon flash lamp system.

Therefore present authors newly developed a new pulse heating thermographic NDI system for the inline inspection of engine cylinder, in which an insert-type xenon flash lamp and an omni-directional mirror were employed for uniform pulse heating and subsequent multi-directional temperature measurement of the inner surface of engine cylinder. In this paper, several experimental results of the thermographic NDI for embedded defects in engine cylinder are shown. First preliminary experiments by the conventional pulse thermography were carried out for plate specimens and half-cut cylinder specimens with artificial flat-bottom hole defects. Further the proposed NDI system using the omni-directional mirror was tested for an actual engine cylinder block with artificial defects for demonstrating the applicability of the proposed technique for the inline NDI applications.

2. Pulse heating thermographic NDI

A schematic illustration of the pulse heating thermographic NDI is shown in Fig. 1. When a pulse heat flux is applied to the objective sample, out-of-plane heat flow is generated in it. If the sample has no defects, uniform temperature rise is observed on the sample surface. If the sample has defects such as delamination or void on the contrary, localized high temperature regions appear on the sample surface just above the defects due to the thermal insulation effect of the defects. These high temperature regions reflect shapes and sizes of the defects. Thus the defect shapes and sizes can be determined from characteristic temperature distribution on the sample surface.

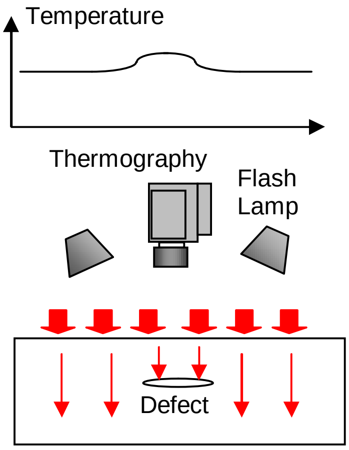
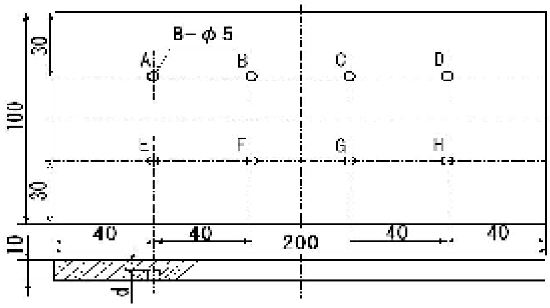


Figure 1*: Schematic illustration of thermographic NDI*



Defect depth d (mm)	
A	1
B	2
C	3
D	4
E	5
F	6
G	7
H	8

Figure 2*: Plate specimen with flat-bottom hole defects*

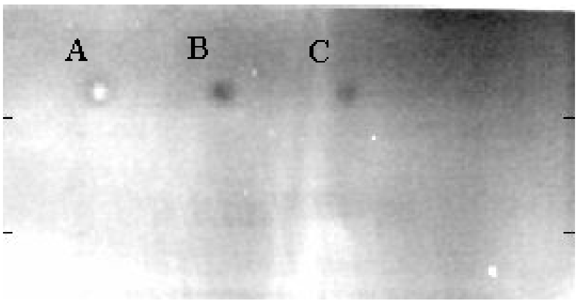


Figure 3*: Temperature distribution on surface of plate specimen*

3. Preliminary Experimental Studies

Feasibility of the proposed technique was tested by preliminary experiments using a plate specimen and a half-cut cylinder specimen with artificial flat-bottom hole defects.

3.1. Plate specimen

The plate specimen with artificial flat-bottom hole defects is shown in Fig. 2. It is difficult to make embedded defects like voids. The bottom-hole defects are often employed in the feasibility test in thermographic NDI, since thermal response during a short time duration after pulse heating around the bottom-hole defect is almost similar to that around the embedded defect.

The specimen was made of SS400, which has similar thermal properties as the actual engine cylinder. The diameter of the defects was set to be 5 mm. Depths of the defects, i.e., remaining thicknesses were 1, 2, 3, 4, 5, 6, 7, and 8 mm. The surface of the specimen was coated by flat black paint to keep high emissivity. Sequential thermal images on the surface of the specimen were taken by the infrared thermography (Indigo Phoenix Mid), after the pulse heating by xenon flash lamp. Output power of the xenon flash lamp was set to be 12800 J. Obtained thermal images are shown in Fig. 3. It is found from the figure that detectable depth is 3 mm. Expected performance of the NDI system in the actual in-line test is detection of casting defect of 6mm in radius and 3mm in depth. Therefore, this result shows that the pulse heating thermographic NDI has enough ability for the inspection of casting defects in actual engine cylinder.

3.2. Half-cut cylinder specimen

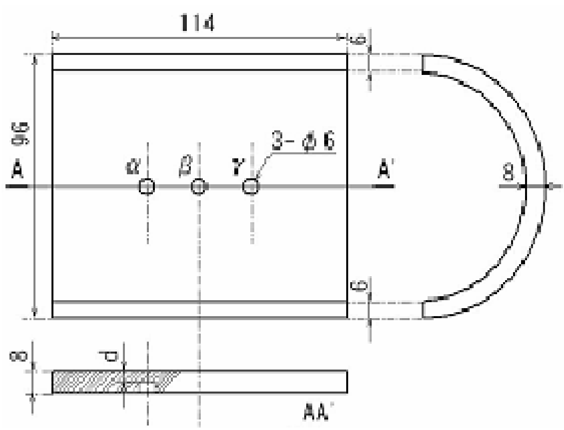
The half-cut cylinder specimen with flat-bottom hole defects is shown in Fig. 4. The diameters of the defects were set to be 4 and 6 mm, and the depths of the defects were 1, 2 and 3 mm. Output power of the xenon flash lamp was 12800 J. The surface of the specimen was coated by the flat black paint. Obtained thermal images after pulse heating are shown in Fig. 5. It is found from these images that localized high temperature regions are identified above defects. It is concluded that the detectable depth is 3 mm for the defects of 4 mm and 6 mm in diameter. These experimental results also show the enough performance of the pulse heating thermographic NDI technique for the casting defects.

4. Experimental Investigations Using Actual Engine Cylinder Sample

4.1. Experimental conditions

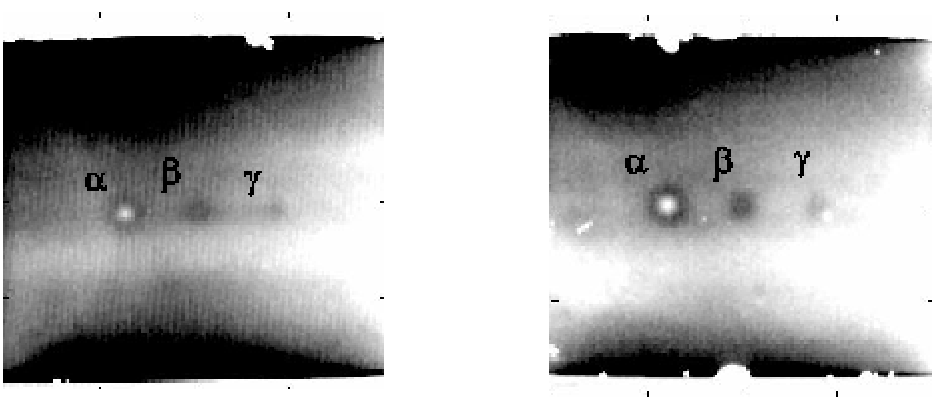
Actual cylinder block used for diesel engine shown in Fig. 6 was employed for experimental investigation. Flat-bottom hole defects were machined in the cylinder block. The diameter of the defects was 6 mm, and the depths of the defects were 1, 2, and 3 mm. The inner surface of the engine cylinder was coated by the flat black paint.

It is difficult to apply uniform pulse heat to the inner surface of engine cylinder by the conventional xenon flash lamp system. Further it is impossible to conduct direct measurement of the whole inner surface of the cylinder by the infrared thermography. Therefore the present authors developed a new in-line thermographic NDI system using an insert-type xenon flash lamp and a omni-directional mirror. Schematic illustration and photograph of the proposed NDI system is shown in Fig. 7. A straight xenon flash



Defect depth (mm)	
α	1
β	2
γ	3

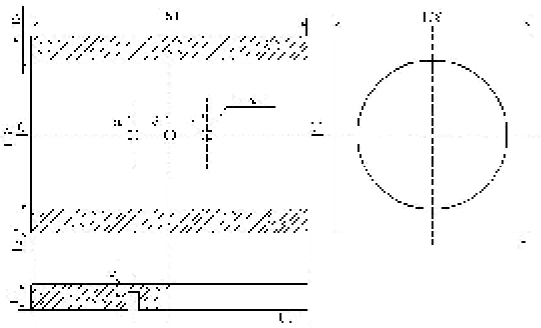
Figure 4*: Configuration of employed half-cut cylinder specimen with flat-bottom hole defects*



(a) Defect radius 4 (mm) *(b) Defect radius 6 (mm)*

Figure 5*: Obtained thermal images on surface of half-cut cylinder specimen*

lamp tube was prepared for pulse heating. The omni-directional mirror was attached at one end of the xenon tube as illustrated in the figure. The xenon tube and the omni-directional mirror were inserted into the cylinder. When xenon tube was activated, near infrared light was emitted from the xenon tube and uniform pulse heat flux was applied onto the inner surface of the cylinder. The output power of the xenon flash lamp was 3200 J. Sequential thermal images of the entire inner surface of the cylinder were reflected on the omni-directional mirror and were measured by the infrared thermography located outside of the engine cylinder. Thermal images on the omni-directional mirror were transferred into the panoramic thermal images of the inner surface of the cylinder by the numerical post processing technique.



Defect depth (mm)	
α'	1
β'	2
γ'	3

Figure 6*: Actual cylinder block sample with flat-bottom hole defects*

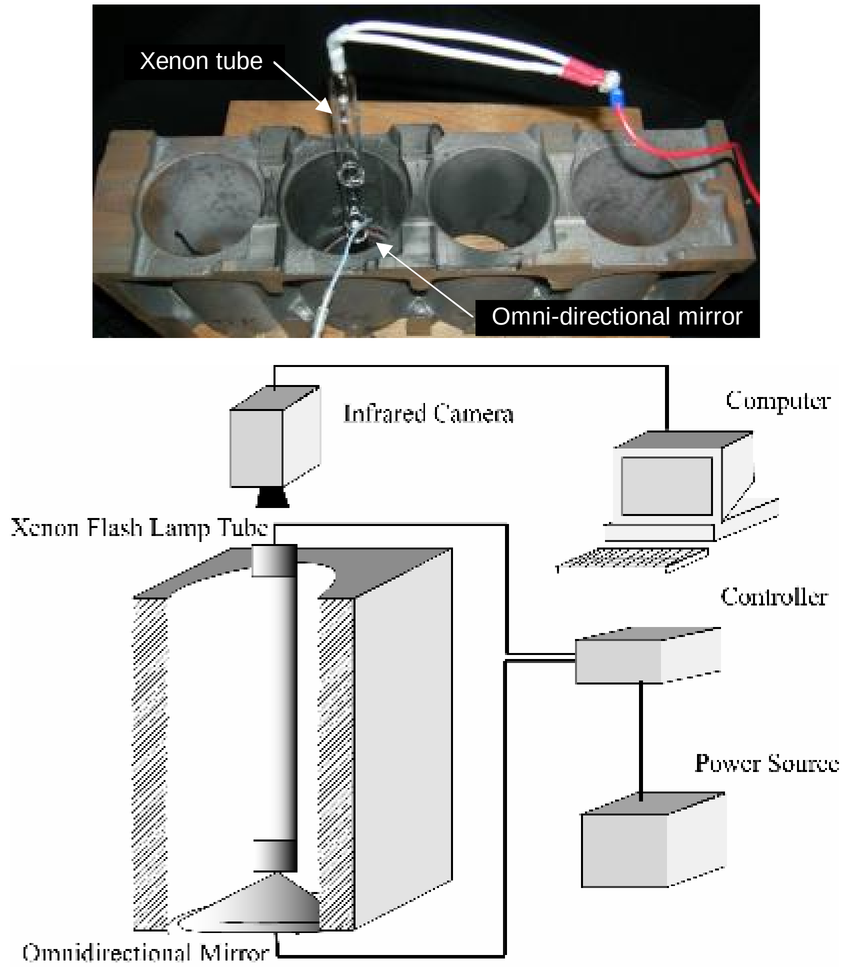


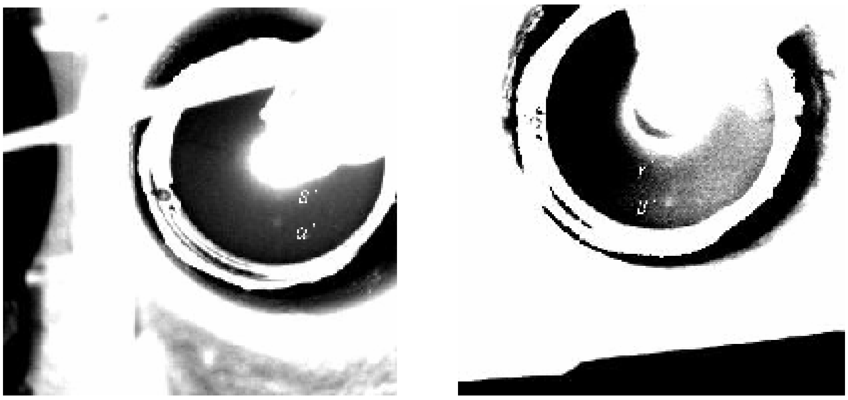
Figure 7*: Schematic illustration and photograph of thermographic NDI system*

4.2. Results

The diameter of the employed xenon tube was large compared with that of the omni-directional mirror and makes hidden area near the center of the mirror. Therefore the infrared camera looked at the omni-directional mirror from the slightly tilted position. In this case the thermal image of the entire inner surface cannot be taken at once. The thermal images were taken by changing the tilted angle of the infrared thermography to get the entire image of the inner surface of the cylinder.

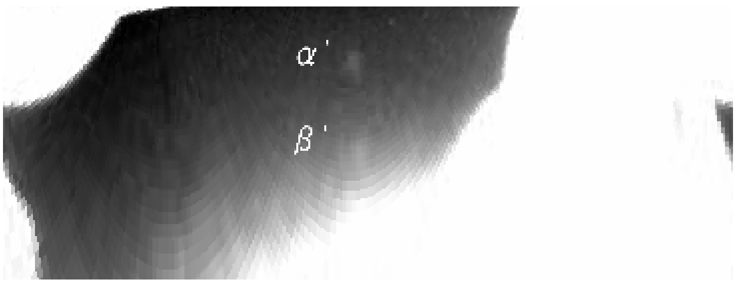
Obtained thermal images reflected on the omni-directional mirror are shown in Fig. 8. It is found that the flat-bottom hole defects of 1mm and 2mm in depth can be identified in Fig. 8(a), and the defects of 2mm and 3mm can be identified in Fig. 8(b).

The thermal images reflected on the omni-directional mirror were transferred into the panoramic images by the numerical processing. The results are shown in Fig. 9. It is found that the contrast changes due to the defects are again identified in the panoramic images. The contrast change is slightly degraded in the panoramic images, instead the location and shape of the localized temperature change are accurately determined.

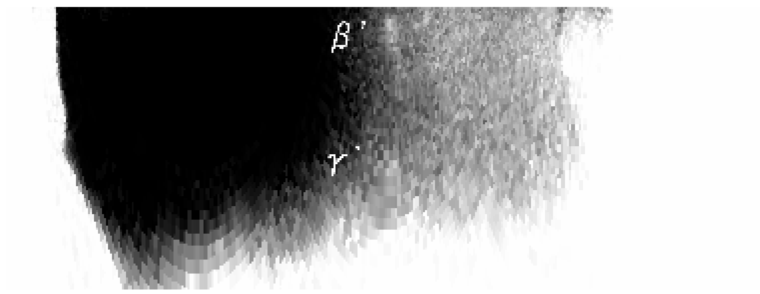


(a) Defect depth 1 mm and 2 mm *(b) Defect depth 2 mm and 3 mm*

Figure 8*: Thermal images of inner surface of cylinder reflected on omni-directional mirror*



(a) Panoramic image of Fig. 8 (a)



(b) Panoramic image of Fig. 8 (b)

Figure 9*: Panoramic image of inner surface of cylinder transferred from thermal images in Fig. 8.*

5. Conclusions

A new pulse heating thermographic NDI system for the inline inspection of engine cylinder was developed, in which an insert-type xenon flash lamp and an omni-directional mirror were employed for uniform pulse heating and subsequent multi-directional temperature measurement of the inner surface of engine cylinder. Feasibility of the proposed technique was demonstrated by the several experimental investigations using test samples with artificial bottom-hole defects. It was found from these experimental studies that defects were accurately identified in the thermal images obtained by the infrared thermography using the insert-type flash lamp heater and the omni-directional mirror.

6. Acknowledgment

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7. References

[1] Maldague, X. P. V., *Theory and Practice of Infrared Technology for Nondestructive Testing*, Wiley-Interscience, 2001.

[2] Sakagami, T. and Kubo, S., "Applications of pulse heating thermography and lock-in thermography to quantitative nondestructive evaluations", *Infrared Physics and Technology*, 43, 211-218, 2002.