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Continuous Line Laser Thermography for Damage Imaging of Rotating Wind Turbine Blades

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Abstract

This paper proposes a continuous line laser thermography technique for damage visualization of wind turbine blades under rotating condition. Although a number of non-destructive testing techniques have been proposed for damage inspection of wind turbine blades under stationary condition, a few prior studies on the operating blade monitoring have been reported due to technical challenges associated with actual implementation issues. The proposed continuous line laser thermography technique is able to inspect wind turbine blades with fully noncontact mechanism, no couplant requirement, data acquisition without spatial scanning mechanism and intuitive data interpretation. First, thermal waves are generated by a continuous line laser beam targeted onto the rotating wind turbine blades, and the corresponding thermal responses are simultaneously measured by an infrared camera. Then, a new pixel tracking and statistical pattern recognition algorithms are developed and applied to the measured thermal images in the time domain so that only damage features can be extracted even under the rotating condition of wind turbine blades. The performance of the proposed continuous line laser thermography technique is verified through scaled wind turbine model tests under varying rotating speed.

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Keywords: Continuous line laser thermography; Rotating wind turbine blade; Non-destructive testing; Damage visualization;

1. Introduction

The wind turbine blades are mainly composed of the composite materials due to its unique characteristics such as high strength, light weight and corrosion resistance. Since the composite materials are, however, fabricated by

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laminating multiple layers, they are often susceptible to temperature, humidity, external impacts and especially repeated cyclic loadings [1, 2]. Such susceptibility may cause critical damage inside the blades themselves. The main technical challenge for inspection of the internal damage is that one cannot recognize the damage on the surface by naked eyes. Recently, since the wind turbine blades are getting larger to maximize the wind turbine's energy output, the collapse of such large wind turbine blades may lead to more serious safety accidents [1]. For example, nowadays, to generate 3000 kW, 50 m wind turbine blade has been typically used. To prevent these accidents, in-situ wind turbine blade monitoring methods are strongly required.

The most widely used in-situ wind turbine blade monitoring technique, especially for the rotating condition, is vibration analysis technique [3, 4]. By measuring the various vibrating frequencies of the wind turbine blades, the physical conditions of material such as damage occurrence and growth can be estimated. Then, strain gauges have been applied for in-situ monitoring with measuring the local strain of the wind turbine blades. However, they are often vulnerable to the long term use [5, 6], and insensitive to internal damage. Although optical fiber sensors have been used as an alternative thanks to their long-term durability [7], the internal damage is still difficult to be detected. More recently, the sensor based ultrasonic technique has been developed for in-situ wind turbine blade monitoring on the basis of its superior sensitivity to the local and internal damage even though its size is small [8]. However, the sensor-based ultrasonic technique often requires complex data processing and low reliability, meaning that it can cause the false alarm due to the vulnerability to the operation noises [9, 10]. Furthermore, permanently installed sensors and wirings will be deteriorated over time, and their maintenance and replacement might be challenging when it comes to embedded sensors. To address these problems, a laser based ultrasonic technique has been developed as non-contact approach [11]. Although it has advantages of the high detectability for internal damage and intuitive damage interpretation, long data acquisition time and low signal-to-noise ratio disturb its field application.

In this paper, a fully non-contact continuous line laser thermography system is proposed for in-situ wind turbine blade monitoring. In addition, the damage imaging algorithm is newly proposed to instantaneously visualize only damage even under operating or rotating conditions. The proposed system and algorithm have following advantages: (1) intuitive damage interpretation by reconstructing the multiple dynamic images to a single static image using coordinate transformation, (2) fully non-contact and automated damage imaging, (3) simultaneous detection of surface damage as well as subsurface one, and (4) no restriction of the field of view in infrared (IR) camera. The performance of the proposed system and algorithm is experimentally verified using a CFRP wind turbine blade specimens in the rotating condition.

This paper is organized as follows. Section 2 describes the continuous line laser thermography system including the hardware configuration and the working principles. Section 3 proposes the damage imaging algorithm for a rotating wind turbine blades, and the experimental validation is shown in the Section 4. Finally, this paper concludes with a summary and discussion in Section 5.

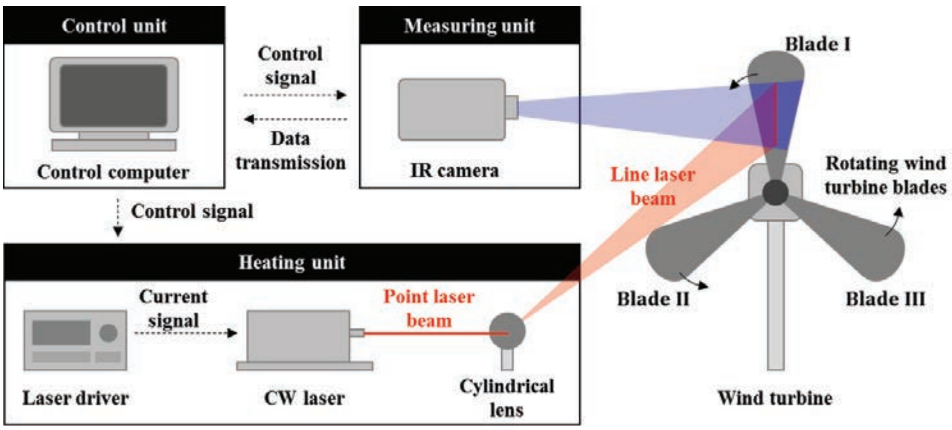

Fig. 1. Schematic diagram of the continuous line laser thermography system.