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Breakpoint detection of heating wire in wind blade moulds using infrared thermography

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HIGHLIGHTS

- Breakpoint may appear in the heating wire of wind turbine blade moulds.
- Heat is generated at breakpoint when a HVD circuit is connected.
- Two recognition algorithms are proposed based on the heat diffusion features.
- The constructed system successfully detect many breakpoints in a very fast way.

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ABSTRACT

In order to manufacture the fibre glass wind blades, one kind of mould embedded with heating wire is used not only for making numerous 'copies' of the original sample, and also heating the mould to a certain temperature for curing. The heating wire is embedded in fibre glass as a sandwich structure, and it may break after a long time usage at high temperatures. In this study, a high voltage discharging (HVD) circuit is used to trigger HVD at the breakpoint, which generates heat and therefore causes temperature increase at the corresponding front surface, one infrared camera is used to monitor the temperature evolution. It successfully and quickly detects breakpoints in spar moulds.

1. Introduction

Wind power is a very promising source of environmentally safe, renewable, and the fast-growing energy source over the past several years. The blades of a wind turbine are considered to be an important component in wind turbine generator. Currently, bigger and more powerful wind blades are being built to increase the swept area of the turbine and extract more energy from the wind [1]. In order to create the fibre glass blades, the moulds must be first manufactured to make numerous copies. One wind blade mainly contains three parts: two shells, spars and shear web, all those parts are manufactured with the corresponding moulds which allow large components fabrication.

The general procedure of manufacturing spar, shell or shear web is that: the mould is first preheated to a specific temperature, such as 30 °C. The carbon layers are stacked as per the thickness requirements; the stacked layers are then bagged, and a vacuum is applied to remove the air trapped between layers before resin infusion. The resin is infused at one end of the vacuum bag, and the vacuum is applied at the other end of the bag. At the time of infusion, the resin is warmed above the ambient temperature and the mould is also heated to a similar temperature. Once the resin infusion process is complete, the part is cured in the mould at a specific high temperature under external pressure [2].

During the manufacturing of each part of a wind blade, the mould heats the part as programmed. One kind of mould is designed to supply heat source by embedding electrical heating wire in glass fibre as a sandwich structure. The wind blade mould is normally divided into many zones depending upon the blade structure design. Each zone includes temperature sensors, an overheating safety switch and one heating wire, which is designed like meanders. The heating wire may break because of long time usage at high temperatures, the precise location of breakpoint need to be detected in order to reduce the cost and time. Induction

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electroprobe could be used for breakpoint detection of a heating wire, however, it is too sensitive because of close row-spacing of heating wire. Therefore, it is hard to detect the real location of a breakpoint.

Infrared thermography can be classified as either passive or active. In passive thermography, infrared camera is used to analyze and record data without applying additional heating or cooling techniques. Passive thermography could be used for heating uniformity detection of wind blade mould, however, it cannot be used for breakpoint detection since no heat is generated from a broken circuit. Active thermography involves a deliberate change in temperature in which a stimulus is directly applied to cause a subject to heat or cool, and the infrared camera is used to observe how the temperature decays with time. There are many heat source applied in the field, such as flash lamp, lamp, laser, ultrasound, eddy current and hot air. Flash pulsed thermography is the most applied method, and it has been used in aerospace, automotive, etc. [3,4]. However, it cannot be used for breakpoint detection since the heating wire is wrapped with electro-resistive tape and it is several milimeters below the upper surface. Sonic IR, also known as thermosonics and Vibrothermography, is a method for finding cracks through thermal imaging of vibration-induced crack heating [5,6]. It is not applicable for breakpoint detection since two ends of a breakpoint are fully separated and the sonic gun may damage the mould surface. Induction thermography employs an infrared camera to detect defects, typically cracks at the surface of a component, by imaging the effects that they have on the heating of a component produced by a pulsed eddy current heating system [7,8], it is not applicable either since the GFRP is not a conductive material. Other known heating methods and modes, such as lamp, laser and hot water or air, working as pulsed, step heating or locking modes, all cannot be used to detect such kind of breakpoint in wind blade mould.

In this study, a HVD circuit is used to trigger HVD at the breakpoint of the heating wire, when the high volt between two ends of the breakpoint is high enough that electrical breakdown occurs with the surrounding air and therefore generates heat. One infrared camera is used to monitor the generated heat caused by HVD, two method based on heat diffusive features are proposed to automatically recognize breakpoints within wind blade moulds.

2. Method

2.1. The mechanism of high voltage discharging

Under normal circumstances, atmospheric air is considered a good insulator and contains very few mobile charge carriers, atmospheric ions. Electrical breakdown may occur when the ion concentration is substantially increased locally. The breakdown is usually caused by the effect of an electrical field on the already existing mobile charge carriers in the air, atmospheric ions and a few free electrons both originating from natural radioactive decay. The ions as well as the free electrons participate in the random, thermal movement of the molecules. It should be stressed that the thermal energy of ions as well as of electrons is far too low to make a thermal collision result in an electron being knocked off an air molecule, i.e. causing ionization. However, if an electric filed exists in the gas, the charged particles will be accelerated in the field and gain an extra kinetic energy. If a particle with charge q is moved a distance Δx by a field with the strength E, the particle gains an increase in its kinetic energy equal to [9,10]

$$W_{kin} = q \cdot E \cdot \Delta x \tag{1}$$

Provided that the particle does not collide with other particles over the distance Δx. When it is to detect a breakpoint of a heating wire, the physical condition of the breakpoint is fixed, which means two parameters q and Δx are fixed values. Therefore, the kinetic energy is proportional to the electrical field strength E. When the electrical field strength exceeds the breakdown point, or as Paschen's law states that a spark discharge is expected to occur between plane electrodes at a distance d as long as the voltage difference v fulfills the condition

$$v \geqslant E_b d \tag{2}$$

where E_b is the breakdown field strength for plane electrodes. An arc flash is the sudden release of electrical energy through the air when a high-voltage gap exists and there is a breakdown between conductors. An arc flash gives off thermal radiation (heat) and bright, intense light that can cause burns. High-voltage arcs can also produce considerable pressure waves by rapidly heating the air and creating a blast. Therefore, the wrapping tape could absorb more heat from inside air to cause heat diffusing to the front surface to be monitored by an infrared camera.

2.2. The mechanism of heat diffusion

Similar as thermosonics or sonicIR, under the excitation of HVD, the breakpoint could be taken as a thermal source because of heat generated by a HVD spark. The mould geometry could be approximately taken as a semi-infinite slab of finite thickness D, with a rectangular breakpoint of length L_1 and width L_2, located at a depth d, under the front surface whose temperature distribution is to be imaged. The breakpoint plane could be taken as parallel to the upper surface of mould appearing horizontally in the infrared image, and the center of breakpoint plane is set as the axis origin. The thermal reflection from back surface could be neglected because D is a quite big value, the temperature at position (u, v) on the front surface of the sample during HVD spark excitation is simplified as a function of time τ by Eq. (3) [11–14]:

$$\begin{aligned} T(u,v,\tau) = &\frac{1}{2\sqrt{\pi\alpha}}\int_0^{\tau} e^{-\frac{D^2}{4\alpha\tau'}}d\tau' \\ &* \left[erf\left(\frac{L_1/2-u}{\sqrt{4\alpha\tau'}}\right) - erf\left(\frac{u}{\sqrt{4\alpha\tau'}}\right)\right] \\ &* \left[erf\left(\frac{v+L_2/2}{\sqrt{4\alpha\tau'}}\right) - erf\left(\frac{v-L_2/2}{\sqrt{4\alpha\tau'}}\right)\right] \end{aligned} \tag{3}$$

where α is thermal diffusivity of the material, *erf* is the error function, and the amount of heat emission is not included in Eq. (3) because only relative temperature is necessary in the following processes.

In thermosonics or sonicIR, the thermal source could be approximately considered as a stable source. The temperature evolution during the excitation should increase continuously which is similar as expressed in the simplified model in Eq. (3) or the finite element models [15]. And after the removement of heat source, the temperature at defect location should decrease due to heat conduction. When the arc spark is used as heat source, the temperature increase is similar as in thermosonics during the heat excitation with HVD spark, however, it may not be taken as a stable source. In practical applications, the temperature evolution is complicated that the temperature evolution during the heat excitation may not have significant increase as expressed in Eq. (3). However, there is a temperature increase when heat excitation is turned on, and a temperature decrease after the heat excitation is turned off in both techniques.

2.3. The experimental results

Many sections in several different moulds were tested, in all those moulds, the diameter of heating wire is 0.8 mm, the tape