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Nondestructive Evaluation of Surface Defects Using Scanning Infrared Thermography

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Nondestructive evaluation techniques are important for the aircraft industry and infrared scanning systems have the potential to analyze materials and parts, quickly, accurately, and at a reduced cost compared with other systems. This technique has been developed to create an interface using commercial software packages. New hardware components have been designed to work in concert with specially developed analytical models to treat surfaces with changing emissivity and uniformly finished surfaces such as those used in traditional infrared scanning systems. The current scanning system has been tested using crack defects in thin metal sheets with a variety of surface finishes and defect geometries. The system has been successful at detecting defects on coated surfaces on which cracks were oriented parallel to the heating element and at suboptimal angles. However, the system has only been marginally successful at removing artifacts of reflected radiation from the thermographic images, making temperature correction and crack detection difficult.

Nomenclature

J = radiosity
T = temperature
α = absorptivity
ε = emissivity
ρ = reflectivity
Σ = Stefan–Boltzmann constant
τ = transmissivity

Subscripts

actual = true value
amb = ambient
cam = camera
meas = measured quantity
ref = reflected quantity

I. Introduction

NONDESTRUCTIVE evaluation (NDE) is a method in which materials or parts can be evaluated without damaging the part, such that it can be reused [1]. This saves time and money by allowing data to be collected on a specific device, part, or material instead of using general data from published references. In addition, the first signs of failures can be seen before harmful damage is made, thus avoiding the dangerous consequences a failure can bring. NDE is used frequently in situations in which systems undergo cyclic or repeated stresses. These stresses are below the ultimate failure limits, but over time, these smaller stresses can eventually build to fracture. Therefore, it is imperative to scan systems, parts, and materials for these early defects that can ultimately lead to disaster.

There are numerous nondestructive methods currently available for detecting defects in parts or materials, such as x-ray imaging, eddy current testing, and acoustic methods that are available in both ultrasonic and subsonic frequencies. Although each of these techniques has merit and is successful in certain cases, there are situations in which the best technique is still visual hand inspection, in which trained personnel carefully scan parts and materials for dangerous areas. Unsurprisingly, this can take an unusual amount of time, and so there are searches underway to find a system or method that allows for high defect resolution as well as faster analysis. Infrared scanning is one promising method that could potentially meet these requirements.

Infrared scanning systems are not new; they have been used in numerous applications in biology, astronomy, and even the military. Even in basic infrared evaluation, surface temperature is the valued information that is used to infer characteristics of the given item. However, infrared scanning systems can add a new dimension to their capabilities when principles of heat transfer are considered, particularly Fourier's law of heat conduction. Fourier's law states that the amount of heat transfer through a material is based on three factors: temperature gradient, cross-sectional area, and thermal conductivity. Therefore, if the amount of heat transfer is held constant, changes in the thermal conductivity or cross-sectional area directly affect the temperature gradient within the material. As a heat flux passes through a pure substance, it will create a smooth temperature gradient based on the material's thermal conductivity and cross-sectional area. However, if either of the properties varies through a particular part or piece, the temperature gradient will veer from the expected distribution and display anomalies. Although these anomalies might be difficult to detect using physical contact temperature measurement devices, they become very easy to see when using an infrared scanning device [2,3]. From this point, one only has to identify the locations of the temperature anomalies and perform closer examinations to determine the reason for the shift.

The idea of using infrared scanning systems in conjunction with prescribed heat transfer to detect anomalies has been studied for several years [4–11]. Up to this point, most of the systems are purely laboratory variety, in which they are not adapted to real-world applications. Presently, many of these systems are still too complex and the technology too involved to be used by most laymen. There are many opportunities to not only adapt a system to fit more applications, but also to simplify the process to allow for easier acquisition and data processing. The system presented within is an attempt to tackle one particular application: the scanning of airplane skin for crack defects. In addition to this particular application for the aircraft industry, the system created has also been built with a much simpler user interface that will allow for varying levels of analysis complexity that can be contoured to the changing skill level of the user. As well as simplifying the interface, another innovation presented within is the ability to scan materials and parts regardless of their surface coating.

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