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A reverse engineering methodology for nickel alloy turbine blades with internal features

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ABSTRACT

The scope of this work is to present a reverse engineering (RE) methodology for freeform surfaces, based on a case study of a turbine blade made of Inconel, including the reconstruction of its internal cooling system. The methodology uses an optical scanner and X-ray computed tomography (CT) equipment. Traceability of the measurements was obtained through the use of a Modular Freeform Gage (MFG). An uncertainty budget is presented for both measuring technologies and results show that the RE methodology presented is promising when comparing uncertainty values against common industrial tolerances.

Introduction

In order to face the strong competition existing in the global scenario, the aerospace industry is nowadays reducing the number of large components through re-engineering of product, design and manufacturing processes. Such modifications range from changes in the available design data to changes in manufacturing hardware and software technology [1].

Reverse engineering (RE) is one of the methodologies for obtaining information of these components in order to improve them. RE of aerospace components plays a crucial role in reconstructing mathematical geometric models for FEM analysis, rapid prototyping and the re-engineering procedures [2,3].

This work focuses on the development and study of a RE methodology for an aerospace turbine blade made of a nickel super alloy. The blade is formed having surfaces with free form shapes. This kind of surfaces may be classified as complex geometrical features, which cannot be represented as a combination of planes, spheres, cylinders or other simple shapes [4].

Turbine blades are subjected to extreme working conditions where the temperature may be raised as high as 1500 °C, with high mechanical and thermal stresses. To overcome these conditions, turbine blades are designed with an internal cooling system made out of several veins. Cooling air at around 650 °C is extracted from the compressor and passes through the air foils, lowering the temperature of the blade to approximately 1000 °C [5,6].

Currently, most of the research work in the area of RE is focused on the accuracy of the scanning process or the development of reconstruction procedures for complex external surfaces [1–3, 7,8]. The present work aims to develop a high accuracy and reliable method to perform RE operations on complex freeform components, taking into consideration the internal features of the component.

The structure of this work starts with a brief explanation of the technologies used and a description of the proposed methodology. The experimental procedure, based on a case study of a small turbine blade of a jet engine with a cooling system, is presented. Results of the investigation are discussed and an evaluation of the uncertainty of the measurements obtained using three different measuring technologies is presented.

Reverse engineering technologies

The main task of RE is the reconstruction of an object whose geometry is composed of a number of surfaces of different shapes. The basic process stages of RE are [9]:

- Coordinate measurements.
- Surface approximation.
- Use of data for specific tasks.

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The proposed methodology uses two different measuring technologies for measuring 3D coordinates onto the work piece surface. This section presents a small briefing of each technology used: optical scanning and X-ray computed tomography.

Optical scanning

Triangulation sensors in optical scanners have become frequently employed for dimensional metrology in a wide variety of industries that go from the automotive to the medical industry [10,11]. Compared to mechanical probing systems, e.g., a tactile coordinate measuring machine (CMM), optical methods often can acquire more data in less time, with the advantages of measuring parts without contacting them [10].

These kinds of technologies have been used in RE procedures, but the scanning result may not achieve a high accuracy and have a higher uncertainty when compared to tactile systems [12]. Another disadvantage of optical systems comes from the preparation required for measurements of reflective parts. Such preparation requires spraying parts, which affects the accuracy of the measurement.

In order to address these issues, the combination of optical measurements and tactile systems, even at different times and locations, can yield a highly accurate 3D representation of the physical object, while reducing the time required for the data acquisition process [8,13].

For this work, an optical system based on a triangulation sensor was used to scan the external surface of a work piece. In order to ensure the quality and traceability of the measurements, a tactile CMM was used.

X-ray computed tomography

X-ray computed tomography (CT) has recently become an accepted inspection tool for a large number of industrial applications. Using CT, the internal geometrical features of a work piece can be measured without destroying it, which makes it unique and in many cases preferable to commonly used tactile or optical systems [12–15]. However, there are several sources of error in CT measurements that may affect scan quality and measurement accuracy. These sources include work piece related interaction effects of X-ray radiation (i.e. work piece material), source power (voltage and current), work piece orientation, etc. An example of these sources of error is beam hardening, which refers to the fact that, as the X-ray beam moves through material, low energy photons (i.e. soft X-rays) are more frequently attenuated than high-energy photons, resulting in a non-linear relationship between penetration lengths and attenuation coefficients and, as a consequence, to image artefacts in CT images. Another example is scatter radiation caused by scattered photons inside the work piece, resulting in image contrast losses. A classical approach to reduce, e.g., beam hardening artefacts, is to place a thin plate of Cu or Al in between the X-ray source and the work piece to filter out soft X-rays and to perform CT measurements with only the hard spectrum of the entire photon energy spectrum [16].

For this work, a CT scan for the RE of the internal features of a work piece, in our case a turbine plate, was used. The uncertainty of the internal measurements was not determined with the CMM, since this would have required destroying the turbine plate.

Methodology

The proposed RE methodology is shown in Fig. 1. The procedure involves a reference fixture as a basis for the digitization and measuring procedures. The measurements are then carried out on an optical scanner, CT scanner and a CMM, respectively.

The CMM is used for the generation of reference measures of the part and in order to achieve traceability to the meter unit, using a

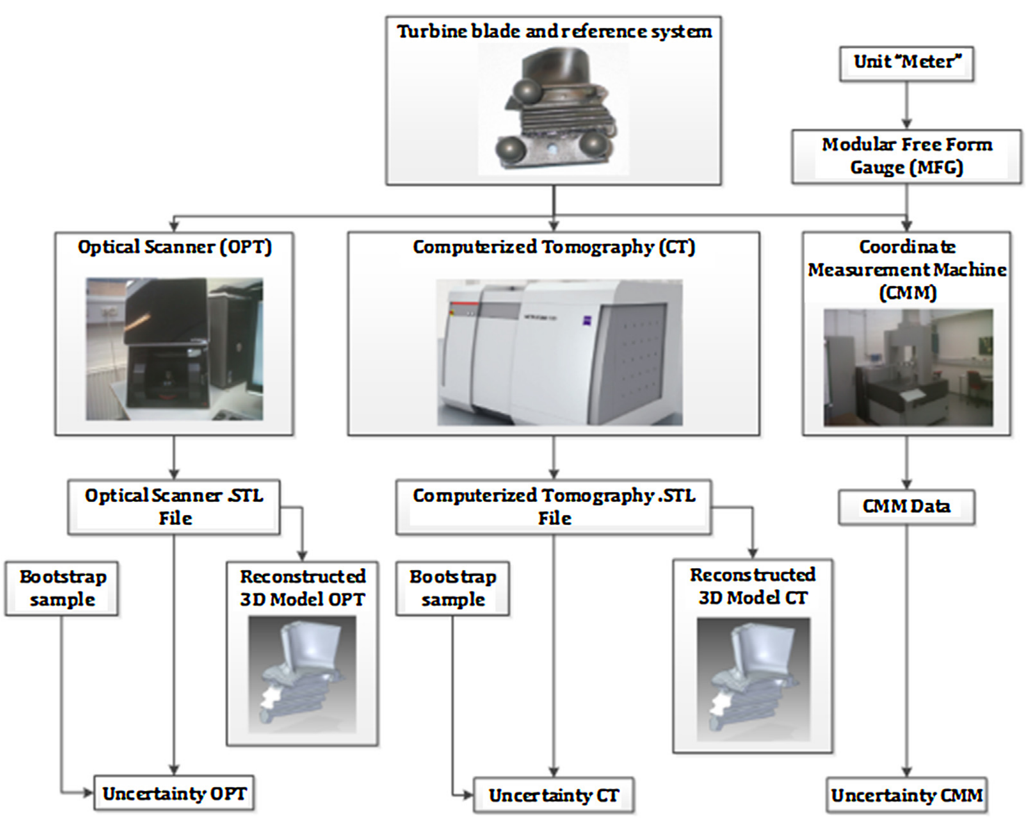

Fig. 1. Proposed RE methodology.