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MODELING TURBINE BLADE CRACK DETECTION IN SONIC IR IMAGING WITH A METHOD OF CREATING FLAT CRACK SURFACE IN FEA (PREPRINT)

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14. ABSTRACT

Sonic Infrared (IR) Imaging Nondestructive Evaluation (NDE) technology has shown inherent advantages for defect detection in aircraft structures. It can image a wide area within a second or two for metal material targets. Due to high stresses aircraft engine turbine blades bear during their operation, fatigue cracks can form after a number of hours of service. Sonic IR imaging shows great potential for this application. However, interaction of the sonic excitation and subsequent crack heating requires fundamental understanding of physical and thermal processes in complex geometries such as turbine blades. Simulation modeling can provide results to better understand contributions of some parameters where experimental arrangements are hard to produce. Because of the irregular shapes of turbine blades, their Finite Element Analysis (FEA) models are always dominated by tetra elements. The usual procedure of using tetra elements, it is very difficult to create flat crack surface in such complex shapes. A new method to create a flat crack surface is designed for an actual blade.

15. SUBJECT TERMS

sonic infrared imaging, fea, crack detection, turbine blade

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MODELING TURBINE BLADE CRACK DETECTION IN SONIC IR IMAGING WITH A METHOD OF CREATING FLAT CRACK SURFACE IN FEA

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ABSTRACT. Sonic Infrared (IR) Imaging Nondestructive Evaluation (NDE) technology has shown inherent advantages for defect detection in aircraft structures. It can image a wide area within a second or two for metal material targets. Due to high stresses aircraft engine turbine blades bear during their operation, fatigue cracks can form after a number of hours of service. Sonic IR imaging shows great potential for this application. However, interaction of the sonic excitation and subsequent crack heating requires fundamental understanding of physical and thermal processes in complex geometries such as turbine blades. Simulation modeling can provide results to better understand contributions of some parameters where experimental arrangements are hard to produce. Because of the irregular shapes of turbine blades, their Finite Element Analysis (FEA) models are always dominated by tetra elements. The usual procedure of using tetra elements, it is very difficult to create flat crack surface in such complex shapes. A new method to create a flat crack surface is designed for an actual blade. In this paper, we will present data of modeling turbine blade crack detection with external ultrasound excitation as the results of applying this new method, guided by our experimental Sonic IR imaging study on the blade.

Keywords: Sonic Infrared Imaging, FEA, Crack Detection, Turbine Blade
PACS: 81.70-q, 81.70.Fy, 81.70Cv, 81.70Pg

INTRODUCTION

Turbine blades play very important roles in turbine engines and face high temperatures, high stresses, and high vibration environment. Due to the strenuous environment that aircraft engine turbine blades bear during operation, fatigue cracks can form after a number of hours of service. Since the failure of one blade can potentially destroy the whole engine, NDE technologies for turbine blades before their failure are critical.

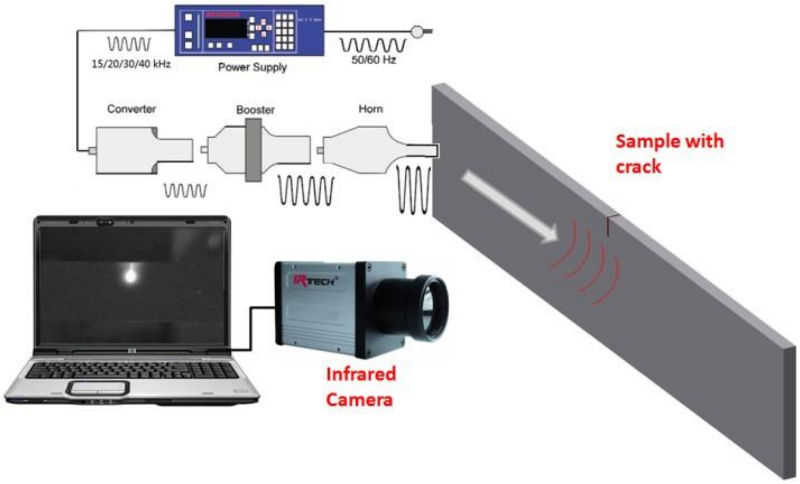


FIGURE 1. Sonic IR technology experimental arrangement

Sonic IR is a relative new member in NDE technology family and it has shown great potential to detect defects in various materials and structures [1-10]. In Sonic IR technology, the ultrasound energy is converted in the material into thermal energy and the defects can be directly seen by detecting the thermal radiation in a sample via a thermal camera. Fig.1 shows the experimental arrangement of Sonic IR technology in our lab. We use Branson welders as ultrasound sources to introduce ultrasound into a sample and when the propagating ultrasound wave interacts with defects in a blade, such as a crack, the two surfaces of the crack will produce frictional heating by rubbing. Defects in the sample then are readily shown in the acquired images.

Because turbine blades are made of metal, the attenuation of ultrasound in them is small enough that we can detect defects far from the exciting source. Failure of a blade begins with the initiation of small fatigue cracks, and it generally can be easily detected by Sonic IR technology. The image in Figure 2 shows that multiple tiny cracks are detected in a single Sonic IR excitation of a small turbine blade. The dimension of these cracks is approximately 0.4mm. As shown, Sonic IR technology can detect such small cracks in turbine blades effectively.

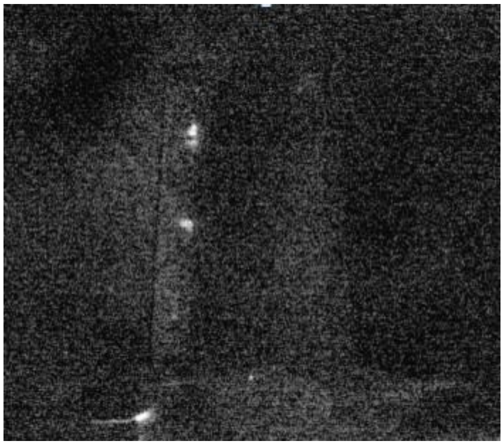


FIGURE 2. Cracks detected in a small commercial turbine blade

FINITE ELEMENTS ANALYSIS

To learn more about some fundamental physical and thermal processes in Sonic IR which cannot be learned experimentally, FEA method may fill the gap. Because of the irregular shapes, turbine blades are often meshed with tetra elements, in which the usual method of creating crack is challenged. Usually, a crack in a FEA model is created by detaching the element nodes along the assumed crack surface to form two flat surfaces of the crack. However, it is almost impossible to create a flat crack by detaching those tetra element nodes that don't locate on a flat plane. In this paper, an improved method is introduced for creating a flat surface crack in irregular turbine blades and the simulation results are presented. This method can be applied to any shape samples while creating meshed models with any type of elements. A commercial turbine blade is used as an example to show this method.

Step 1: Partition. Figure 3 shows a commercial turbine blade created in Inventor, a 3D CAD software. The whole length of this blade is approximately 220mm. The first step of our method is to use the "split" function in Inventor to partition the blade into two parts with a predefined plane exactly along the crack position. The partition plane is highlighted in yellow in Figure 3.

Step 2: Unite. After splitted in Inventor, the blade model is transferred into ANSYS and the two parts of blade are united with Boolean operation in ANSYS. The blade model is restored as a whole part again and the flat interface is left in it, as shown in Figure 4.

Step 3: Mesh and Refine. After the blade is meshed with tetra elements, the tetra elements are along the interface, from which the flat crack will be created. In order to improve the precision of the results, it is necessary to refine the mesh around the crack with the "Sizing" function in ANSYS. As shown in Figure 5, the elements around the crack are much finer than others.

Step 4: Detach and Define contact. After the LS-DYNA file produced in ANSYS is imported into Hypermesh, we can follow the typical simulation procedures to define the crack and finish the simulation. The last step of creating a flat crack is to detach the nodes along the interface left after partition and unite operations. The size of the crack depends on the number of nodes detached. Figure 6 demonstrates one of the contact surfaces created in Hypermesh. The size of the contact surface is approximately 3.5x3mm^2, and the dynamic friction coefficient is 0.35. After defining contact surfaces and the properties of the contact, we then finished the whole process of creating a flat surface crack in a blade meshed with tetra elements.

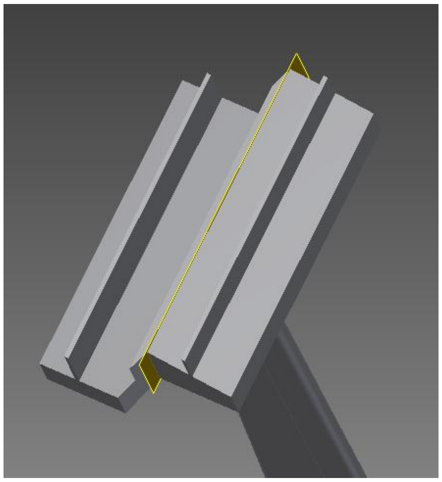


FIGURE 3. A commercial turbine blade CAD model split with a predefined plane

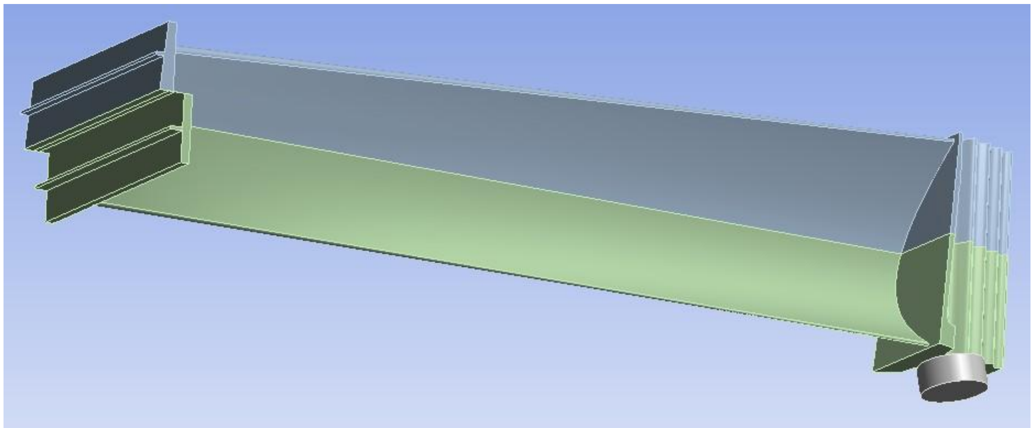


FIGURE 4. Two split parts of blades are united and the interface between them left

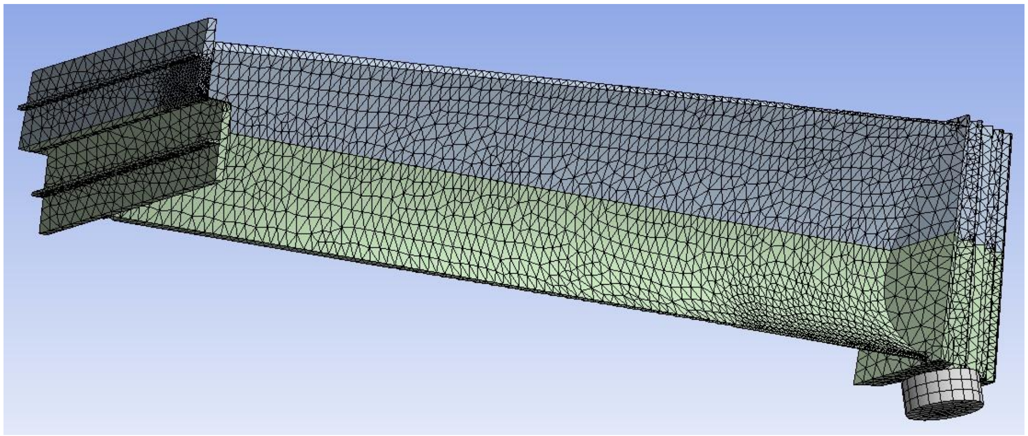
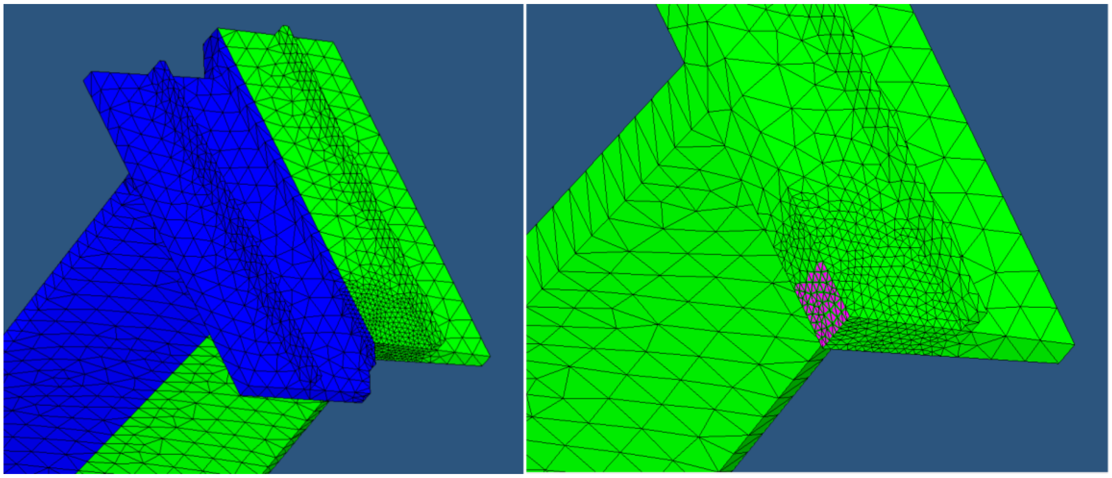


FIGURE 5. The commercial blade meshed with tetra elements and the mesh around crack is refined



a) The blade model shown in Hypermesh

b) A contact surface defined in Hypermesh

FIGURE 6. FEA model of the blade

RESULTS OF FEA AND COMPARISON WITH EXPERIMENTAL DATA

After defining the ultrasound excitation source and thermal properties, the simulation of this blade can proceed with LS-DYNA. The cylinder in Figures 4 and 5 represents an ultrasound transducer, which introduced a 0.6 second 20 kHz sound pulse into the blade model. The diameter of the transducer is 12mm and the amplitude of the excitation is 10 microns. After the 0.6 second excitation, the thermal distribution around the crack is shown in Figure 7, and the Temperature–Time (T-T) plots of two nodes are shown in the top graph of Figure 8. The bottom graph in Figure 8 shows the T-T plot around the corresponding crack from an experiment. It is clear the simulation T-T plot has similar trend as the experimental results. Since we know little about the crack properties in the blade, we do not compare the specific temperature values in these curves.

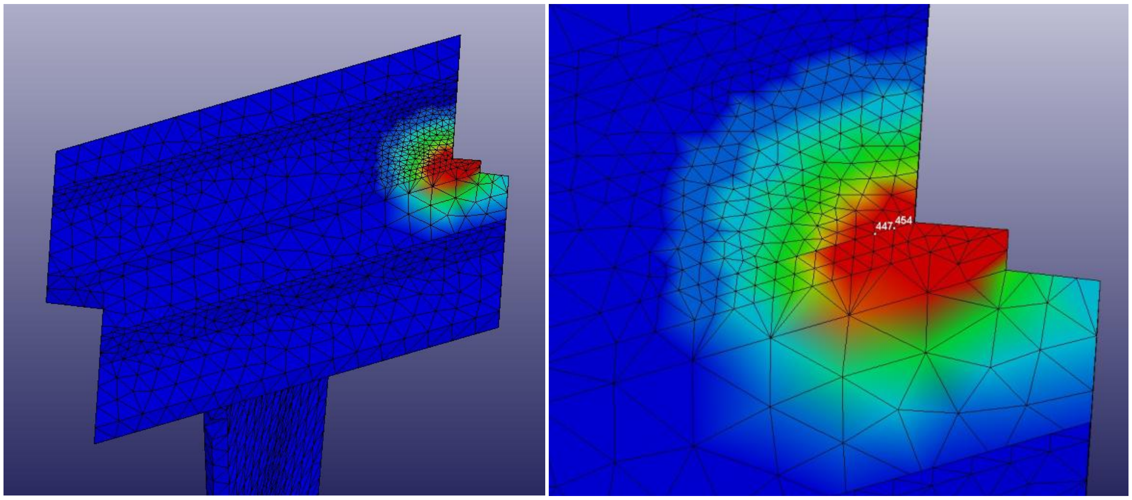


FIGURE 7. Thermal distribution around crack after 0.6 second excitation from FEA modeling

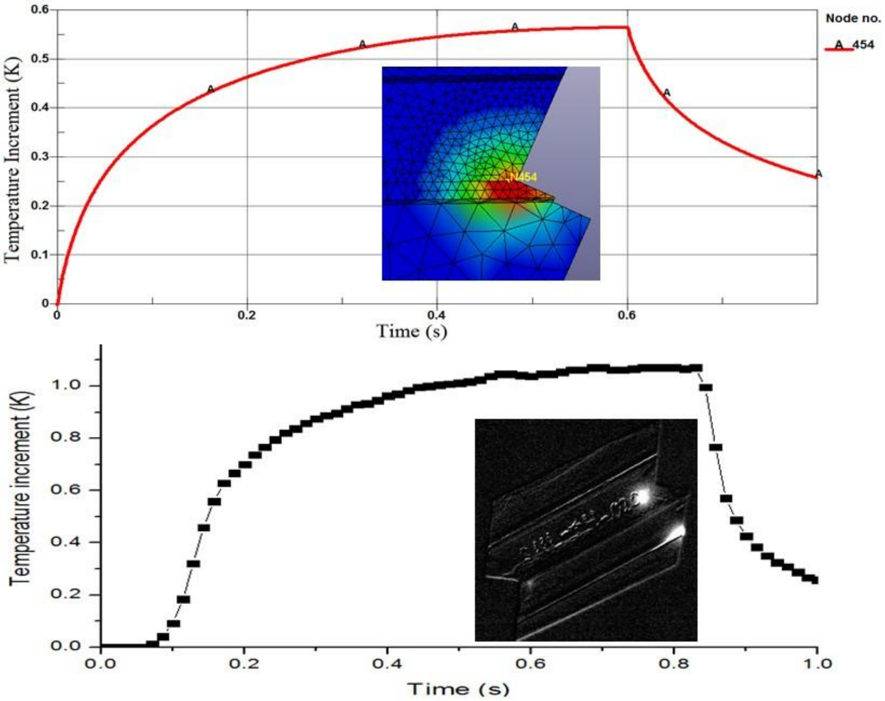


FIGURE 8. The Temperature -Time plots at the same spot from simulation and experiment

CONCLUSION

Sonic IR technology can detect defects in turbine blades with different sizes and shapes. Finite Element Analysis is a good tool which can be used to model material and structural properties, which define how the structure will react to certain loading conditions in complex geometries such as turbine blades. A method creating flat surface cracks in FEA model is presented in this paper. The FEA results from this method produce the same trend with the experimental data. Further investigation will be carried out.

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