Integrative In-situ Detection of Defects in Aeroengine Blades Combining Borescope and Eddy Current Techniques

Wugang TIAN, Mengchun PAN, Dixiang CHEN

College of Mechatronics Engineering and Automation, National University of Defense Technology, Changsha, Hunan, China; Phone: +86-731-4576479, Fax: +86-731-4576479;
E-mail: twg_1978@163.com, pmc_nudt@vip.163.com, Chendixiang@163.com

Abstract
Defects often arise in aeroengine blades, which will endanger flight security, thus nondestructive testing (NDT) should be carried out during the service period of aeroengines. Ultrasonic, radiography and liquid penetration inspection techniques are hardly be used to achieve in-situ detection of blade defects. Borescope is a widely used means to detect and examine surface cracks inside narrow tubes or chambers, but it cannot find subsurface defects and estimate the depth of cracks. Although eddy current is sensitive to surface and subsurface defects in metal material, the testing system is difficult to be operated when the interface between the eddy current probe and the object cannot come into view. Because these two techniques are complementary, it is a feasible way to achieve in-situ detection through combining them into a single probe. In this paper, an integrative testing probe combining borescope and eddy current sensor was designed for aeroengine blades, and a testing example of aeroengine blade using the probe was given. The testing results show that this inspection method can be used to detect cracks with good performance, and the cracks can be estimated quantitatively. It was concluded that this integrative testing technique is superior to single inspection, and it is very valuable in practical application.

Keywords: In-situ detection, borescope, eddy current, aeroengine blade

1. Introduction

Aeroengine blades are crucial parts of airplane. They usually work in the condition of high temperature, high pressure and high rotation speed. Fatigue cracks easily arise in the aeroengine blades. They would grow quickly, and make blades rupture, which endanger flight security badly [1]. Owing to the special structure of aeroengine, the conventional nondestructive testing techniques like magnetic particle, liquid penetrate, radiographic testing and so on can not be used for in-situ detecting cracks of aeroengine blades [2-3]. At present, blades were in-situ detected using borescope. But it is difficult to estimate cracks of aeroengine blades [4]. Because aeroengine blades were treated by shot peen on the surface in order to enhance work life of aeroengine blades, blades substrate surface become subsurface. Experiments and failure analysis show cracks appear in the subsurface of the blades by shot peen treatment. Combining several techniques within one probe will be a feasible means.

Eddy current testing is an important nondestructive testing technique. Eddy current testing need not use coupling medium, so can detect defects quickly. It is sensitive to surface and subsurface flaws of metal material and can evaluate the depth of cracks [5-6]. But eddy current testing has limitations too. When the interface between the eddy current probe and the object cannot come into view, it is hardly to operate correctly.

Borescope and eddy current testing techniques are complementary, and no detrimental interference is observed. A dual probe containing an eddy current probe and a borescope was designed and realized, which can completely achieve in-situ detecting cracks in aeroengine blades.

2. Borescope and eddy current integrative NDT techniques

2.1 Borescope and eddy current integrative NDT system
Figure 1 shows the schematic structure of borescope and eddy current integrative NDT system. The system adopts framework design thought of modularization, which divides the system into sensor module and computer module. The sensor module mainly contains borescope and eddy current dual probe. It mainly achieves detecting the defects and transmitting the data to the computer module. The computer module is made up of borescope image acquisition, image processing, ADC, signal processing, defects evaluation, information fusion, and human interface, etc.

2.2 Borescope and eddy current integrative probe

The integrative probe has been designed to hold a borescope and an eddy current probe as shown in Figure 2. The borescope is placed in the front. User can observe the image of the sample through borescope which can make the eddy current probe scanned over the sample exactly. The borescope is flexible and rotatable. The eddy current probe is placed in the bottom side of supported shank which can make the lift-off between probe and sample decrease. No interference was found between the two probes.

In order to enhance work life of components detected in aeroengine, they usually were disposed on surface like painting, shot peen, and so on. The conventional eddy current probe is limited to detect defects of these components in aeroengine because it has lift-off effect. A uniform eddy current probe was adopted in this paper. It nearly has no lift-off effect [7-8]. A uniform eddy current probe is composed of an exciting tangential coil and a small pancake detecting coil as shown in figure 3. It can evaluate the cracks length and depth quantitatively.
Borescope probe uses video borescope that is a new kind of borescope. It is mainly composed of illuminant, lenses and image sensor. In this paper, the illuminant adopts four white LED as shown in figure 4(a). The outer diameter of the borescope is 10mm. The lenses adopt a reverse-telephoto configuration [9] as shown in figure 4(b). It has character such as large angle of view, large depth of field, low distortion, long back working distance, large relative aperture, and small exterior size.

![Figure 4. Schematic structure of video borescope](image)

3. Simulation analysis of the uniform eddy current probe

To analysis the phenomena that the uniform eddy current probe affects on the blade and optimize the sensor design, a three dimensional finite element method (3D FEM) has been performed [10]. The 3D FEM model was shown in figure 5. All material properties were used as real values. The size of exciting coil is 20mm in width, 30mm in length, and 20mm in height. The size of the crack is 10mm in length, 1mm in width, and 1mm in depth. The testing frequency is 10 kHz. The current of exciting coil is perpendicular to the crack.

The inductive eddy current is shown in figure 6. The eddy current is nearly uniform under the exciting coil. The exciting coil moves along the scan direction. The component \( B_z \) of magnetic induction density was shown in figure 7 at each point per mm. The distance of peak of \( B_z \) gives the crack length 10mm.

![Figure 5. 3D FEM model](image)

![Figure 6. Eddy current of the blade](image)
4. Experiment

4.1 Experiment samples

Two experiment samples were made. One is a real aeroengine blade sample. The other is 4mm thickness aluminum alloy sample. The real aeroengine blade sample has two cracks. The size of one crack is 10mm in length, 0.5mm in width, and 1mm in depth. The other is 2mm in length, 0.5mm in width, and 1mm in depth, as shown in figure 8. The aluminum alloy sample has six cracks. The six cracks length and width are all 10mm×0.5mm. Their depth are 0.5mm, 0.8mm, 1.0mm, 1.2mm, 1.5mm and 2.0mm, as shown in figure 9. The real blade sample was installed in the areoengine. The cracks were in-situ detected with borescope and eddy current integrative NDT techniques.

4.2 Experiment results

Figure 10 shows the eddy current testing results of the real blade sample. From the curve, we can estimate that the cracks length is about 10mm and 20mm using projection in x axial from the minimum to the maximum of the eddy current inductive voltage amplitude, which was in accordance with the FEM simulation results.

Figure 11 shows the borescope detecting result of the real blade sample. From the borescope image, we can observe the crack. Through the image, in order to get the cracks length we can operate the borescope and eddy current integrative probe to make the eddy current sensor scan along the cracks length direction.

Figure 12 shows the eddy current testing results of the aluminum alloy sample. From the curve, we can estimate the cracks depth by the eddy current inductive voltage amplitude. Because the crack depth is deeper, the eddy current inductive voltage amplitude is larger.
5. Conclusions
The borescope and eddy current integrative NDT techniques were described. The dual probe containing an eddy current probe and borescope for in-situ detecting defects in aeroengine blades was designed. A real aeroengine blade and aluminum alloy samples containing machined cracks was detected using the integrative NDT techniques. The primary experimental results show that the integrative techniques can realize in-situ nondestructive for aeroengine blades, and that cracks length and depth can be evaluated quantificationally. It would be valuable for aeroengine blades practical in-situ nondestructive testing.

References