Comparison of Non-destructive Testing Methods for Fan Blades

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Abstract. Among the power components of an engine, the probability of damage to the fan blades is extremely high. The broken fragments may fly out with the airflow, injuring the parts at the rear of the engine casing and even breaking down the casing, seriously affecting the reliability and working efficiency of the engine, so the non-destructive testing of the fan blades is of far-reaching significance to ensure the normal and stable operation of the engine, and can also prevent the occurrence of major aviation accidents. In this paper, several non-destructive testing methods are analyzed and compared for specific blades, in order to find the most suitable detection methods.

Keywords: Fan blades, Nondestructive testing method comparison, Phased array testing technology.

1 Application background

Because the fan blades are often in a very harsh working environment, with the increase of flight time, it is easy to cause fatigue fracture failure. Therefore, it is required that the blade material should have high lasting strength and creep strength, sufficient toughness, good thermal fatigue resistance and mechanical fatigue resistance, and high resistance to high temperature oxidation and thermal corrosion at high temperatures. On the other hand, due to the unevenness of the temperature that the blade bears, so that it has a high thermal stress, the fan blade needs to withstand high temperature and high stress in the process of service, and the high-temperature alloy is usually used as the material for making the fan blade[1].

The particularity of the working environment has led to a very high damage rate of the blade, once the defect occurs, it will cause unimaginable serious consequences to the engine, so in order to prevent the occurrence of major aviation accidents, the timely discovery of fan blade defects is particularly important, and this article discusses that through the comparison of the advantages and disadvantages of various non-destructive testing methods, it is hoped that the most reasonable and practical detection methods can be obtained in the actual application environment to reduce the failure rate of the engine.

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2 The detection method is determined from the failure mode

The main failure modes of fan blades include low-cycle fatigue fracture failure, high-cycle fatigue fracture failure, high-temperature creep fracture failure, fretting fatigue and corrosion fatigue fracture failure. There are many reasons for the damage of high-pressure fan blades, such as thermomechanical fatigue caused by high-temperature gas impacting the blades for a long time; sulfur and oxidative corrosion of gas; Cracks, corrosion and coating peeling caused by inhalation of sand and dust in harsh flight environments[2].

Without damaging the workpiece, it can be determined by non-destructive testing. The common methods for blade detection usually are penetrant testing, magnetic particle testing, eddy current testing, radiographic testing, ultrasonic testing, the above detection methods have their own advantages and limitations, and the types and performance indicators of detection defects are also different[3-5].

3 Comparison of various detection methods

3.1 Surface defect detection means

Restricted by the material, shape, surface roughness, working environment and other conditions of the blade, there are penetrating flaw detection, magnetic particle testing method, eddy current testing method and surface ultrasonic flaw detection for surface and near-surface defect detection. Magnetic particle testing is limited by the material, and can only detect ferromagnetic materials, while ferromagnetic materials are rarely used in engine blades, so the practical use of this method is not very extensive. Eddy current testing technology requires the fan blade to be made of aluminum alloy material, which can complete the in-situ flaw detection of the blade, but it is also limited by the material and affects the scope of use. Although surface ultrasonic flaw detection can also be used to detect surface quality, this method is greatly affected by the surface shape and surface finish of the workpiece, so it cannot be used in realistic inspection scenarios[6].Conventional blade defect detection methods, such as penetrant flaw detection, magnetic particle testing method, eddy current testing method and surface ultrasonic flaw detection, are mainly used in the detection of opening defects on the blade surface, near the surface and below the surface.

3.2 Internal defect detection means

For the inspection of internal defects, ultrasonic testing and radiographic inspection are commonly used. Both methods have their advantages and disadvantages:

3.2.1 Prospect analysis of radiographic inspection technology in blade inspection

Radiographic inspection technology has no requirements for appearance shape and material, suitable for the characteristics of various materials and defects, and has high sensitivity, high resolution, high precision, can better quantify defects, but when choosing to use radiographic inspection, it is necessary to consider its cost, operational difficulty and radiation risk and other factors, considering the actual application environment, such as the safety factors of personnel near the aircraft docking, there are many hidden dangers, so there is no widespread operability.

3.2.2 Prospect analysis of blade inspection in ultrasonic testing technology

The ultrasonic testing method is simple and easy to operate, convenient and fast, and has strong ultrasonic penetration, good directionality and concentrated sound wave energy. Restricted by the geometry of the blade, the ultrasonic inspection method generally uses high-frequency, small-size, shear wave oblique probe for detection, but due to the extremely high utilization rate of the blade layer composite material, the probability of missing detection is also continuously improved, which also seriously affects the accuracy of detection, and the low detection accuracy also directly affects the production efficiency and production cost.

In the past year, a large number of ultrasonic testing tests have been carried out on leaf testing, and the accuracy calculated is shown in the figure 1.below after the analysis and comparison of the detection accuracy of 244 samples with detailed records and follow-up analysis:

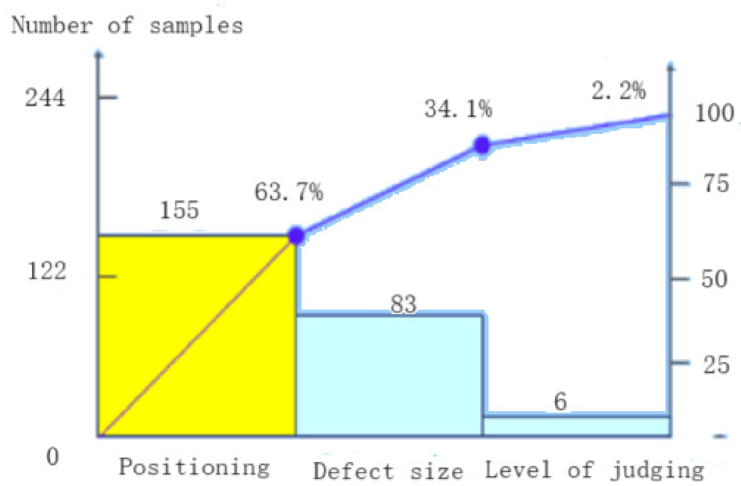

Fig.1. Factors affecting the accuracy of ultrasonic testing

In view of the above factors that affect the accuracy of ultrasonic testing, after our long-term work experience summary, and a period of time to track the detection process of the inspectors, we found that the main factors affecting the accuracy of ultrasonic testing:

1. The measured probe parameters are inaccurate

2. The proportion of baseline scanning is inaccurate

3. Ultrasonic is insensitive to composite materials

4. The inspectors have incomplete knowledge of professional knowledge and the influence of human factors in the actual operation process

The detection accuracy information is shown in Table 1.below:

Table 1. Detection Accuracy Information Table

Serial number	Sample type	Sample size	Inaccuracy rate
1	Inaccurate positioning	155	63.7%
2	Inaccurate defect size measurements	83	34.1%
3	The level judgment is not accurate	6	2.2%

In view of the above factors that affect the accuracy of ultrasonic testing, after our long-term work experience and tracking the detection process of inspectors for a period of time, we found that the main factors affecting the accuracy of ultrasonic testing are:

1. The measured probe parameters are inaccurate

2. The proportion of baseline scanning is not adjusted accurately

3. Ultrasonic is insensitive to composite materials

4. The inspectors have incomplete knowledge of professional knowledge and the influence of human factors in the actual operation process

Through tracking, investigation and statistical findings, the following measures can improve the accuracy of ultrasonic testing to a certain extent:

1. Inspectors can improve the calibration accuracy of probe parameters, use CSK-I.A comparison test block to repeatedly measure probe parameters 3 times or more in accordance with the requirements of specifications and standards, and take the average value as the detection parameters.

2. The inspector uses CSK-I.A, RB-2 and other comparison test blocks to scientifically and repeatedly adjust 3 times or more in accordance with the requirements of specifications and standards, so as to make the baseline scanning ratio as accurate as possible, so as to reduce the positioning error caused by the inaccurate baseline scanning ratio and improve the accuracy of probe parameters.

3. Improve the professional knowledge of testing personnel, and consolidate the professional foundation through training.

4. Use multi-probe and multi-angle detection scheme to improve the defect miss detection rate.

Combined with the above survey sampling, it is found that the accuracy and uncontrollability of ultrasonic detection of leaves are relatively high, and although targeted measures are taken, it will still affect the detection results to a certain extent. In view of the particularity of blade inspection, it is still hoped to find a more stable, more concise and procedural method to improve the accuracy of the inspection results and the detection rate of defects.

3.3 Phased array inspection technology

With the development of the industry, the requirements for non-destructive testing technology are also constantly improving, phased array ultrasonic testing technology has incomparable superior reliability in conventional ultrasonic testing technology, due to the use of electronic control of sound beam focusing and scanning, can reduce the rapid movement of the probe for rapid scanning in order to improve the detection speed, and can detect complex geometric workpieces; Detection resolution, signal-to-noise ratio, and sensitivity can all be improved through optimal control of focus size, focal depth, and beam direction[7].A phased array ultrasonic transducer consists of a series of piezoelectric elements arranged in a formation, each with a separate electronic unit that controls its transmitting and receiving delays. The phased array transducer generates an ultrasonic signal when excited by a high-frequency electrical signal with a frequency of 650kHz-20MHz. Ultrasonic wave acoustic field control is to control the system to adjust the difference between the pulses excited by each element, which is emitted through a phased array polycrystalline transducer, and then enters the specimen through the coupling medium.

4 Inspection steps for phased array technology for fan blades

Phased array ultrasonic testing technology is a major advancement in ultrasonic nondestructive testing technology, which has a large scanning range, high efficiency, and a very low probability of missed detection, so it has been greatly used in the inspection process of fan blades[8].

The following is an example of the Olympus Omniscan2 series equipment commonly used in aircraft fan blades, and the basic steps of inspection can be described in detail, from which the operation can be standardized, so as to minimize the influence of human factors.

A 200x120x6.5mm titanium alloy plate is usually used as the measurement test block (as shown in the Figure 2.below), and its surface is engraved with a groove with a depth of 1～6mm, so that the components on the phased array probe are corrected when the probe echo passes through the 5.5mm position, so that the sensitivity of the 64 elements on the probe is consistent.

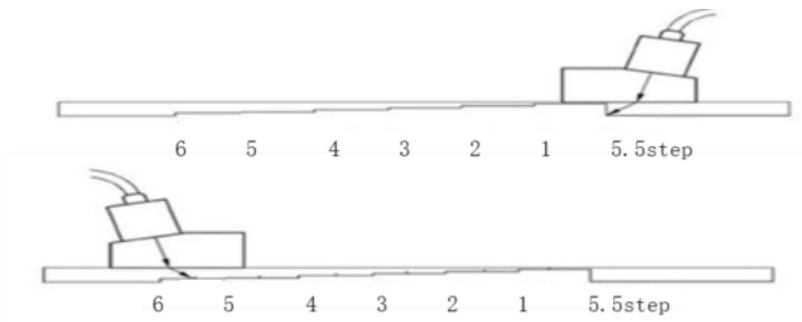

Fig.2. A 200x120x6.5mm titanium alloy plate

Fix the special scanning frame to the blade to be detected, determine that the probe and the blade surface are tightly attached, and then press the probe and move in an orderly manner, so that the probe passes through every part of the fan blade, the signal height in the display screen is greater than 60% of the scale of the blade is the feedback of the defect signal, which needs to be paid enough attention, and if the wave height is basically the same twice, it can be judged as an unqualified blade, which can be repaired or scrapped. The inspection steps are shown in Figure 3.below.

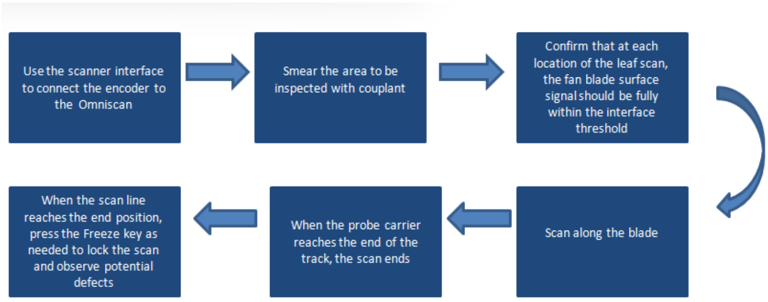

Fig.3. Inspection steps for phased array technology

In addition to many advantages, ultrasonic phased array detection technology is not very perfect, and there are aspects that need to be further improved, such as the integration of many components to make the probe too large, especially in the narrow space on the aircraft, many places are difficult to use, how to do a good job of miniaturized probe is a major trend in the future industry. In addition, due to the large number of probe wires, which are very delicate and easy to damage, the thermal insulation and destructive defense of the outside of the wires also need to be improved in the future[9]. Finally, because the instrument parameter setting is very complex, there are many buttons, and the operation is inconvenient, especially for beginners, it is very challenging to control the instrument, and how to make the instrument interface as concise as possible and the operation is more humanized in the future is also the key area of research[10].

5 Summary and outlook

In the non-destructive testing methods of blades, in addition to the above-mentioned detection methods, there are other non-destructive testing methods, such as: industrial CT technology, infrared thermal imaging detection technology, metal magnetic memory method, etc. Compared with traditional non-destructive testing methods, they also have many advantages, but due to the imperfection of technology and the limitations of use scenarios, they have not been widely used.

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