Materials Physics and Mechanics 47 (2021) 657-664 Received: May 1, 2021
Research article

DETECTION OF A NEW METHOD FOR CORROSION DEFECTS IN TURBINE IMPELLER BLADES BY NON-DESTRUCTIVE TESTING

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Abstract. The turbine impeller is a separate component that forms an important part of a turbine. These blades are used to extract energy and play a very important and key role in a turbine. The evaluation of the blades can be evaluated by non-destructive tests depending on their shape and dimensions, and the ability to detect the amount of corrosion in these blades is the main discussion of this article, which was accurately measured by ultrasonic testing method. This defect Due to its high performance in turbines in the oil and water industry, it will be an interesting challenge to test it for non-destructive testing. Corrosion diameter is personalized by ultrasound, which is a new method in this test. An experimental test was performed for turbines with defective blades selected from 100 blades with corrosion defects. 20 blades with more corrosion were selected. Defect signal size and defect size are simulated by Comsol software. According to various tests on the size of the corrosion defect diameter, the approximate life and operating hours of each turbine can be largely determined. The relationship between corrosion defect and its hourly function has a direct relationship and a direct effect on it.

Keywords: turbine impeller blades, non-destructive testing, ultrasonic testing, corrosion defect, simulation

1. Introduction

Turbine blades are important components of the turbine that convert the linear motion of high temperature and pressure into the rotational motion of the turbine shaft [1-2]. In the last few decades, in order to achieve greater power and efficiency of gas turbines, their operating temperature has increased. On the other hand, most gas turbine components are exposed to high operating temperatures and high-stress conditions, especially during turbine start-up and stopping times. The same high temperature and centrifugal force applied to the blades reduce the strength and corrosion of the blades. Failure of the blades in a gas turbine will lead to damage to the next rows of the turbine and the shutdown of the power plant [3-4]. A gas turbine is a rotating machine that works with the energy of combustion gases [5]. Each gas turbine includes a compressor to compress the air, a combustion chamber to mix the air with the fuel and its combustion, and a turbine to convert the energy of hot and compressed gases into mechanical energy [6-7]. Part of the mechanical energy produced in the turbine is used to spin the compressor itself, and the rest of the energy, depending on the application of the gas turbine, may spin the generator (turbogenerator), accelerate the air (turbojet and turbofan), or directly (or later) [8-9]. Effects of corrosion, abrasion, surface cracks, or collision of foreign objects are visual indicators of the phenomenon of gas turbine blade destruction. Coagulation of gas turbine blade degradation phase sediments, formation of creep cavities in grain boundaries, decomposition of carbides, and their uneven distribution in the emergence of brittle and brittle phases such as sigma are microstructural indicators of blade degradation

http://dx.doi.org/10.18149/MPM.4742021_14

phenomenon [10]. Degradation factors of gas turbine blades are generally related to both mechanical and corrosion fields. High temperature corrosion that causes equipment problems includes oxidation, carburizing and contamination of the metal, nitrification, corrosion caused by ash and salt, corrosion of salt and molten metal. The effective mechanical factors in the destruction of the turbine blade are creep, fatigue, and thermal fatigue, which are investigated in this article [11]. The duty of the impeller is to transfer the energy of the pump motor to the fluid. Due to the high performance of the impellers, if they are in the oil and gas industry, they will corrode. Butterflies that are tightened with bolts and nuts are repaired and these defects can also be seen with the naked eye [12-13]. Another disadvantage is the micron cracks that form over time. The repair defect of the weldable part is also the porosity defect that occurs in the weld of these blades [14-15]. Rapid identification of defects, the detection of which leads to the catastrophic failure of the part and is economically costly and involves the risk of death, is one of the clear advantages of the rational application of non-destructive testing [16]. This method of evaluation, which is used for moving blades and turbine stator blades, generally includes visual inspection and inspection by the penetrant-colored liquid in the cracks. Sometimes eddy current probes are used in this method. This technique is used to detect cracks in turbine blades. Since stator blades are less sensitive to crack growth than moving blades, this method is sufficient for fixed blades [17-18]. However, since the life of the moving turbine blade ends with the start of the crack, this technique provides the basis for replacing the cracked blades if they are detected. Since the main damage occurred before the crack was detected in the moving blade of the turbine, it is necessary to develop and increase the ability of non-destructive methods for the moving blades. The device (FDDP) that is made in the year can be used to diagnose and diagnose it [19]. In 2012, Jasiczek et al. examined a new approach to the characteristics of gas turbine components affected by pitting corrosion. They tested compressor blades made of scale-resistant martensitic stainless steel, a phenomenon known as pitting corrosion that can occur on component surfaces when exposed to a marine environment. They found that this could lead to surface degradation followed by cracking and further propagation with fatigue in the high cycle as the main condition, and increased gas turbine time performance would have a major effect on the occurrence of pitting corrosion in the axial compressor blades [20]. In 2019, Tian et al. reviewed non-destructive testing methods based on steam turbine blade failure analysis. They reviewed non-destructive testing techniques that included all methods and concluded that non-destructive testing (NDT) technologies play an important role in turbine blade inspection and that different NDT methods have their own advantages and limitations during the detection process of blade defection [21]. In 2020, Wei et al. analyzed on corrosion fatigue cracking mechanism of 17-4PH blade of low-pressure rotor of the steam turbine. The results show that the blade cracks due to corrosion fatigue. Cl^-,K^+react with the turbine blades in the steam environment in physical, chemical, and electrochemical ways, causing local spot corrosion on the blades, forming corrosion pits. In addition, the steam condensated has an erosion effect on the blades, both of which form a corrosion fatigue source. The autocatalytic process of block cells is formed when Cl^-, K^+ reacts with the turbine blades. They considered physical, chemical, and electrochemical pathways to cause local corrosion and corrosion pits on the blades. In addition, condensed steam has an erosion effect on the blades, both of which cause corrosion. They concluded that crack growth was significantly related to the stress, depth, and width of the corrosion pits [22].

In this paper, the corrosion defect in the turbine impeller blades was measured and its size of reduced diameter has been examined. This is a new method that was investigated by ultrasound and the reduction in their diameter was expressed by a new method for determining the amount of corrosion. The extent of these defects was plotted in a diagram, and the performance of the turbine impeller was determined according to hours. With regards to this examination and measurement of corrosion and obtained diagram about the defect, it will be determined efficiency hours and it reduced time of repairs and maintenance. The experimental and simulation results were consistent and the measured defect in simulation confirmed the accuracy of experimental results [23].

2. Experimental test

A turbine in the compressor and turbine parts (compressor turbine or power turbine) has one or more rows of fixed and moving blades. Movable blades, which are also interchangeable, were tested in this test. These blades, which had corrosion defects based on their function, were selected from 100 cut blades, 20 blades with more corroded diameters.

In the experimental test, the ultrasonic wave test was used to measure corrosion defects. The selected probe is a 5 MHz probe in which the impeller is tested by immersion. The test was then performed on a blade that was corroded and showed a certain amount of defect. In this case, we observed the recursive echo of the defect, which fully represents the size and amount of the diameter. Figure 1 shows the amount and size of corrosion diameter in several selected turbine blades by defective and non-defective return echo.

Then, by using the diameter and size of the corrosion, Additive Manufacturing (AM) was proposed for it, which has been approved by industrial societies and many companies and has made great progress. The exact size of the defect meant that the material used for the Additive Manufacturing (AM) test was determinable.

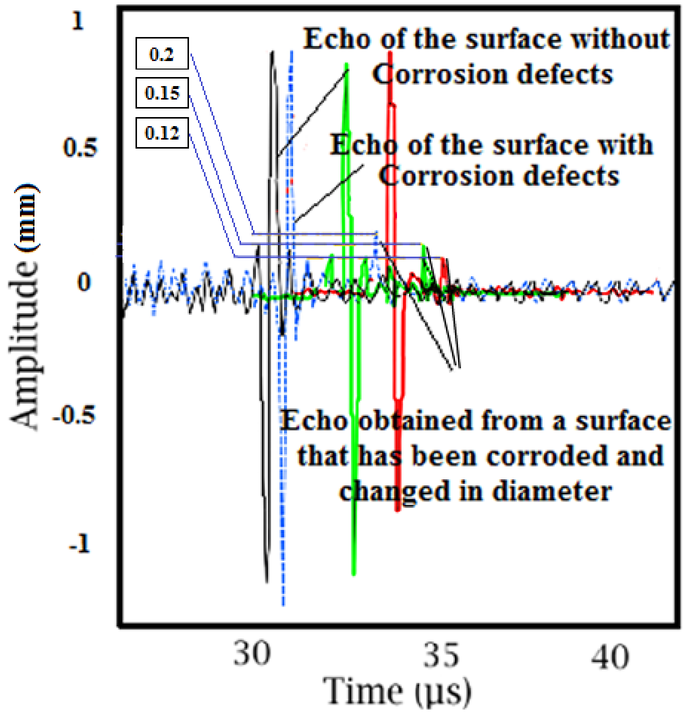

Fig. 1. Return echo of the defect (without/with corrosion defects with the exact size of the corrosion)

Table 1 indicates the corrosion diameter and size in 20 blades of different turbines measured by the A-scan system [23].

Table 1. Ultrasonic test of 20 blades [23] tested were 20 samples of different blades from different turbines with corrosion defects. Each test of the blade was repeated 6 times for accurate measurement diameter of corrosion pit

Piece (blade)	Size of 6 scan samples A (repetition of each test) for accurate measurement of turbine blade corrosion diameter (mm)
Blade 1	0.162, 0.163, 0.161, 0.162, 0160,0161
Blade 2	0.188, 0.188, 0.186, 0.186, 0.187, 0.187
Blade 3	0.111, 0.113, 0.112, 0.112, 0.112, 0.111
Blade 4	0.122, 0.123, 0.123, 0.121, 0.122, 0.122
Blade 5	0.125, 0.125, 0.125, 0.126, 0.124, 0.124
Blade 6	0.131, 0.132, 0.131, 0.131, 0.130, 0.130
Blade 7	0.113, 0.113, 0.113, 0.112, 0.111, 0.111
Blade 8	0.143, 0.144, 0.144, 0.144, 0.143, 0.143
Blade 9	0.140, 0.141, 0.141, 0.141, 0.140, 0.140
Blade 10	0.155, 0.155, 0.157, 0.156, 0.156, 0.156
Blade 11	0.176, 0.177, 0.177, 0.178, 0.175, 0.175
Blade 12	0.121, 0.121, 0.121, 0.122, 0.120, 0.120
Blade 13	0.211, 0.211, 0.211, 0.212, 0.211, 0.212
Blade 14	0.250, 0.251, 0.250, 0.251, 0.252, 0.252
Blade 15	0.243, 0.243, 0.243, 0.243, 0.243, 0.243
Blade 16	0.278, 0.277, 0.277, 0.277, 0.277, 0.276
Blade 17	0.303, 0.304, 0.303, 0.303, 0.303, 0.303
Blade 18	0.311, 0.311, 0.311, 0.312, 0.311, 0.313
Blade 19	0.321, 0.322, 0.321, 0.322, 0.321, 0.321
Blade 20	0.341, 0.342, 0.341, 0.342, 0.341, 0.341

3. Simulation

COMSOL Multiphysics software is a modeling suite for simulating any physical process that can be described by partial differential equations (PDE). The software has a modern analyzer that solves complex problems quickly and accurately while being very flexible in terms of visual structure for ease of use. The simulation in this paper was performed by Comsol software. First, a blade 200 mm long and 15 mm thick, with a width of 80 mm at the bottom and 80 mm at the top, was selected and simulated. The smallest mesh size was selected for the exact answer. Then, according to the size of the defect in the experimental test, the size of the defect was simulated according to the same size. Figures 2 and 3 are different examples of the blade shape on which the defect is simulated. Defects were created in a circular and oval shape with different depressions. To stimulate the probe, the Tone burst function is used, which leads to the focused wave and thus increasing the energy of the wave. In the desired function the central frequency is $f_c = 5$ MHz, which is defined as follows [24]:

$$F(t) = 0/5\sin(2\pi t f_c)\left[1 - \cos\left(\frac{2\pi t f_c}{n}\right)\right]. \tag{1}$$

The excitation signal by applying the Gaussian window is taken by adopting 2.5 cycles for the sinusoidal signal, it was shown in Fig. 4 [23]. This simulation was performed to determine the size of the corrosion and Fig. 5 was indicate the simulation results are obtained with and without defects. Different results of defect signal echoes have been obtained for different sizes of corrosion defects. This size of the return echo of the defect indicates the exact size of the corrosion defect.

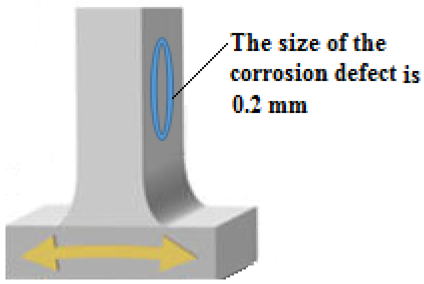

Fig. 2. Simulated shape of a corrosion defect defect with a diameter of 0.2 mm

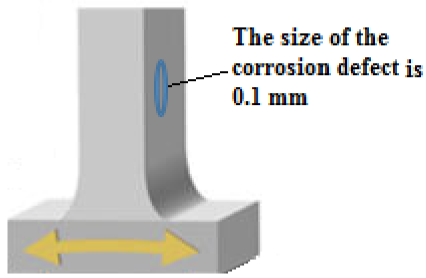

Fig. 3. Simulated shape of a corrosion with a diameter of 0.1 mm

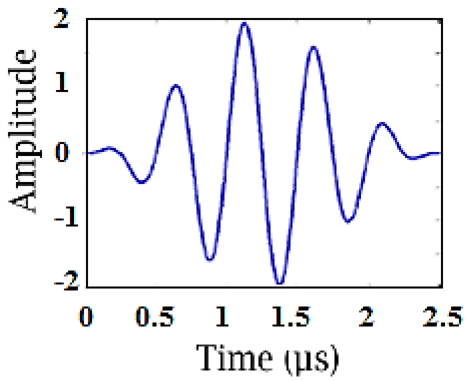

Fig. 4. Wave signal excitation at 5 MHz [24]

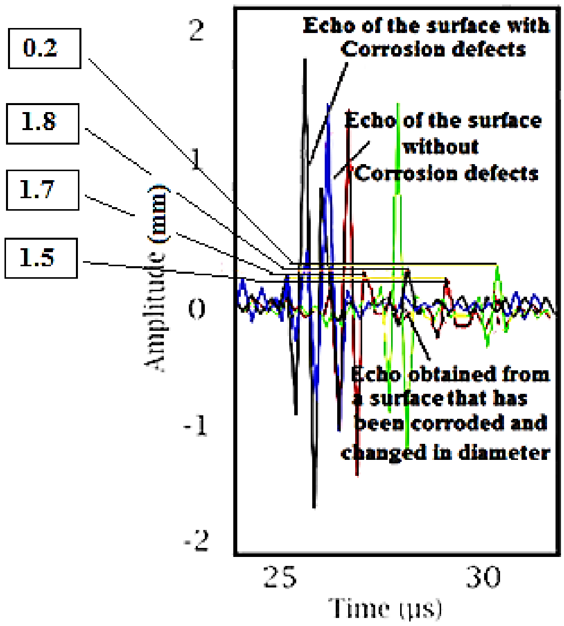

Fig. 5. Simulated corrosion defect echo (with and without corrosion)

4. Analysis of diagrams for blade life

In this section, the results of an experimental test were performed to evaluate the selection of more efficient turbines and impellers that have been corroded. In all selected blades from 20 turbines, the blades that were corroded were chosen. The remaining life of the blades was estimated by using the Larson-Miller calculation method. The Larson-Miller relationship is according to the following formula [23-25]:

$$\mathrm{P} = \mathrm{T} \times 10^{-3}\,(C + \log t_r). \quad (2)$$

According to the operating documents and citing the standard for the blades, the surface temperature of the blade during service is approximately 780°C, the applied stress is 186 MPa and the operating time of the blade is 61.325 OEH (Equivalent Operating Hours). The P parameter can also be obtained from the Larson-Miller curve of the IN738LC alloy (a cast nickel-based superalloy). The parameter C for the corresponding curve is 16.59 [23-25]. Figure 6 indicates the Larson-Miller curve for IN738LC alloy with P-value obtained from this diagram. The Larson-Miller curve was used for the IN738LC alloy with a P-value of 26.50 for C of this diagram perpendicular to its curve.

The effect of corrosion is divided according to the percentage of size and diameter of blades corrosion to determine the average use in relation to its efficiency hours. The number of blades is corroded according to the tenth percentile variable and the number of blades is divided. Their main operating reference is obtained in 32,000 hours [23-25].

And it indicates the amount of change based on the percentage change in corrosion diameter on the blades, from which it can be concluded that with increasing corrosion diameter, the number of efficiency hours will decrease. According to the above curve, the P-parameter for this alloy is equal to 26.5. The calculated temperature, which is 780°C, according to the calculation table for this reference temperature [23-25] is equal to 1053×10^{-3}.

To calculate the number of hours for a blade according to the formula, we form the following equations, and finally, we calculate the amount and size of corrosion according to its percentage, which in this sample is 0.162 mm.

$$\mathrm{P} = \mathrm{T} \times 10^{-3}\,(C + \log t_r) \Longrightarrow 26.5 = 1053 \times 10^{-3}(16.59 + \log t_r)\; t_r = 93325hr\;. \quad (3)$$

The amount of operation time before corrosion is equal to:

$$t_r = 93325 - 61325 = 32000\,hr. \quad (4)$$

The amount of operating time after corrosion is equal to:

$$t_r = 32000 \times 0.162 = 5184\,hr, \quad (5)$$

$$t_r = 32000 - 5184 = 31948.16\,hr. \quad (6)$$

The percentage of corrosion will have a great effect on the efficiency hours, so that according to the calculations, with every 0.1 mm change in the diameter of the blades, their life will be reduced by 3200 hours. It is completely solvable, for example, for a place where the diameter change was 0.2, the value of the original operating hours should be reduced by 6400 hours [23].

This diagram, which is obtained by measuring the diameter by ultrasonic waves, is an approximate solution for detecting the operating hours of each of the blades that have been corroded [23].

5. Conclusion

In this paper, the amount of corrosion (defect diameter) was associated with acceptable results and repeatability of the test 6 times. The new method for obtaining the diameter and depth of corrosion determined both its diameter and the amount of corrosion. The results of the experimental test and the simulation test together with the alignment had acceptable and identical results. In the study, the obtained results of corrosion defects will be described as follows:

- The new method, signal reversal from the turbine blade, was compared with fault-free and fault-free to obtain the true size of the corrosion defect, its depth, and diameter.
- All tests were performed on 20 defective turbine blades out of 100 turbine blades with corrosion defects, each of which according to Table 1 has different depths and sizes and has 6 repeatabilities for accurate results in the experimental test.
- The simulation and experimental results show the actual size of the corrosion that can be used to validate the results that industries can benefit from.

- According to the relationships, the amount of 0.1 mm of corrosion will reduce the life by 3200 hours, and the approximate life of each 20 turbine blade can be identified and used according to the time period (Table 1) [23].
- To advance the work, an Additive Manufacturing (AM) was proposed to eliminate the corrosion defect, which can be eliminated waste (Table 1) [23].

Acknowledgements. *No external funding was received for this study.*

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