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Positioning rub of the aero-engine based on acoustic emission and Mathematical Morphology in noise background

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Abstract

Aiming at the practical requirement of locating and diagnosis of aero-engine rub fault and the impact of noise on the positioning accuracy, this paper introduces Mathematical Morphology to preprocess the acoustic emission (AE) signals, and uses Matrix Locating Method to confirm rub fault and its position: firstly, the improved Matrix Locating Method and Mathematical Morphology are introduced by referring the rub AE source locating; then, the rub AE signals were collected by sensor arrays on the case of rub fault simulated test-bed, and locating precisions of some typical issues are compared between before and after using morphology filter, and the results show that the introduction of Mathematical Morphology receives favorable effect on AE locating of rub fault in noise background.

Locating; acoustic emission; Mathematical Morphology; rub; fault diagnosis

1. Introduction

Rotor-stator rub is a common fault of aero-engine. Rotor-stator rub in gas turbine engines may have a severe impact on the availability of engines and on the management of engine airworthiness. Much research has been done by the vibration analysis [1, 2], and there has already been great breakthrough in detection of rub existence. As to the continued airworthiness of the engine which has multiple blades, the detection of rub position is of great importance to the diagnosis and repair of rub fault. However, because

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the vibration response of rotor-stator rub is nonlinear and related to rub condition, there has not been an effective method to carry out the locating diagnosis of rub from the perspective of vibration so far [3].

When rub fault happens in aero-engine, rotor and stator at rub position have elastic strain and results in AE, which carries on rub information. Compared to traditional vibration method, the amplitude of AE is directly related to the energy of rub [4], and AE can also be used to locate rub. The research of AE on rub fault diagnosis has just arisen, which mostly focus on the detection of rub AE signal and linear locating of rotating system. Nevertheless, noise can have impact on AE signal's arrival time which will cause large locating error or even locating failure. So, the noise should be eliminated before locating rub. However, noise characteristics such as wide broadband of pulse noise and filter characteristics such as the time delay have great influence on locating precision, which means there is special requirement for the preprocessing method of AE signal.

Mathematical morphology has unique advantage in noise reduction, with simple algorithm and high efficiency. There has been a paper combining AE and morphology filter to diagnose bearings fault [5]. Showed by research, Mathematical Morphology can also filter signals without time delay and eliminate pulse noise effectively, which is better than traditional filtering methods and wavelet transform in these points [6]. There has been no application of Mathematical Morphology for processing aero-engine's signal by now, but it has a bright future in the preprocessing of the rub fault AE signal of aero-engine. Therefore, this paper introduces Mathematical Morphology into the preprocessing of AE signal, reducing the influence of noise on locating and finally realizes the precise locating of rub fault.

2. Matrix Locating Method

This paper uses time difference of arrival (TDOA) method to locate the AE source. TDOA favors both precision and complication, which is widely applied to the detection of damage positions. Since the sensors of this paper are set up in a semicircle region, considering that the axial and circumferential lengths are almost equivalent, we can deploy the cylinder to process it as a two-dimensional plane.

One common and effective method for two-dimensional plane is Matrix Locating Method [7]. Each arrival time in this paper is the time of the first wave crests. The sensor arrangement and the coordinates are showed in Figure 1.

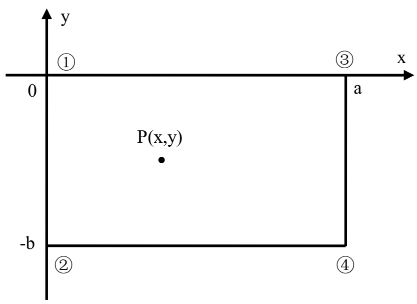

Fig. 1 Sensor arrangement

In Figure 1, four sensors are at four corners of the rectangle with length *a*, width *b*. Assume the speed of AE propagation is *v,* the arrival time of sensor 1 from the AE source *P(x, y)* is t_1, and the time difference between sensor 2,3,4 and sensor 1 is $\Delta t_2, \Delta t_3, \Delta t_4$. So AE source position should satisfy the four equations as below,

$$\begin{cases} x^2 + y^2 = v^2 t_1^2 \\ x^2 + (y+b)^2 = v^2 (t_1 + \Delta t_2)^2 \\ (x-a)^2 + y^2 = v^2 (t_1 + \Delta t_3)^2 \\ (x-a)^2 + (y+b)^2 = v^2 (t_1 + \Delta t_4)^2 \end{cases} \tag{1}$$

The solution of Equation 1, that is, coordinate(x, y) is the position of the AE source.

3. Filtering theory of Mathematical Morphology

If noise can be eliminated to determine wave arrival time clearly by preprocessing the original AE signal, it will be very helpful to the locating. Mathematical Morphology is an effective means for denoising, which can construct many different filters just by a few simple basic operations. Because complicated operations like multiplication and division are not involved in Mathematical Morphology, time and space needed for Mathematical Morphology operation is very small.

This paper uses flat structure element [8, 9] with length of *20* points as probe. Assume original signal is $x(t)$, the length of which is T, $t=0,1,..,T$, and the structure element is $g(m)$, $m=0,1,\dots,19$. So the corresponding expansion and erosion morphology process is as below,

$$(x \oplus g)(t) = \max_{m=0,1\dots,19} \{ f(t-m) + g(m) \}, t = 0,1,\dots,T \tag{2}$$

$$(x \Theta g)(t) = \min_{m=0,1\dots,19} \{ f(t+m) - g(m) \}, t = 0,1,\dots,T \tag{3}$$

With expansion and erosion, two important morphology operators, open and close operation, are defined as below,

$$(f \circ g)(n) = ((f \Theta g) \oplus g)(n) \tag{4}$$

$$(f \bullet g)(n) = ((f \oplus g) \Theta g)(n) \tag{5}$$

Because of so many advantages of Mathematical Morphology in signal processing, proper morphology operators are introduced to eliminate the noise in AE signal, in order to the determination of wave arrival time easier and more precise. Flat structure element with length of *20* points is used in this paper, which can eliminate pulse noise with width less than *20* points.

4. Research on locating rub fault based on Mathematical Morphology and Matrix Locating Method

4.1. Experimental facility

Acoustic emission signals generated from rub are usually burst AE signals. In this paper, rub signals are generally simulated by the signals emitted from the broken lead cord inclined to the surface of the stator in pencil lead break tests. Test-bed and sensors array are shown in Figure 2. We use a steel cylinder with radius *160mm*, height *350mm* to simulate rotating engine stator.

4.2. Characteristics of pulsing signal processed by Mathematical Morphology

Figure 3 shows the detailed signal before the first rub arrives, the upper one is the original wave, and the lower one is processed by Mathematical Morphology Open-close filter. There are two noises at point *250* and *500* of the original wave, and their ranges are both over *500mV*. After being processed, the noise at point *250* is eliminated, but the one at point *500* cannot be totally eliminated because its width is longer than *20*. In practical operation, structure elements with proper length can be selected according to the property of the original wave, to eliminate the noise without destroying the useful information.

Fig. 2 Rub Fault simulating stator

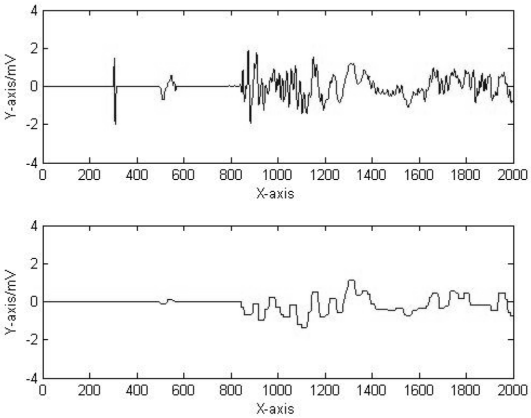

Fig. 3 Effect of flat structure element with length *20*

4.3. Locating precisions comparison between before and after using morphology filter

Due to the influence of the noise, locating result of Matrix Locating Method can have large error because of wrong determination of wave arrival time, as shown in Figure 4. After processed by Mathematical Morphology, a better locating result has gained. Compare the tow locating results, locating result of the data processed by Mathematical Morphology is much better than that not, and it is very close to exact the AE source.

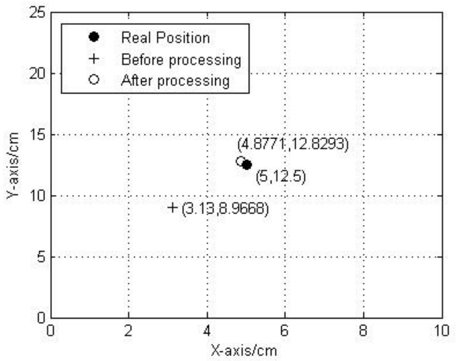

Fig. 4 Mathematical Morphology applied to signal with noise

4.4. Failure situation of matrix locating

Sometimes because there may be heavy noise in the signal, the locating method can fail, causing locating result obviously wrong. However, the acceptable locating result can be gained by processing the data by Mathematical Morphology. The vertical coordinate of the result is very close to the real position, and the horizontal coordinate of the result still has some error, as shown in Figure 5. Nevertheless, this locating result has some advantage compared to locating failure and can be applied to engineering.

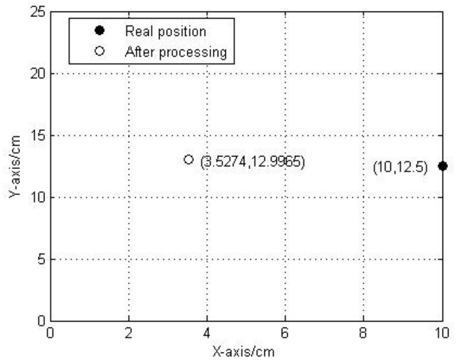

Fig. 5 Mathematical Morphology applied to signal with heavy noise

4.5. Ideal signal using Mathematical Morphology

For the case of no noise in signal, we carry out the aforementioned locating and the results are shown in Figure 6. Two locating results are very close, and the Mathematical Morphology processing does not reduce the precision of locating. In situations without noise, the precision remains the same if the signal is preprocessed by Mathematical Morphology.

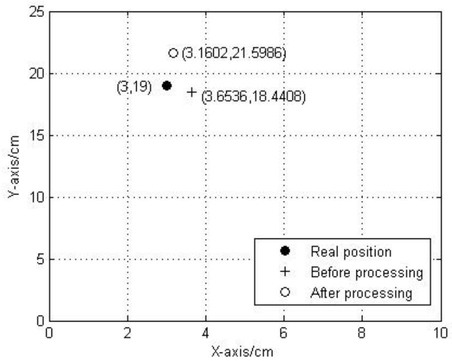

Fig. 6 Mathematical Morphology applied to ideal signal

5. Conclusions

This paper introduces Mathematical Morphology to preprocess the AE signal, and then uses Matrix Locating Method to locate rub fault. The results are concluded as below,

1) Mathematical Morphology can eliminate the influence of noise, improving the precision of Matrix Locating Method.
2) As to some experimental data using which cannot work out the locating result, the application of Mathematical Morphology can give us some locating results with reference value.
3) As to rub fault locating without noise, the employment of Mathematical Morphology will not have negative influence on the precision of locating.

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