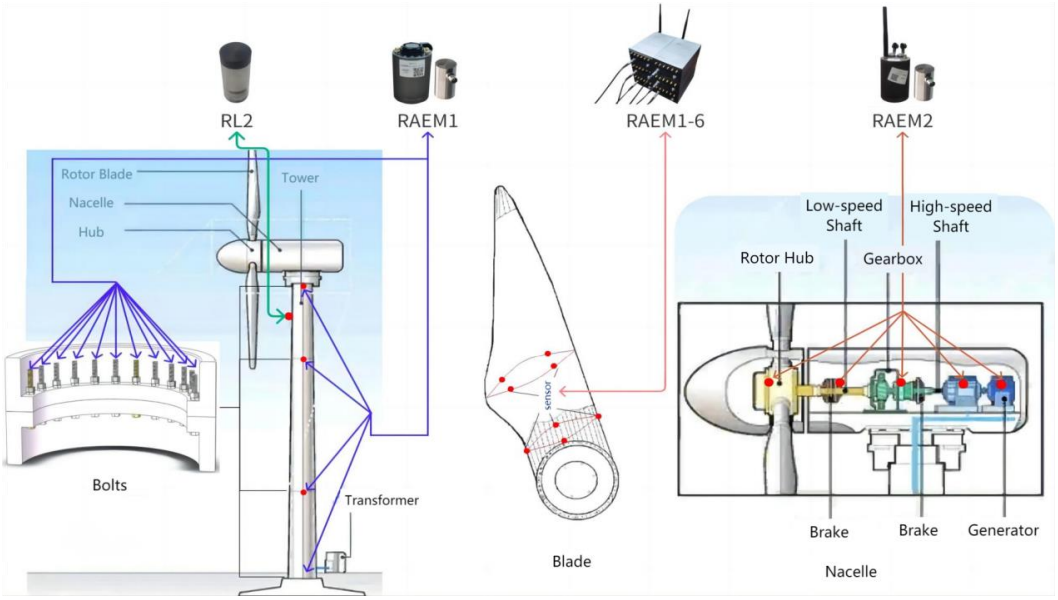
Acoustic Waves (Acoustic Emission) Monitoring and Testing of Wind Power Equipment

1. Introduction

The acoustic wave (acoustic emission) monitoring and testing of wind power equipment are mainlydivided into two categories: **structural damage monitoring and testing (blades, support tower,bolts), and status monitoring and testing of the rotating machines (lubrication, wear, damage,etc.)**.

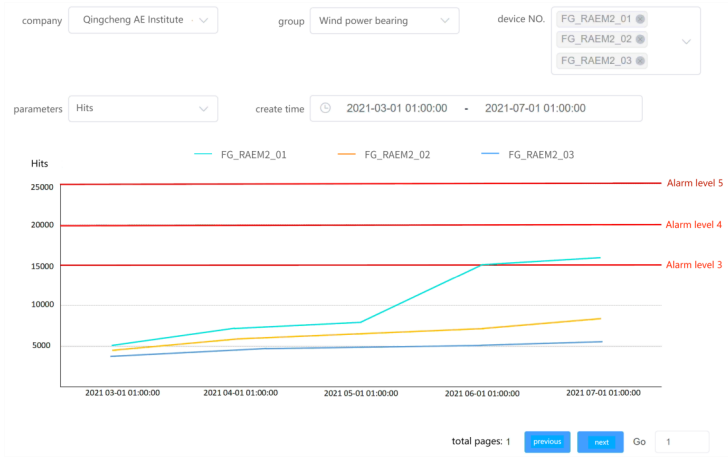


Position	Model and Features	Qty	Principles
The position of the support tower facing the midpoint of the blade length	RL2, through NB-IoT to the cloud; 3 years operation with battery	1	When deformation and cracks occur on the surface of the blades, the visible damages will continue to generate acoustic waves significantly larger than the previous backgroundnoise. The system receives and analyzes these acoustic waves regularly to obtain the damage situation of the blades.
Inside the blades	RAEM1-6, Access to the wind power network system; Use the tower internal power supply	Multiple (close to blade root)	The system continuously monitors the acoustic signals generated by significant damage processes such as blade debonding, fiber fracture and crack growth, and evaluates the health of the blades.
Suitable positions on the rotating machines	RAEM2, 2-meter sensor spacing each rotating machine; Access to the wind power network system.	Multiple	The wear, pits, cracks and other faults of the rotating machines lead to characteristic acoustic signals. The system collects and analyzes the acoustic signals regularly to obtain fault information and get the damage status of the rotating equipment.
			Impurities in lubricating oil and lack of oil will lead to dry

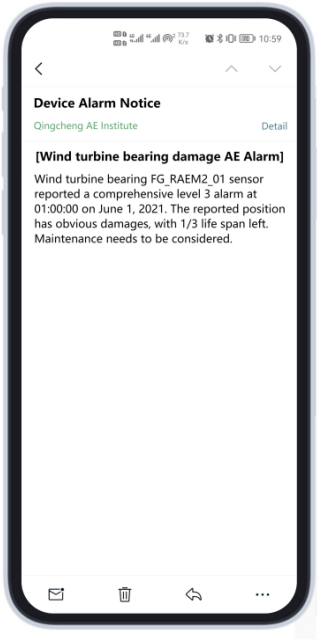
			grinding and other acoustic waves that are different from thatin good lubrication state. The system collects and analyzesthe acoustic signals at regular intervals, and determines thelubrication state of wind turbines based on the changes ofacoustic characteristic parameters along with the changesof the lubrication state.
Bolts, adjacent to flanges, including tower bolts and bearings	RAEM1, Access to the wind power network system for inside the tower; through NB-IoT to the cloud servers for outside the tower. Battery or DC power supply.	Multiple (One for each bolt)	The system receives and analyzes the transient elastic wave released when the wind turbine bolt cracks, breaks, loosens and other defects, and obtains the defect status information of the bolt.
The monitoring parts of the inner tower cylinder	RAEM1, Access to the wind power network system. Battery or DC power supply.	Multiple	Weak acoustic waves are often generated in the damage process of wind power tower, such as deformation, cracking and crack propagation. The system receives and analyzes these acoustic waves to evaluate the health state of the tower.

Results:

- real-time online monitoring and detection for 365 days,
- remote control and use of the Internet of Things,
- automatic analysis of the results,
- mobile phone alarm push notifications.



Cloud platform data display



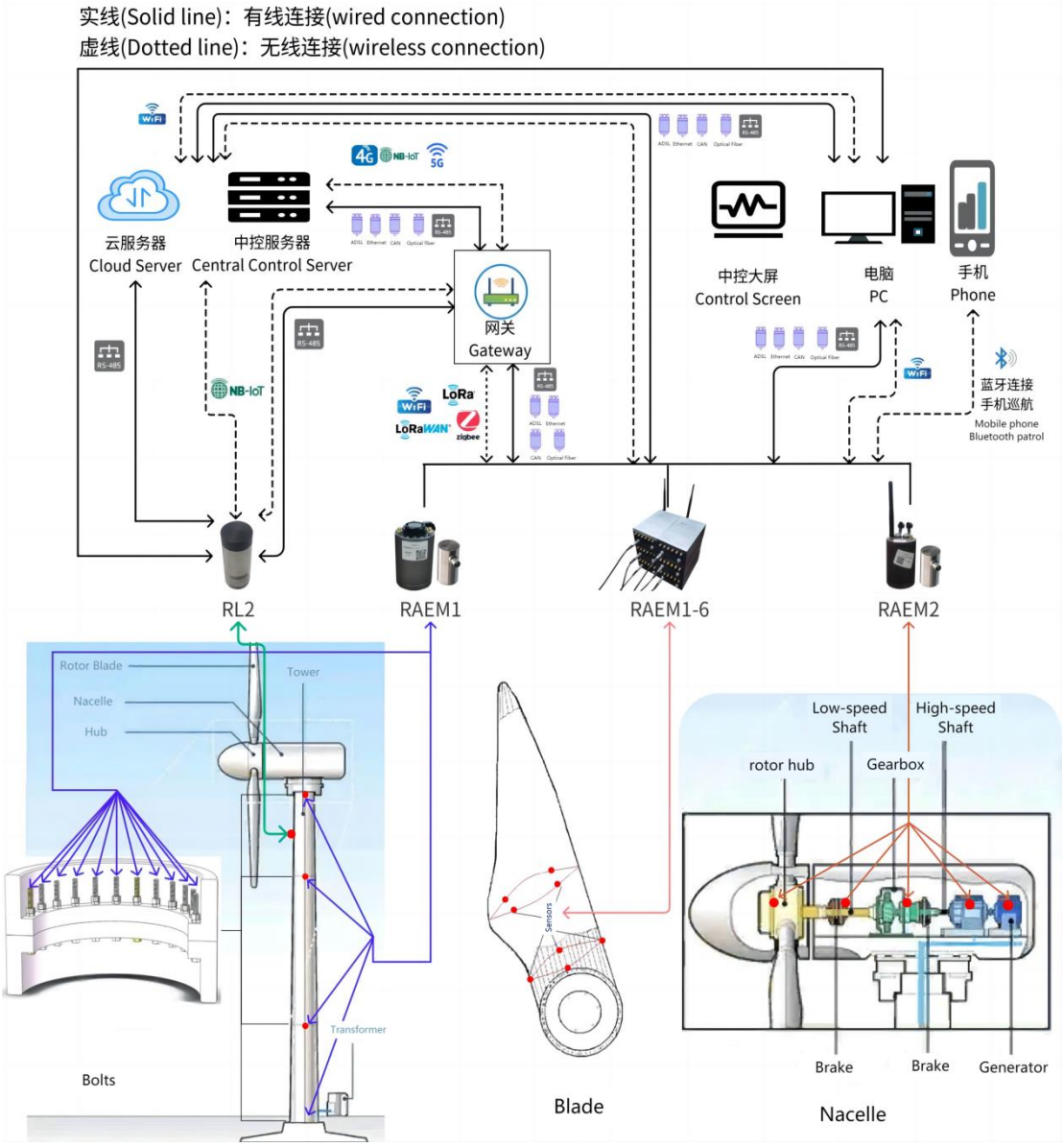
Phone alarm push notifications

- Online real-time and historical data display
- Automatically provide monitoring and diagnosis results

- Online mobile alarm push notifications

2. System connection and communication

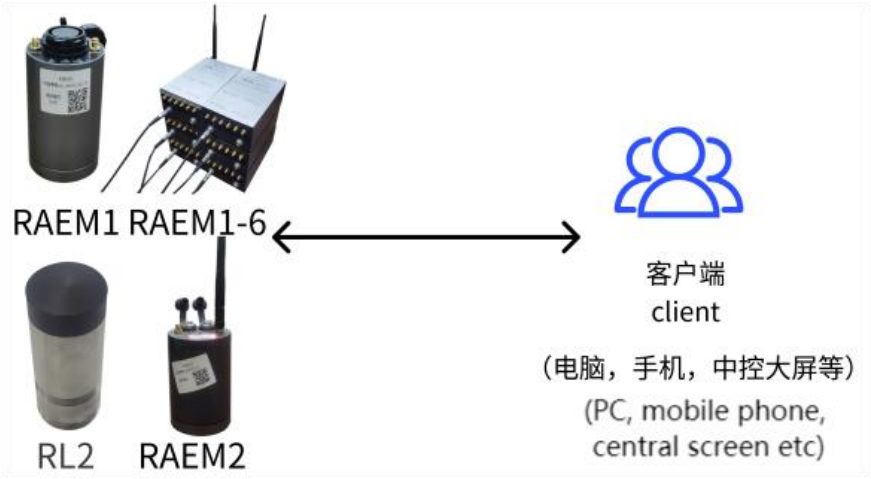
A variety of data output communication modes (Wi-Fi, 4G, Ethernet, RS485, etc.) can be configured according to users' requirements in order to achieve the regular testing, or the local long-term monitoring detection, or the remote long-term monitoring detection, or other application purposes.



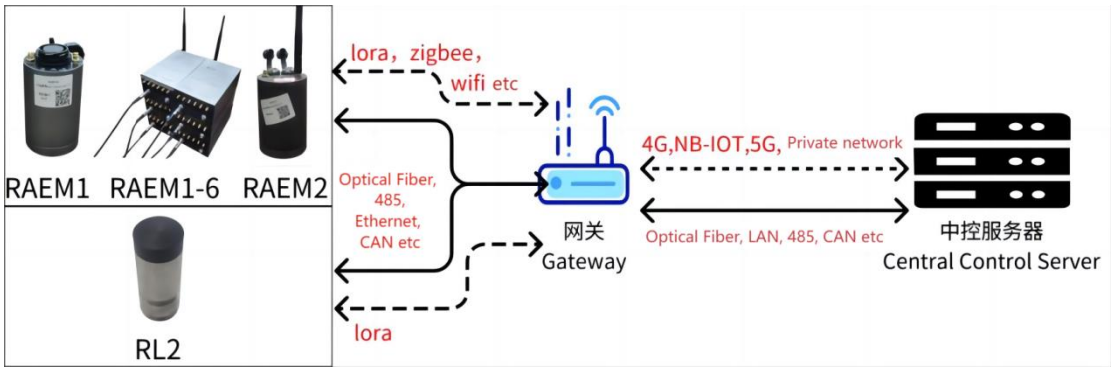
(Choose the appropriate communication means according to the local conditions)

The main 4 kinds of communication situations:

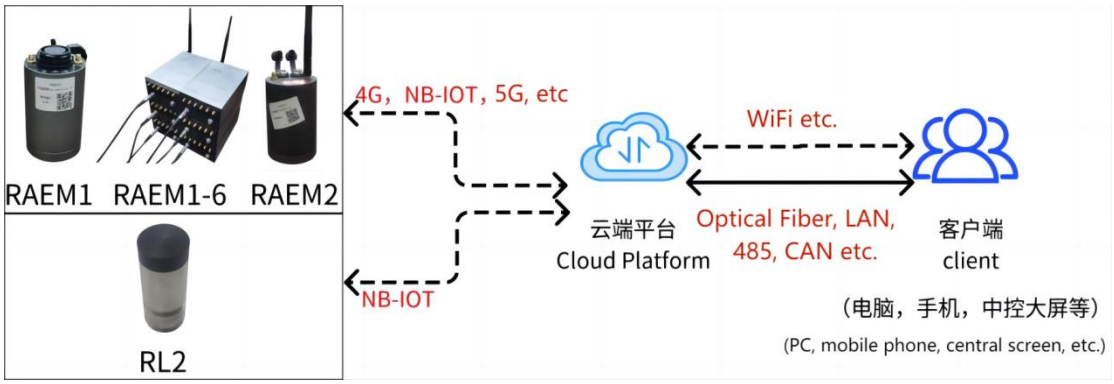
1)onsite operation and display:



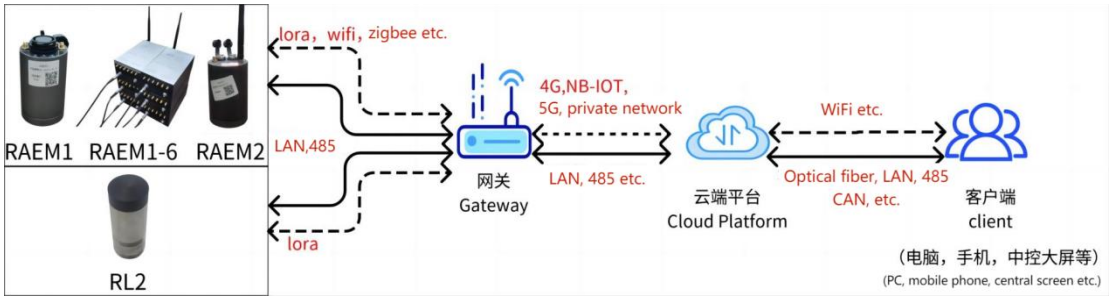
2)control room operation and display



3)remote network direct communication system



4)remote networking communication system:



Note: The above systems have the mobile phone app with Bluetooth communication

functions for patrol inspection and field debugging settings.

3. Main Software and Hardware Introduction

1) Configuration Table

<table>
<tr><td colspan="3">System</td><td>RAEM1-6 SW(AE) Monitoring System</td><td>RAEM1 SW(AE) Monitoring System</td><td>RAEM2 SW(AE) Monitoring System</td><td>RL2 SW(AE) Monitoring System</td></tr>
<tr><td colspan="3">Application</td><td>★Blade damage</td><td>★Tower damage
★Bolt damage</td><td>★Rotating machine (damage & lubrication state)</td><td>★visible damage on blade surface</td></tr>
<tr><td colspan="3">Sensor resonant frequency</td><td>40 kHz</td><td>150 kHz (bolt)
150 kHz (tower)</td><td>40 kHz</td><td>10 kHz</td></tr>
<tr><td rowspan="8">Monitor</td><td colspan="2">Model name</td><td>RAEM1-6 monitor</td><td>RAEM1 monitor</td><td>RAEM2 monitor</td><td>RL2 monitor</td></tr>
<tr><td rowspan="7">Communication</td><td rowspan="3">Wired</td><td>RS-485</td><td>RS-485</td><td>RS-485</td><td rowspan="3">/</td></tr>
<tr><td>CAN</td><td>CAN</td><td>CAN</td></tr>
<tr><td>LAN</td><td>LAN</td><td>LAN</td></tr>
<tr><td rowspan="4">Wireless</td><td>4G (traffic fee refer to the data plan)</td><td>4G (traffic fee refer to the data plan)</td><td>4G (traffic fee refer to the data plan)</td><td>NB-IOT or 4G</td></tr>
<tr><td>WIFI</td><td>WIFI</td><td>WIFI</td><td>LORA</td></tr>
<tr><td>Bluetooth (phone patrol inspection)</td><td>Bluetooth (phone patrol inspection)</td><td>Bluetooth (phone patrol inspection)</td><td>/</td></tr>
<tr><td>LORA (networking)</td><td>LORA (networking)</td><td>LORA (networking)</td><td>/</td></tr>
<tr><td rowspan="9">Terminal output</td><td colspan="2" rowspan="3">Phone</td><td>APP</td><td>APP</td><td>APP</td><td>/</td></tr>
<tr><td>WeChat mini app</td><td>WeChat mini app</td><td>WeChat mini app</td><td>WeChat public account</td></tr>
<tr><td>SMS</td><td>SMS</td><td>SMS</td><td>SMS</td></tr>
<tr><td colspan="2" rowspan="3">Cloud Platform</td><td>Qingcheng IOT Cloud</td><td>Qingcheng IOT Cloud</td><td>Qingcheng IOT Cloud</td><td rowspan="3">USR IOT Cloud</td></tr>
<tr><td>Alibaba Cloud</td><td>Alibaba Cloud</td><td>Alibaba Cloud</td></tr>
<tr><td>AWS</td><td>AWS</td><td>AWS</td></tr>
<tr><td colspan="2" rowspan="2">PC Software</td><td>SWAE</td><td>SWAE</td><td>SWAE</td><td rowspan="2">/</td></tr>
<tr><td>RAEM1 Configuration</td><td>RAEM1 Configuration</td><td>RAEM1 Configuration</td></tr>
</table>

Note: The cloud platform can choose the customer's private cloud platform or

Qingcheng's private cloud platform according to the customer's requirements.

2) Monitor

Multiple monitors can form a multi-channel monitoring system, for real-time monitoring of large equipment.

①RAEM1-6

	• Signal and time triggering • Transient signal and continuous signal acquisition • Long-term monitoring diagnosis and remote monitoring • Multi-channel detector

Channel	Single or six or cascaded channels	**Sample resolution**	16-bit
Trigger	Signal or time	**System noise**	Better than 30dB
Sample rate	Up to 2M points per second per channel	**Dynamic range**	70dB
Input bandwidth	10kHz-800kHz	**Supply**	12VDC
SD card capacity	64G (expandable to 512G)	**Weight**	1.6kg
Analog filter	Two high-pass filters: 30kHz, 125kHz; two low-pass filters: 80kHz,175kHz; Factory default combinations: 30kHz~80kHz, 125kHz~175kHz.		
Digital filter	In the frequency range of 0kHz~1000kH, any value can be set as pass-through, high-pass, low-pass, or band-pass filters. (Combined effects with analog filter)		
Sensor	Integrated sensor series (3 types of integrated preamp available): 28V40dB, 12V34dB, 5V26dB		
Data output	Waveform, parameters, alarm ratings		
AE featured parameters	Arrival time, amplitude, counts, energy, rising time, duration, RMS, ASL		
Clock synchronization	Serial connection(wired) cascaded to a larger system, the clock synchronization accuracy ≤10us		
Communication	Ethernet, 4G, Wi-Fi		
Temperature	LAN: -20℃~60℃; Wi-Fi: 0℃~60℃		
Dimension	L x W x H: 22mm x 13mm x 8mm		

②RAEM1

	• Signal and time trigger • Transient signal and continuous signal acquisition • Long-term monitoring and diagnosis • Remote monitoring and wireless single channel detector

Technical Specs:

Channel	Single, or multiple networking	**Sample resolution**	16-bit
Trigger	Threshold or time trigger	**System noise**	Better than 30dB
Sample rate	Up to 2M points per second	**Dynamic range**	70dB
Protection	IP65	**Input bandwidth**	10kHz-1000kHz
Supply	12VDC	**Weight**	220g
Analog filter	Two high-pass filters: 30kHz, 125kHz; two low-pass filters: 80kHz,175kHz; Factory default combinations: 30kHz~80kHz, 125kHz~175kHz.		
Digital filter	256-order FIR filter, in the frequency range of 0kHz~1000kH, any value can be set as pass-through, high-pass, low-pass, or band-pass filters.		
Sensor	Integrated sensor series (3 types of integrated preamp available): 28V40dB, 12V34dB, 5V26dB		
Data output	Waveform, parameters, alarm ratings		
AE featured parameters	Arrival time, amplitude, counts, energy, rising time, duration, RMS, ASL		
Storage capacity	64G (expandable to 512G)		
Communication	4G, Ethernet, Wi-Fi, RS485 (can customize communication means according to requirements, e.g., NB-IOT, LoRa)		
Temperature	-20℃~60℃ (Wi-Fi: 0℃~60℃)		
Dimension	Cylinder diameter Φ62mm, height = 100mm		
Installation	magnetic base, which can be attached to the surface of magnetic absorption		

③RAEM2

	• Time trigger • Continuous signal acquisition • Remote monitoring, long-term monitoring and diagnosis • Low power consumption and low cost

Technical Specs:

Channel	Single AE input	**Sample resolution**	16-bit
Trigger	Time trigger	**System noise**	Better than 30dB
Sample rate	2M points/second	**Dynamic range**	70dB
Protection	IP65	**Input bandwidth**	10kHz-400kHz
Time parameters output	Amplitude, RMS, ASL, energy		
Communication	4G, Wi-Fi, Ethernet, RS485, CAN, LoRa, Bluetooth etc.		
Power supply	Battery or external power (DC 12V)		
Temperature	-20℃~60℃		
Dimension	Cylinder diameter Φ62mm, height 50mm-120mm, depending on the internal configurations		
Installation	magnetic base, which can be attached to the surface of magnetic absorption		

④RL2

	• Time trigger • Continuous signal acquisition • Remote monitoring, long-term monitoring and diagnosis • Low power consumption and low cost

Technical Specs:

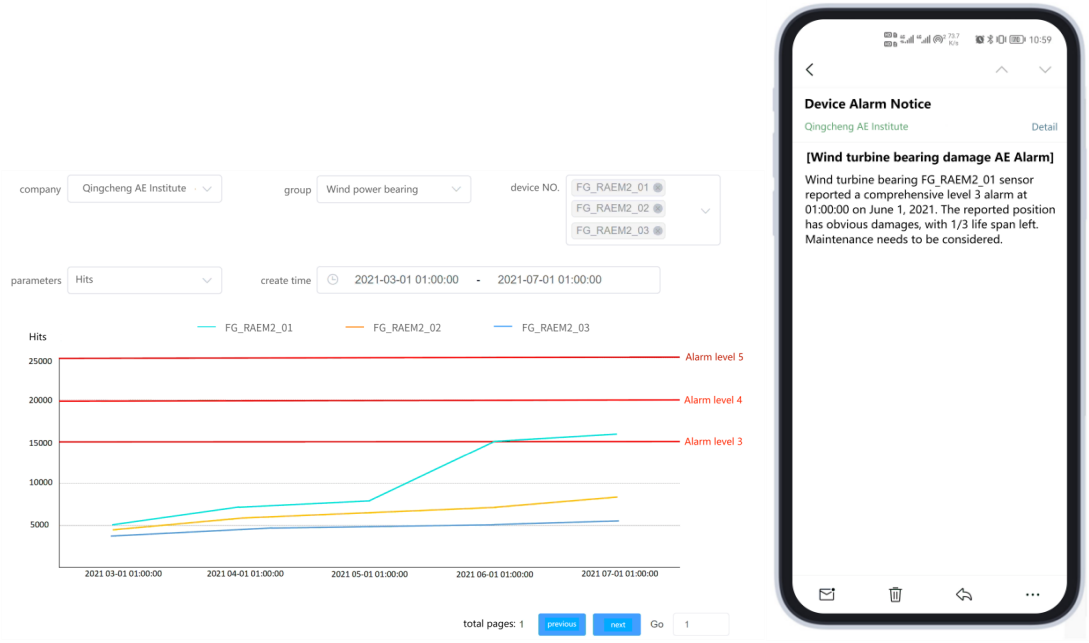
Channel	Single channel input	**Sample resolution**	16-bit
Trigger	Time trigger or internal sampling	System noise	Better than 30dB

Sample rate	Max sample rate 200KHz	**Max sample length**	200K
Protection	IP65	**Input bandwidth**	100Hz-70kHz
Input impedance	50Ω	**Temperature**	-20℃--50℃
Digital filter	Unlimited combinations, high-pass, low-pass at any value		
Preamp power	5V		
Data output	RMS, ASL, power, battery voltage		
Communication	RS485, Modbus prototype		
Power supply	Internal battery with large capacity, power consumption < 1W		
Dimension	Φ51mm×128mm		

3) Cloud platform

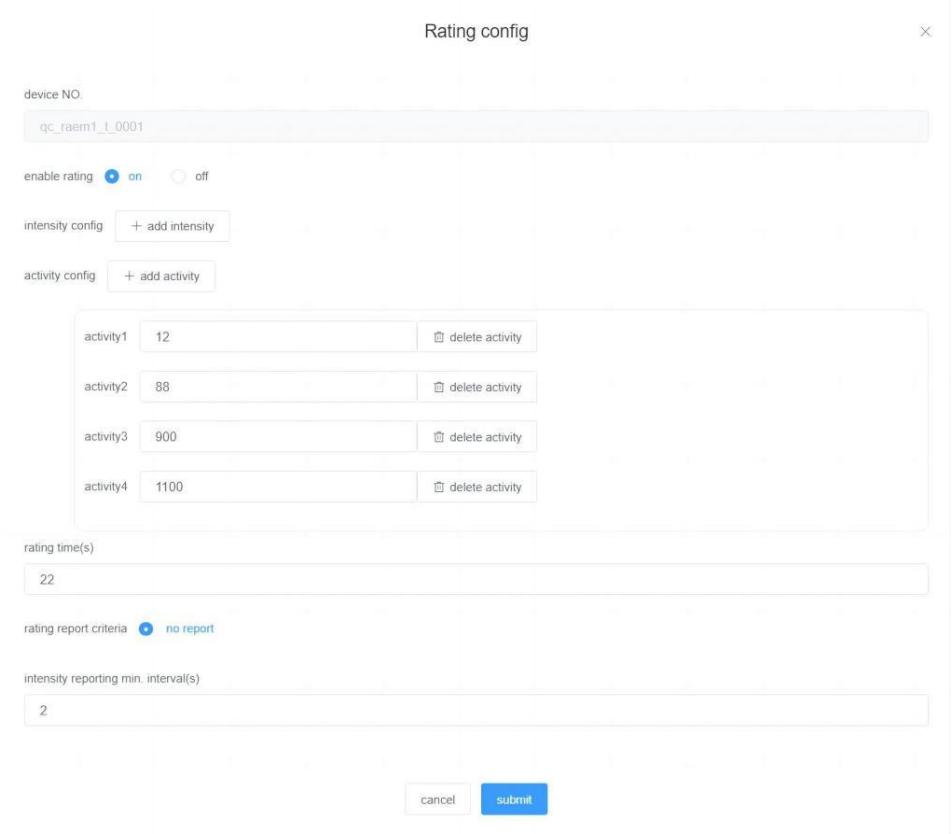
Qingcheng IOT cloud platform, Alibaba Cloud, AWS etc.
(Customer's private cloud platform or Qingcheng's private cloud platform can be chosen according to the customer's requirements)

① Cloud platform data display: Users can carry out remote monitoring through the cloud platform and push the alarm notifications to users.

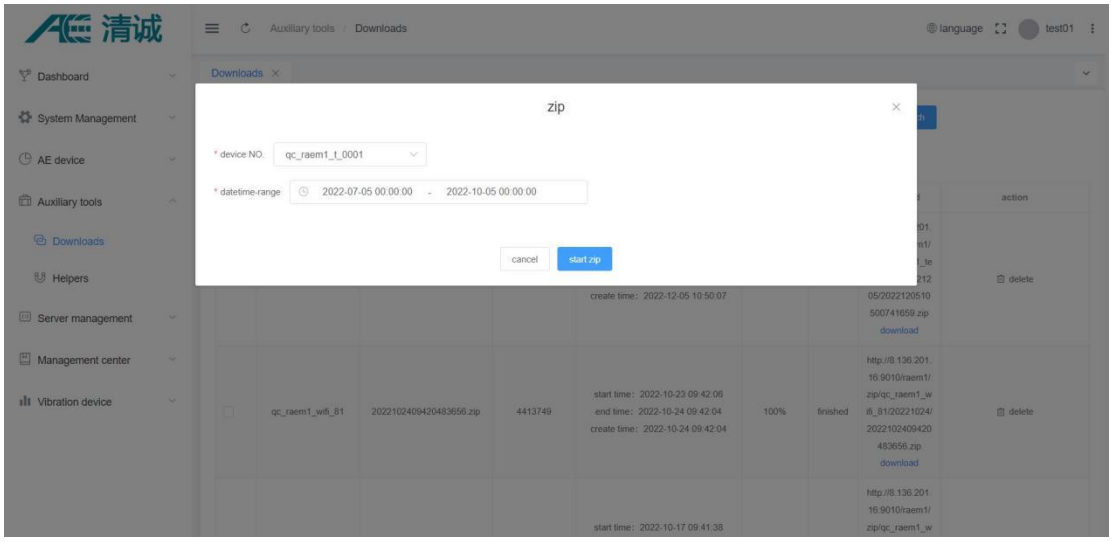


② Remote system upgrade: Users can download and install the upgraded software and system from the cloud platform.

③ Sampling parameter settings: Users can perform remote configurations on the cloud platform, such as parameter configuration, scheduled configuration, and rating configuration.



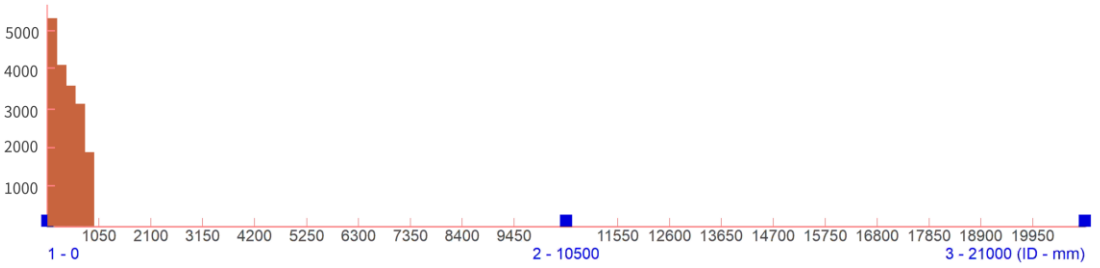
④ Data download: Users can remotely download historical data through the cloud platform.

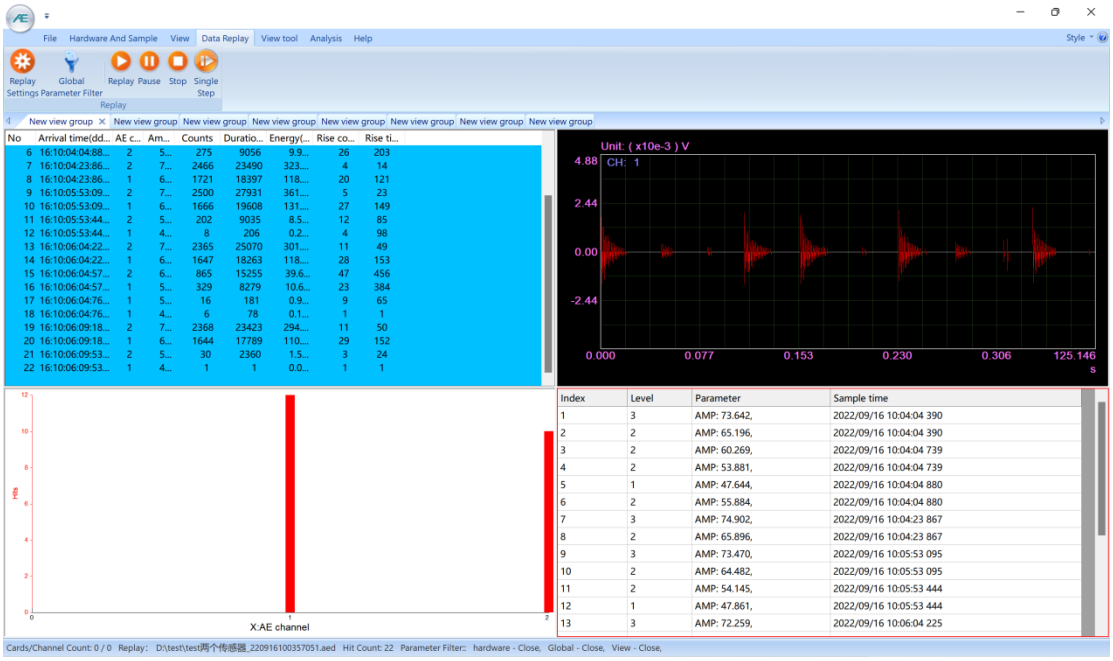


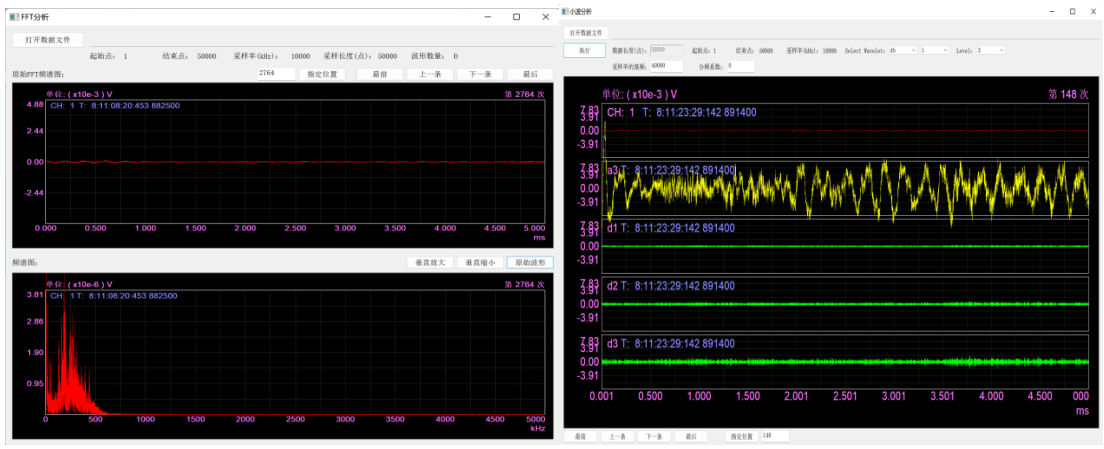
4) SWAE Software - Computer

The data can be downloaded from the cloud for further analysis using Qingcheng SWAE software, or sent directly to SWAE software for real-time analysis and processing to understand the defect details.

Such as location analysis, parameter analysis, correlation graph analysis, waveform analysis, fast Fourier transform, wavelet transform, rating analysis and so on.







4. Applications

1) Wind power blades monitoring detection

Solution: RAEM1-6/RL2 series remote acoustic waves (acoustic emission) monitoring system

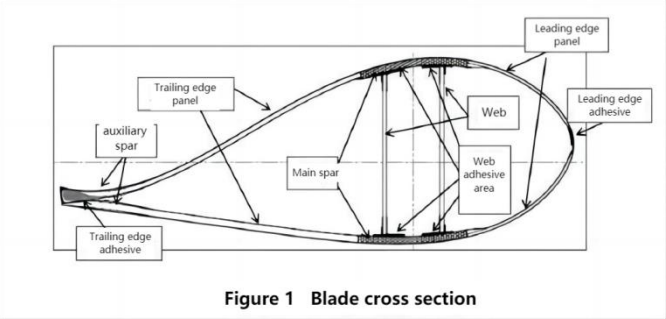


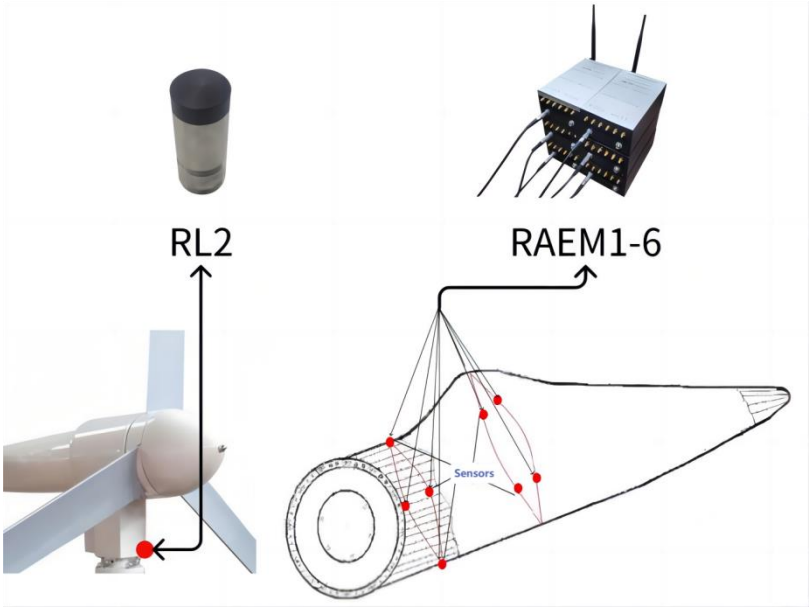
Figure 1 Blade cross section

Principle: When wind power blade materials suffer cracks and other damages, the acoustic waves significantly larger than the previous background noise will be generated continuously when the working load is large. The acoustic waves (acoustic emission)monitoring system receives and analyzes the acoustic waves of the blades to determine the damage situation of the blades and make a health evaluation on the integrity of the blades.

Installation positions:

RL2: the position of the tower facing the midpoint of the blades

RAEM1-6: the inner part of the blade near the root, etc.



Steps:

◆ Multiple RAEM1-6 are installed inside the blade close to the root to continuously monitor the significant damage such as blade unbonding, fiber fracture and crack propagation. The monitors connect to the wind power network system through Wi-Fi or gateway and output to the cloud.

◆ One RL2 (air sensor) is installed on the outside of the tower facing the blade to collect the acoustic spectrum when the blade rotates in the air regularly and monitor the significant damage visible to the naked eye on the outer surface of the blade, such as deformation and cracks. The monitor communicates to the cloud via NB-IOT.

◆ start acquisition, data analysis and verification, to get the criteria.

◆ Good verification effects.

◆ Set criteria and push alarm notifications to the mobile phone.

2) Wind power bolts monitoring detection

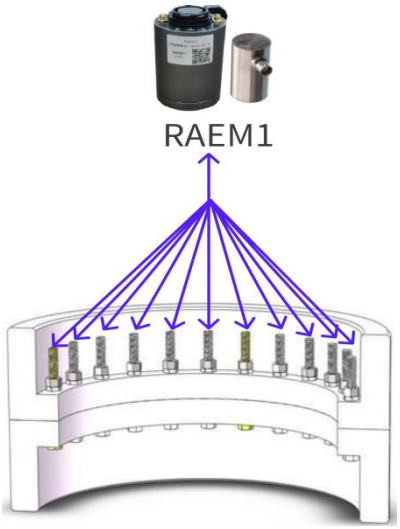
There are many reinforced parts used on the wind turbine, which are mainly concentrated in two parts:

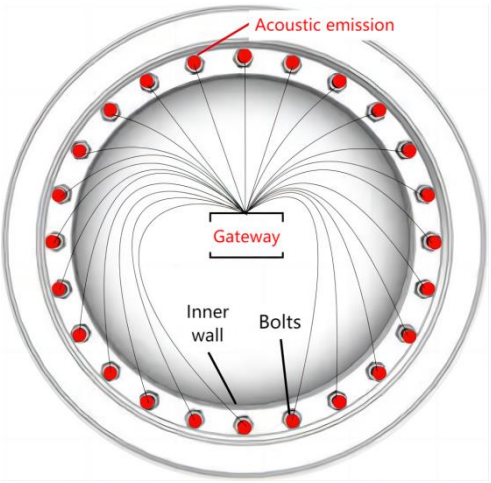
① Blade connection reinforced parts;

② Tower cylinder connection reinforced parts: tower cylinder is generally divided into 3 or 4 sections. The diameter of the bottom section of the tower cylinder is generally about 4-5 meters. The tower cylinder and the ground, and between the tower cylinder sections, are connected with the reinforced parts. The required reinforced parts are about 300 sets.

Solution: RAEM1 series remote acoustic waves (AE) monitoring system

Principle: The system receives and analyzes the transient elastic wave released in the process of crack, fracture and other damage of wind turbine bolts to obtain the defect status information of bolts.





Installation positions:

On bolts (one monitor per bolt), or next to flanges, including bolts on tower and bearings and other components.

Steps:

◆ Install RAEM1 on the key parts, continuously monitor the signal of bolt cracking and loosening.

◆ The bolt monitors inside the tower are connected to the internal wind power network system, and the bolt monitors outside the tower are connected to the cloud server through NB-IOT.

◆ Start acquisition, waveform and parameters output.

◆ Data analysis and verification, to get the criteria.

◆ Good verification effects.

◆ Set criteria and push alarm notifications to the mobile phone.

3) Wind turbine tower monitoring and detection

In the wind turbine, the wind turbine tower mainly plays a supporting role and absorbs the vibration of the turbine. However, due to the harsh environment of wind power plant, it is easy to be affected by its own factors and external environment, resulting in material degradation and structural failure.

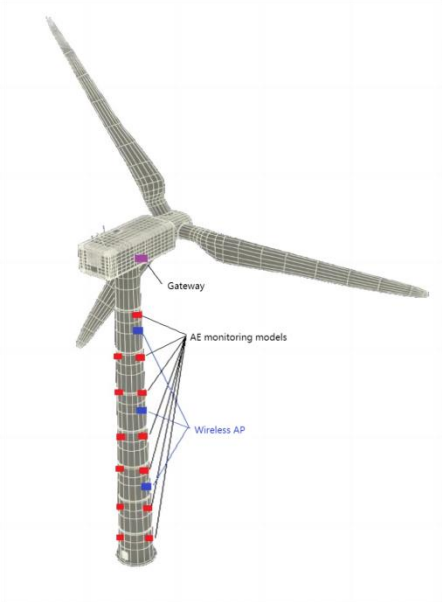
Solution: RAEM1 series remote acoustic waves (acoustic emission) monitoring system

Principles: Weak acoustic waves are often generated in the damage process of wind powertower, such as deformation, cracking and crack propagation. The system receives and

analyzes the acoustic waves to obtain the defect degree and location of the tower andevaluate the health status of the tower.

Installation positions:

Monitoring positions of the tower cylinder inside the tower body (longitudinal seam, circular seam T-slot positions)



Steps:

◆ Install RAEM1 on the key parts that need to be monitored, continuously monitor the important parts of the tower, and monitor the significant damage of the tower, such as cracks.

◆ The monitors communicate with the wind power server and monitoring screen through WiFi or gateway, and outputs to the Internet of Things platform through 4G.

◆ Start acquisition, waveform and parameters output.

◆ Data analysis and verification, to get the criteria.

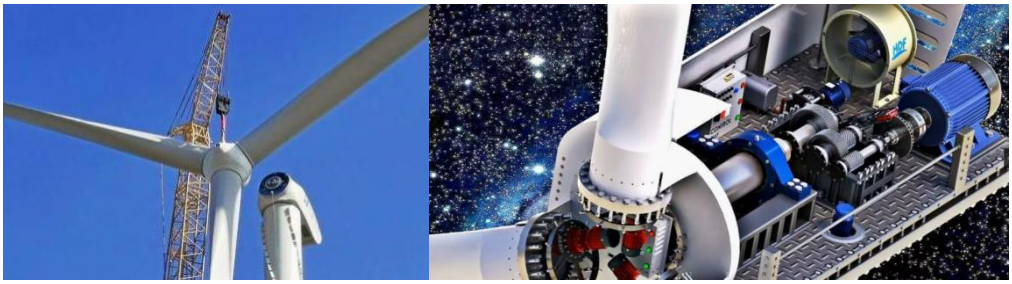
◆ Good verification effects.

◆ Set criteria and push alarm notifications to the mobile phone.

4) Wind turbine rotating machinery monitoring and detection

Wind power rotation system is a key device to convert blade kinetic energy into electric energy, usually including hub, spindle, gear box, reducer, generator, bearing and other parts.

Solution: RAEM2 series remote acoustic waves (AE) monitoring system



① Damage monitoring and detection

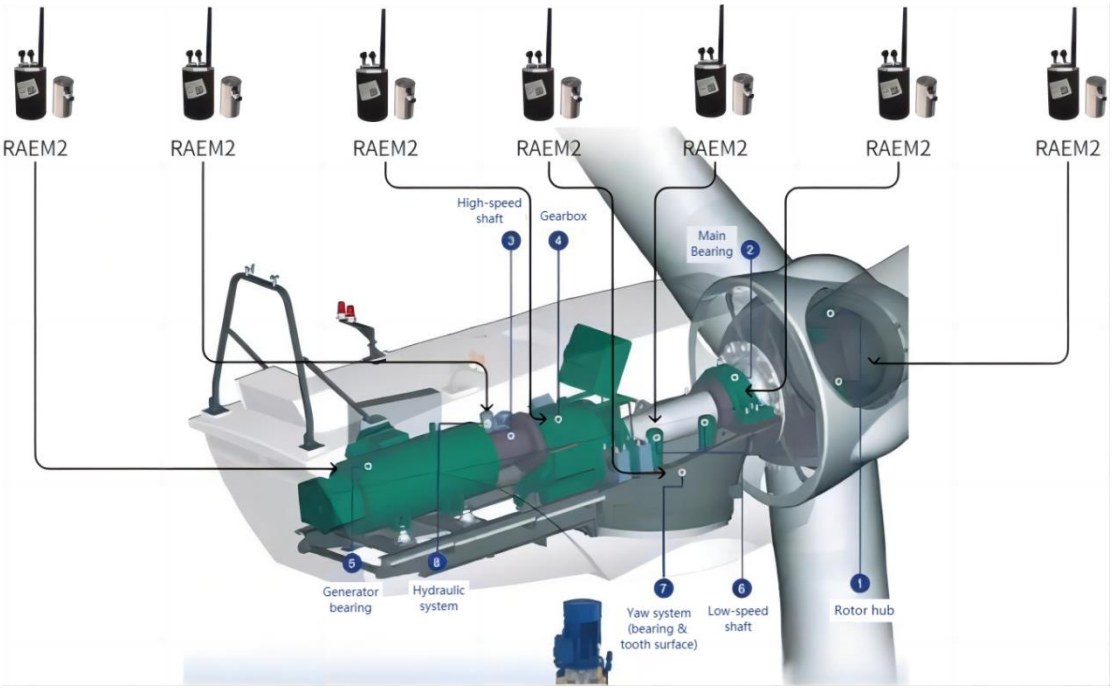
Principle: The wear, pits, cracks and other faults of the wind turbine rotating equipment lead to the characteristic acoustic signals. The acoustic waves (acoustice mission) system collects and analyzes acoustic signals to obtain fault information and wind power rotating equipment damage status.

② Lubrication state monitoring and detection

The main lubrication parts of wind turbine include gearboxes, generator bearings, yaw system bearings and gears, hydraulic brake systems and main bearings, etc. Lubrication can reduce frictions and wear, and ensure the long-term stable operation of wind turbine rotating machinery.

Principle: Impurities in lubricating oil and lack of oil lead to dry grinding and such will produce acoustic signals that are different from the good lubrication state. The acoustic signals are collected and analyzed, and the lubrication state of the wind turbine is determined by the certain patterns of acoustic waves (acoustic emission) parameters along with the change of lubrication state.

Installation: install on the appropriate positions of the rotating equipment.



Steps:

◆ Install one to eight RAEM2 on each rotating equipment (bearings, gear boxes, etc.)

(sensor spacing is about 2 meters apart).

◆ The monitor communicates with the wind power server and the monitoring screen through WiFi or gateway, and outputs to the Internet of Things platform through 4G.

◆ Start and stop the system to collect data on time.

◆ Establish data analysis reference criteria using the field data, by multiple equipment of the same model, or the same equipment (with no failure, or all kinds of failures) monitoring data to obtain criteria.

◆ Good verification effects, close the waveform and parameter outputs.

◆ Set criteria and push alarm notifications to the mobile phone platform.

5. Application Cases

Case: Every other month, the bearing of a wind turbine was monitored online by acoustic emission system for a certain period of time to evaluate the bearing damage.

Comprehensive rating levels (5 levels):

- Level 1: good condition
- Level 2: half life span left
- Level 3: 1/3 life span left
- Level 4: quarter life span left
- Level 5: 1/5 life span left

① **Cloud Platform Display**

Users can perform remote configuration and monitoring through the cloud platform, and upload data to the cloud platform for display and analysis.

Figure 1: Statistical diagram of the hits vs. time of monitoring channels No. 1, No. 2 and No. 3 on the cloud platform in the monitoring of the wind turbine bearing

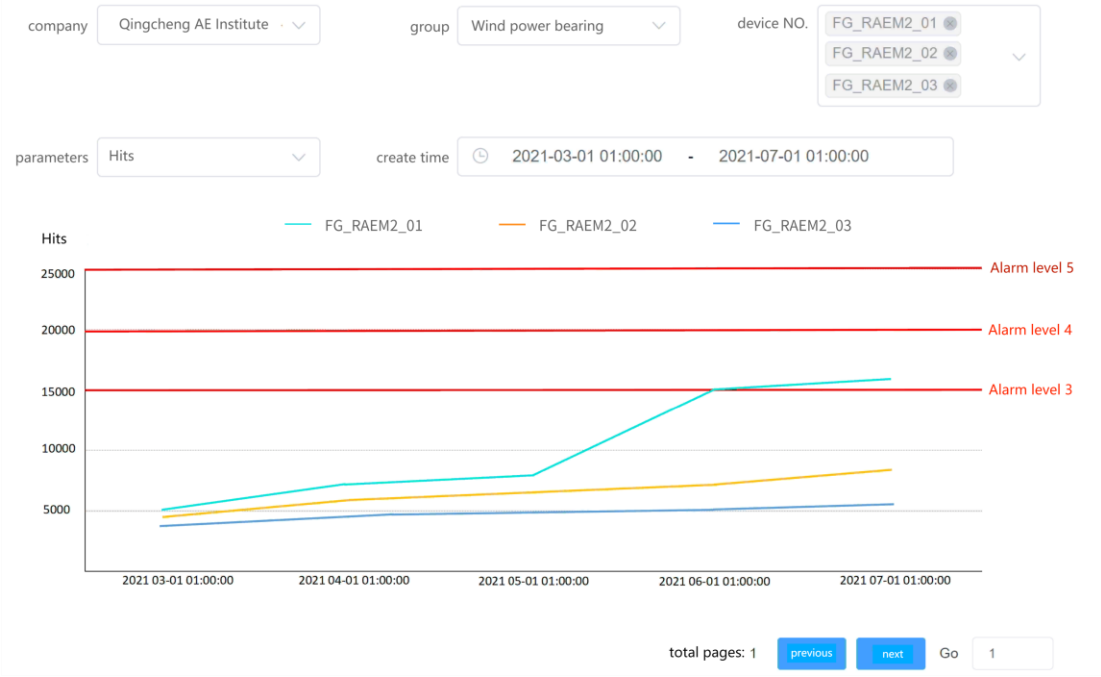
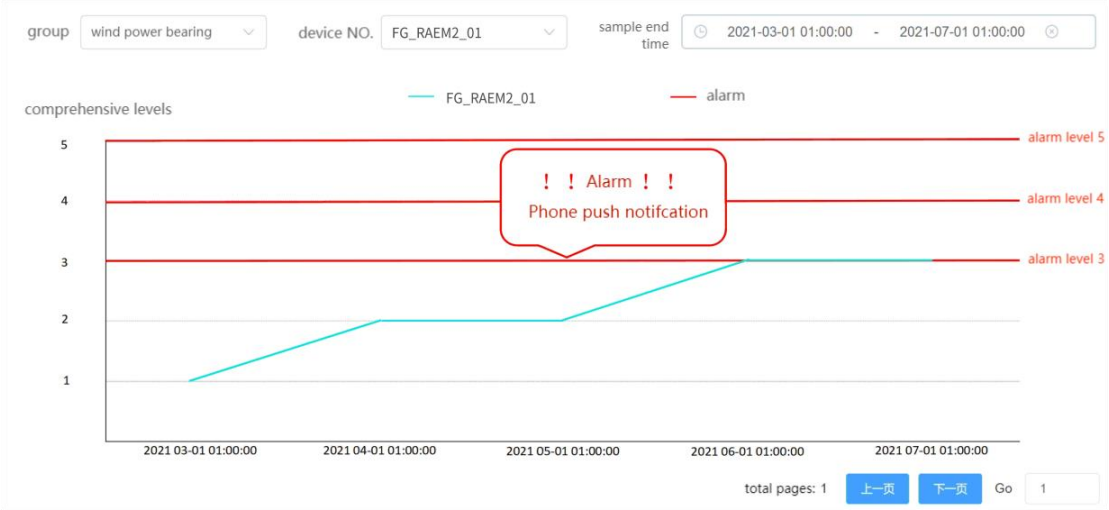


Figure 2: In the monitoring of the bearing of the wind turbine, the corresponding comprehensive

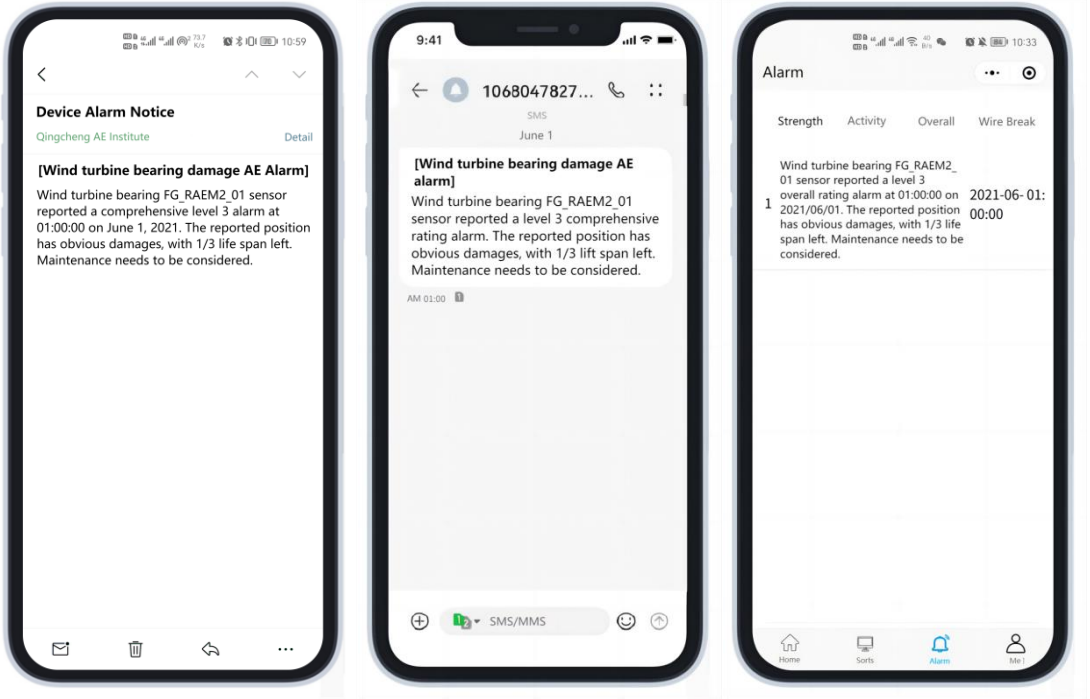
rating levels of channel 1 each month are: 1, 2, 2, 3, 3.



E.g. in June 2021, the alarm level 3 threshold was triggered (the phone received the alarm push notification synchronously).

② Phone Push Notifications

Alarm modes: mini app, App, email etc.

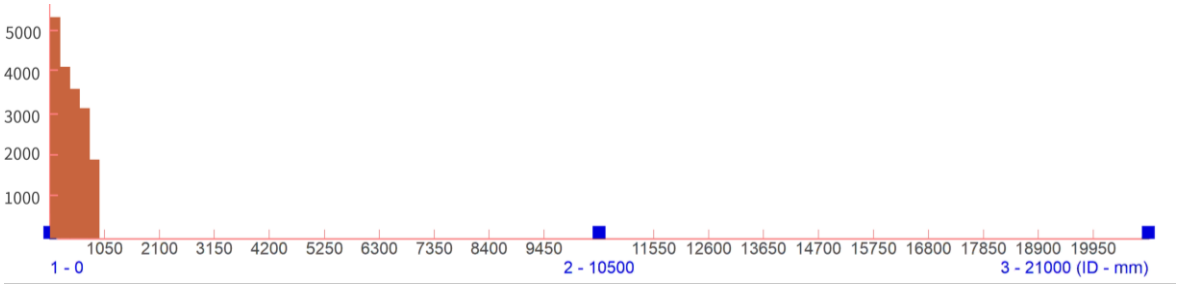


Email alarm notice SMS push notification mini app (App) alarm push notification

③SWAE software

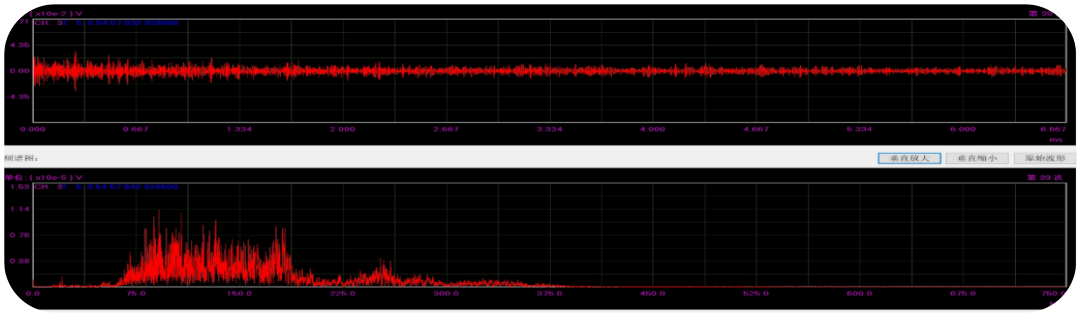
Qingcheng SWAE software was used for in-depth analysis to get a detailed understanding of the bearing defects.

Figure 1: Faulty bearings were located by linear positioning using SWAE software

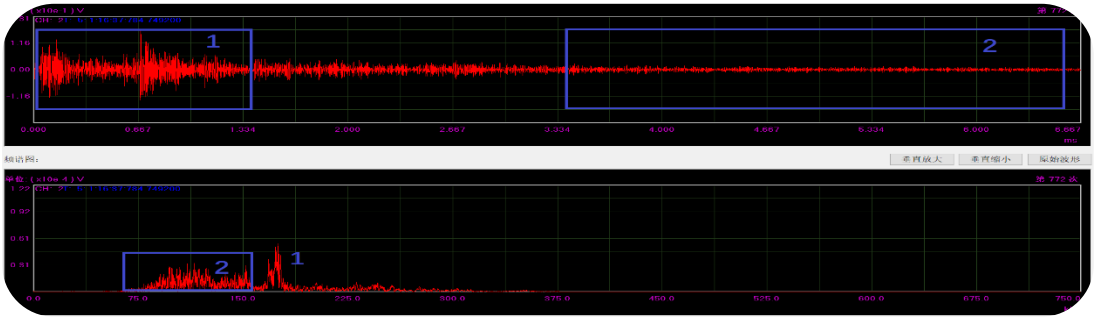


Linear location graph

Figure 2 and Figure 3: The "good" and "bad" bearings were respectively monitoredby wind power bearing acoustic wave (acoustic emission) monitoring system, and the collected data were analyzed in time domain and frequency domain by SWAE software



"Good" bearings in time and frequency domain



"Bad" bearings in time and frequency domain

6. Summary

The acoustic waves (acoustic emission) monitoring and detection of blades, towers, bolts, rotating equipment damage and lubrication state can be achieved, and the alarm notification is automatically pushed to the users, so that users can carry out maintenance in time, so as to prolong the life of wind power equipment and prevent losses and accidents caused by the cumulative development of damage.

Advantages:

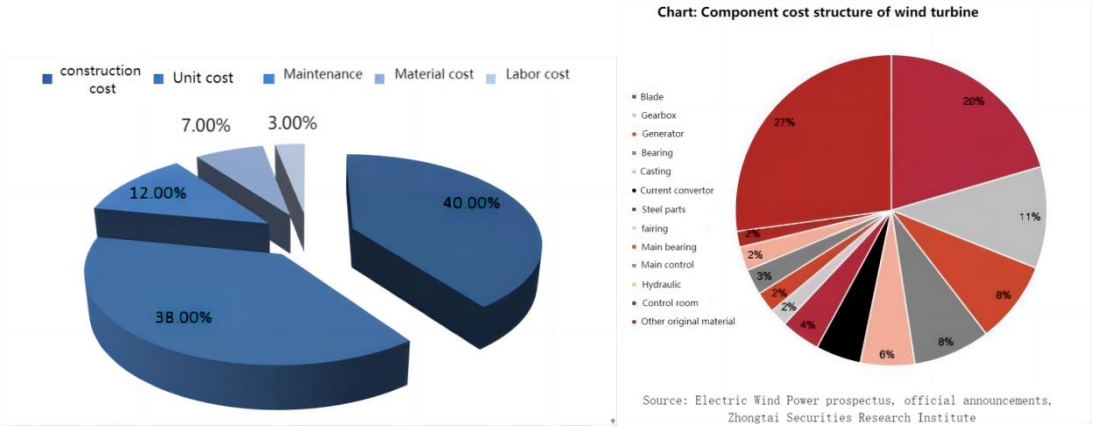
• Online ---- Acoustic waves (acoustic emission) collector is installed on the monitored and diagnosed object to achieve full-time all-weather status monitoringand fault diagnosis.

• Intelligent ---- automatically provides monitoring and diagnosis results without manual data analysis and processing. Data acquisition, analysis, reports and display are automatic for the whole monitoring and diagnosis process.

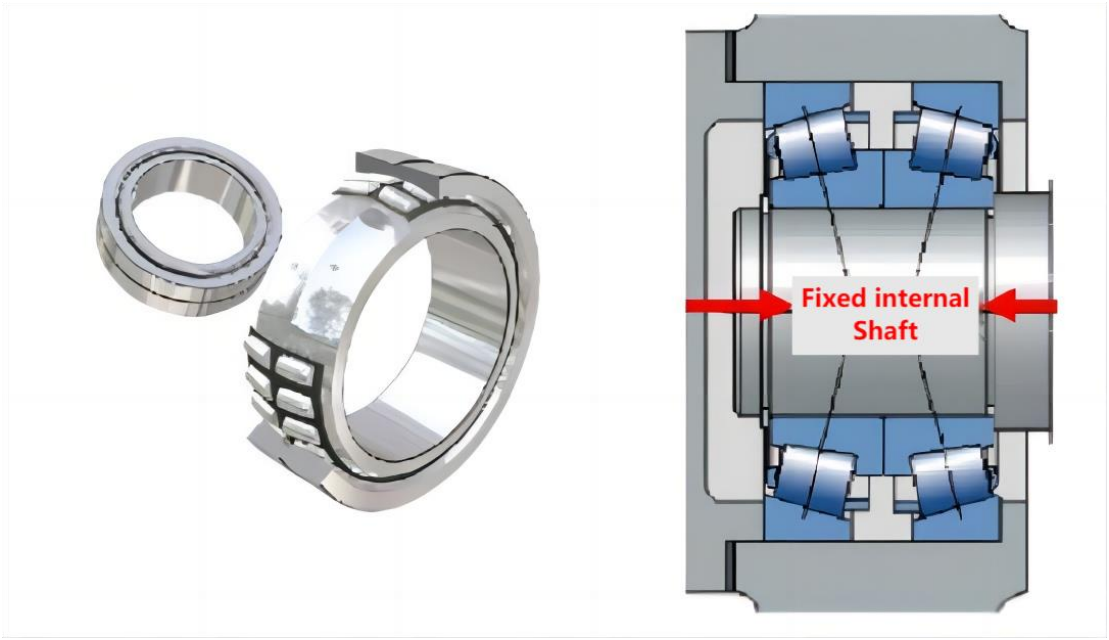
• Remote ---- With the help of the Internet of Things system, users can get the monitoring and diagnosis results of any monitoring and diagnosis points at any distance, both online real-time results and historical process results.

7. Real Cases

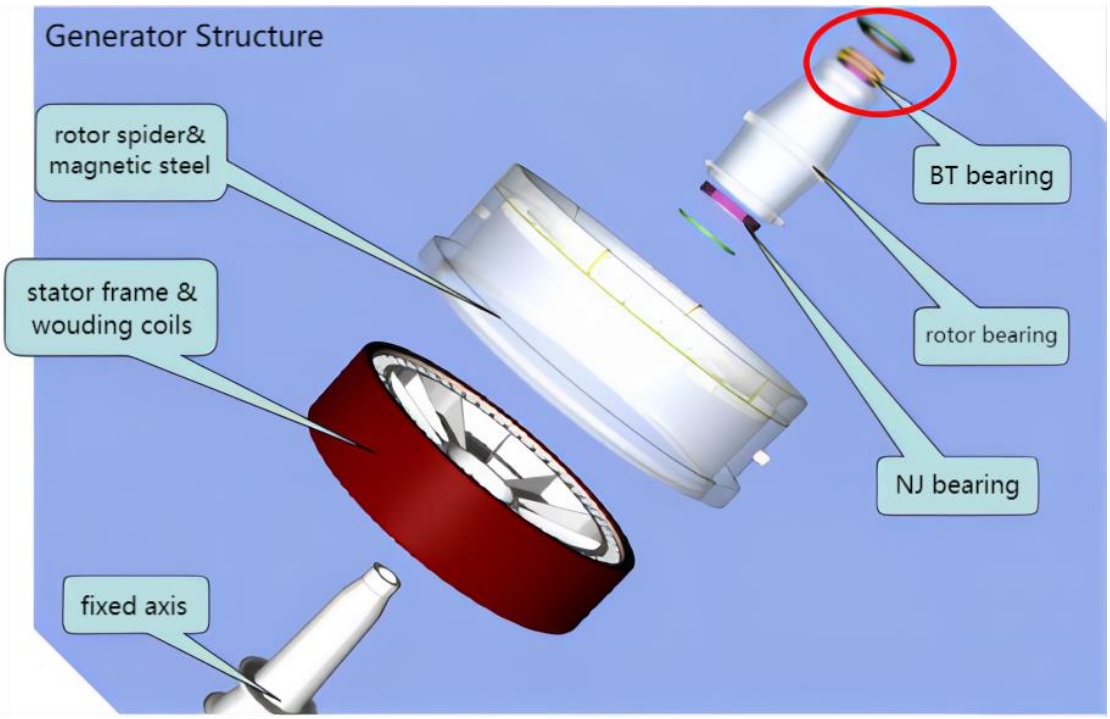
According to statistics, the investment loss of wind power equipment in maintenance is huge. Therefore, early-warning safety monitoring of wind turbines and early detection of equipment fatigue damage cracks are of great significance for early warning of disasters or avoiding failures and improving production efficiency.



1) Wind turbine bearing monitoring (BT bearing)



BT bearing is a double-row tapered roller bearing, with a double raceway of the outer ring and two rows of inner rings, and a separated ring in between. The bearing clearance can be adjusted by changing the thickness of the separated ring. This type of bearing can bear the radial load as well as the axial loads in both directions at the same time, can limit the axial displacement of the shaft and housing in the bearing axial clearance, and is mainly used to bear the combination of the primary radial load and the axial load, with the features of large bearing capacity, low limit speed.



Generator Structure Diagram

The BT bearing is in the middle of the rotating shaft and the fixed shaft, at the front end of the main shaft. The signal line at the back end of the acoustic emission sensor is connected with the system host. It can only be installed in the inside of the fixed shaft, near the BT bearing position.

Sensors and monitors installation

2) Wind Turbine Online Monitoring in Sheyang, Jiangshu

Basic test process of wind power bearing monitoring:

① Sensors, preamplifier, detectors and other hardware installation;

② By calibrating the sensitivity of each channel with the manual simulated source, the channel responses were consistent as possible;

③ The signal conditions, such as signal conduction path and attenuation, were roughly evaluated by applying the manual simulation sources to each structural part;

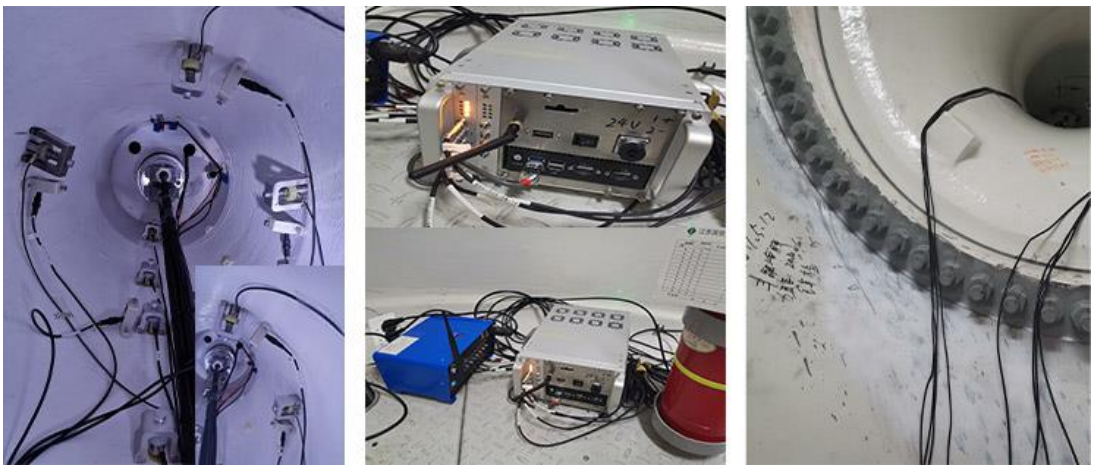
④ When location analysis was needed, the known simulation source and location source should be used for error analysis;

⑤ Instrument sensor self-calibration test (used to determine the state of the instrument in the monitoring process, especially the sensor);

⑥ Determine the threshold value by testing the noise;

⑦ Long time big data acquisition, record the operation, load, environment (weather, maintenance, etc.) states;

⑧ Before the disassembly of instruments and equipment, the post simulation source tests for each channel sensitivity calibration were carried out, to record the differences which were considered when analyzing the data.



Actual operation on site

Basic method of data processing (data for one station) :

(1) The comparison of acoustic emission data of a single monitoring object combined with the loads (selected the data in the early morning of March 27 and April 5);

(2) Look at the trending and distribution of the parameter history chart, combined with the bearing fault characteristics analysis, to determine the structure of the fault point;
(3) The correlation of parameters can be used to roughly determine the signal types, such as: amplitude -ASL, duration - rising time, counts - rising counts, amplitude - energy, etc., can roughly be recognized from the crack or friction signal;
(4) Comparative analysis and classification of typical time-domain signals and their spectrum;
(5) Abnormal characteristic parameters and waveform signal correlation analysis, conformance identification, such as high energy and high amplitude signal is not necessarily the crack signal, mainly verifying the third point (the parameter analysis has higher efficiency than the waveform analysis);
(6) Time difference positioning analysis (uniform structural parts have good effect, high accuracy, but high requirements for channel consistency).