# Internet of Things Acoustic Emission Online Monitoring and Fault Diagnosis of Structures and Equipment

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**ABSTRACT**: Online monitoring and fault diagnosis of various structures and equipment is a hot spot in industry, national defense, and national economy but also is the important technology in a huge demand. With the rapid development of the Internet of Things (IoT), the acoustic waves (acoustic emission) (AE) monitoring and diagnosis technology of the IoT is a new technology for the online monitoring and fault diagnosis of the above structures and devices, and has been successfully applied in a large number of applications, showing a strong and wide application prospect.

## 1 THE PRINCIPLE OF ACOUSTIC EMISSION TECHNOLOGY IN THE INTERNET OF THINGS

The Internet of Things Acoustic Emission (IoT-AE) is composed of acoustic emission sensors, acoustic emission data acquisition and analysis module (acquisition module), Internet communication module, cloud server, and client smartphone /PC. First of all, the acoustic emission sensor acquires AE signals from the monitoring objects (for example, tanks, pressure vessels, pipes, tank bottom valves, bridge wire ropes, wind-power blades, rotating machinery, cutting machines, etc.). The AE sensor transforms the tiny mechanical vibration signal into an electrical voltage signal, which is then transmitted to the acoustic emission data acquisition and analysis module for data processing. At present, the AE signal acquisition and processing methods can be divided into two categories: one is to represent the characteristics of AE signals by multiple simplified waveform characteristic parameters, and then analyze and process these waveform characteristic parameters. The other method is to store and record the waveform of acoustic emission signals and analyze the frequency spectrum of the waveform. Simplified waveform characteristic parameter analysis method is a classic acoustic emission signal analysis method that has been widely used since the 1950s. It is still widely used in acoustic emission detection applications, and almost all acoustic emission detection standards adopt the simplified waveform characteristic parameter for acoustic emission source criteria.

IoT-AE was developed and introduced in terms of hardware, software, and network architecture. IoT-AE transmits data and analysis results to network servers through various in-network communications. The results of the analysis can be sent as an alarm message to end-users' smartphones and PCs. Users do not need an AE professional to operate IoT-AE system. Therefore, IoT-AE can be used as a remote long-term unattended monitoring and automatic alarm system. Compared with traditional AE instruments, which need to manually process data to get detection and monitoring results, IoT-AE system automatically controls data acquisition and analysis through the embedded software. In addition, the long-term self-learning correction cycle of AI on the server based on Big Data makes the system capable of self-learning, self-improvement and continuous performance improvement. The IoT-AE system adopts the simplified waveform characteristic parameters method. It extracts useful AE waveform and parameter information, and then outputs the results (alarm information, waveform and parameters). The output of the AE module is transmitted to the server/ smartphone/ PC via the Internet/Intranet communication modules.

This paper explains the principle of AE technology of the Internet of Things, which consists of three parts, smart acoustic emission devices, cloud network platform and user interfaces. The paper then introduces the application schemes and practical application cases using the newly developed smart AE monitoring and diagnosis equipment of the IoT.

## 2 INTRODUCTION TO RAEM

### 2.1 *Remote Acoustic Emission Monitoring (RAEM) System*

RAEM (remote acoustic emission monitoring) system is an IoT-AE remote monitoring system developed by Qingcheng AE Institute (Guangzhou) Co., Ltd. The system mainly consists of three parts: RAEM (sensor, signal acquisition and analysis, communication), platforms (cloud server/LAN /PC/ mobile phone, etc.), and client terminals (mobile phones, PC, large screen, etc.). The AE signals are automatically collected, analyzed and processed by RAEM, and the processed results are sent to the platform through the communication network.

Customers can view the acoustic emission waveform and parameters on different devices according to their needs, or the platform system actively pushes the preset alarm information to notify users.

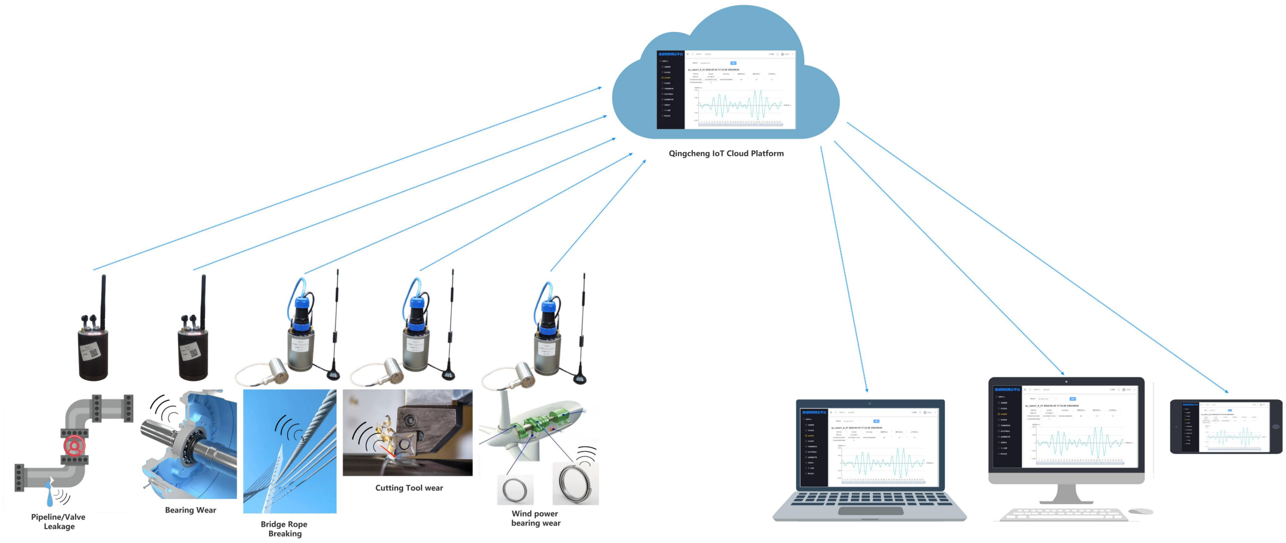


Figure 1: The general structures and applications of RAEM

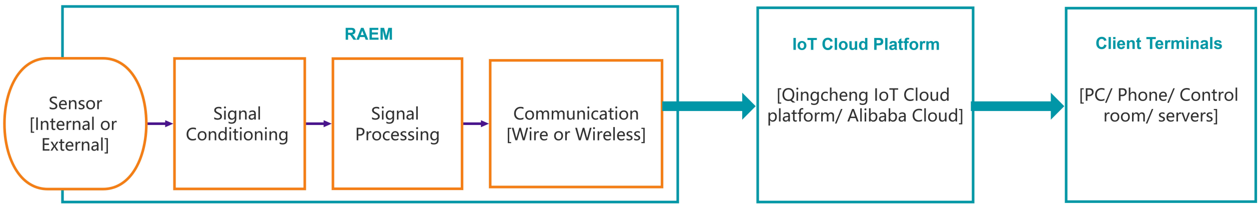


Figure 2: The functional flow chart of RAEM system

RAEM module is an intelligent single-channel acoustic emission collector integrating signal acquisition, signal analysis and communication. After the collected signal is digitized by AD, the FPGA and ARM of SoC start the frequency domain filtering, waveform processing, AE characteristic parameters extraction and parameters evaluations. The data is then transmitted to the IoT platform through the communication module built inside RAEM, for example 4G, WiFi and network cable.

The IoT platform can be Qingcheng IoT Cloud Platform developed by QingCheng company, or Alibaba Cloud, or Amazon Cloud Services, or even the clients' own servers. On the well-configured cloud platform, data storage and data display of waveform and parameters can be achieved, as well as remote dual transmission and configurations of RAEM devices. It can also analyse and alarm of the intensity and activity levels of the acoustic emission events.

Client terminals can also be diverse, including computers, smart phones, industrial computers, servers, tablets and so on.

## 2.2 *Automatic Acoustic Emission Data Rating Algorithm (Automatic Rating)*

RAEM can automatically calculate and analyze the data ratings based on AE parameters to give intensity levels, activity levels and comprehensive ratings. In addition, the rating results are pushed to the users in the form of alarm messages according to the rating severity, so that the users do not need to conduct the complex and professional AE data analysis.

The ratings and levels are based on the rules made by users. Users can select one or more desired parameters and their proper parameter values to specify the intensity levels. The intensity levels are defined by the number of occurrence of the intensity level triggering. For a certain sampling time, if the specific AE parameter values or times exceed a specified intensity level or activity level, it will be assessed as a certain intensity or activity level. Users can set the intensity or activity level trigger alarms, or push the alarm messages according to the comprehensive rating levels.

The comprehensive rating is the highest level of intensity and activity over a period of time, giving the highest level of the system performance evaluation. The comprehensive level conforms to NBT47013.9-2015 standards.

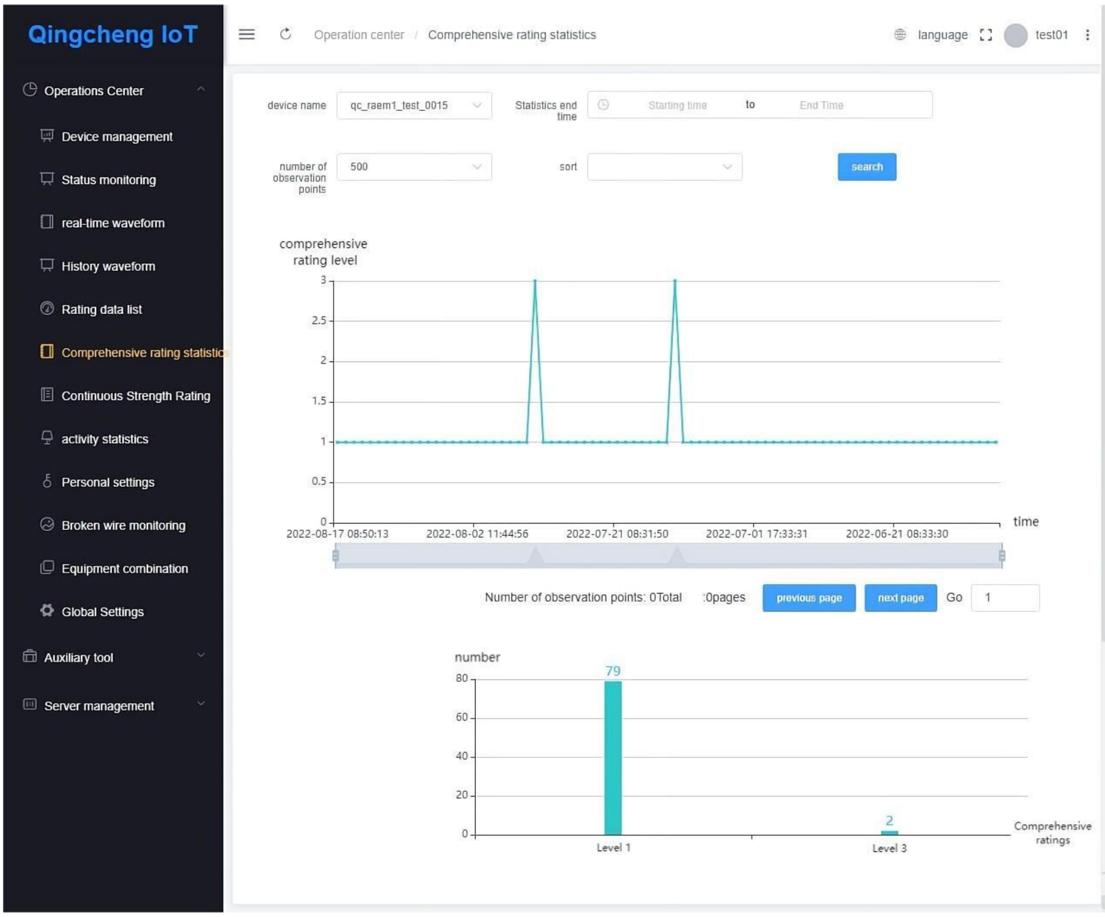

Figure 3: Qingcheng IoT platform comprehensive rating statistics

## 2.3 *High Precision Wireless Clock Synchronization*

RAEM comes with a wireless synchronization module. The wireless synchronization module is dedicated to clock synchronization to other RAEM devices via WiFi. Each RAEM is equipped with a wireless synchronization module. Therefore, multiple RAEM devices can form a wireless IoT-AE network with high-precision synchronous clock.

The working principle of wireless synchronization module is that all wireless synchronization modules themselves constitute a local area network, with a tree-type hierarchy. The LAN wireless synchronization module does not occupy the wireless data transmission network of the WiFi module. One of the RAEM device is designated as the master, and all the other RAEM devices synchronization modules are slaves. The master module sends a synchronization signal every second through the WLAN to the next level of the hierarchy and then to the next level hierarchy and so on. During the clock synchronization process, the wireless synchronization module automatically calibrates the distance and transmission time differences among the modules.

After testing, the wireless synchronization clock accuracy of RAEM system is within 10 microseconds, which can be used for high-precision AE source localization.

## 2.4 *Automatic Sensor Testing*

Automatic Sensor Testing (AST) is sensor automatic testing and calibration, which refers to the sensor under voltage excitation to transmit pulse mechanical signals, received by the adjacent sensors. AST is a useful technology to evaluate the receiver sensor’s sensitivity and coupling status.

RAEM has AST function by obtaining two sensors, one transmitter sensor and one receiver sensor respectively. The signal is automatically sent through the transmitter sensor, and the receiver at the other end receives the signal. Based on the received signal amplitude and energy, the sensor at the receiving end is judged to be well coupled. This feature helps to determine whether the sensor installation and coupling is good at installation time.

# 3 APPLICATION SCHEMES AND CASES

## 3.1 *Bridge Wire Ropes Breaking Monitoring*

Suspension bridge sling, main cable, cable-stayed bridge cable, arch bridge derrick (cable) tie rods consist of twisted wire strands. After a long time operation under the affects of heavy loads, environmental corrosion, stress corrosion and corrosion fatigue, hydrogen embrittlement, it is prone to bridge wires breaking phenomenon. The broken wires release sudden strong elastic wave signal propagation along the steel wire rope. The acoustic emission sensor located within a certain distance detects and converts the signal into electrical signal and transmits it to the acoustic emission collector. The acoustic emission collector identifies the broken wire by processing the signal, uploads the warning of broken wire to the cloud platform and then pushes it to the mobile phone, achieving the purpose of real-time monitoring of broken wire.

Cable breakage is a random event that may happen at any time. Therefore, it is required to continuously monitor the cable breakage of the bridge for a long time. It is not allowed to have the time when data is not collected. RAEM1 in bridge wire rope breaking system can operate for 24 hours and 365 days of uninterrupted trigger acquisition, using Linux software and hardware architecture, watchdog circuit design, for long-term unattended monitoring.

At the invitation of a customer's company, the RAEM1 system of Qingcheng company has accumulated a large amount of data for the acoustic emission monitoring of a full-size bridge cable wire breaking test. The experimental results show that the acoustic emission signal of broken wire has high amplitude, high energy, high counts and high RMS, which can be distinguished from most noise signals. RAEM1 Internet of Things acoustic emission monitoring system can accurately and effectively monitor wire breaking phenomenon. The 100% detection rate of wire breaking in this experimental indicates that no breaking signal is missed. RAEM1 can be unattended and remotely and automatically to monitor wire breakage without missing a single wire breakage signal, and can automatically push the wire breakage alarm and wire breakage rate to mobile phones and emails.

Figure 4: RAEM System Installation and Phone Messages

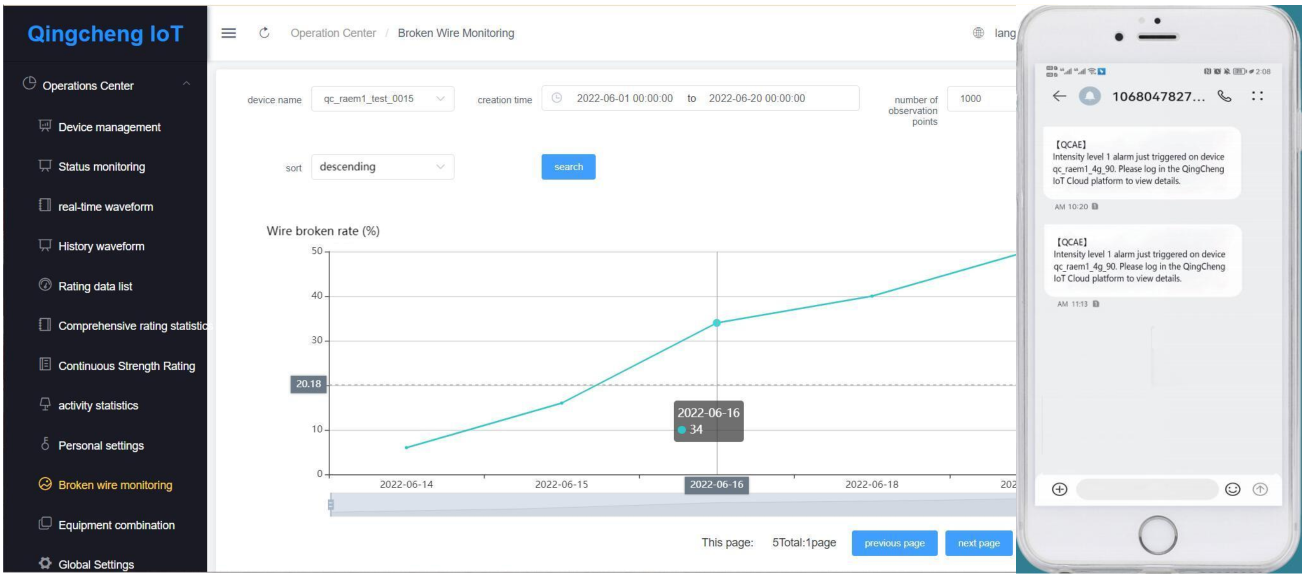


Figure 5: Qingcheng IoT platform wire breaking monitoring

### 3.2 *Pipeline and Valve Leak Monitoring*

When the gas or liquid leaks from the leak hole under a certain pressure, continuous mechanical waves will be excited at the leak hole. The acoustic emission waveform excited by the leak can be observed through an oscilloscope, and its shape is continuous and almost without any regular fluctuation. The frequency band

distribution of leakage acoustic emission wave varies from several Hz to several hundred kHz depending on the size of leakage hole, leakage velocity and leakage medium. Qingcheng's RAEM1 system uses a suitable AE sensor to receive these AE waves from the leakage site, and then converts the mechanical waves into electrical signals and transmits them to the AE host after amplification. After analysis and processing, the information of the leakage amount can be obtained, and an appropriate threshold is set to output an alarm when the threshold is reached. The amount of leakages or alarm parameters will be transmitted to the Internet cloud platform through the Internet of things communication, and then be pushed to the end users to achieve the purpose of unattended quantitative leakage monitoring and intelligent alarming.
In the case of the same medium and the same material size, the different leakage quantity under the same pressure difference condition has a certain quantitative function relationship with the AE parameters (RMS, ASL, energy, etc.). Quantitative relationships can also between different pressures and acoustic emission parameters and leakage under the same valve opening condition; and the characteristic relationship between different leakage openings and AE parameters under the same pressure difference (tank wall plug).

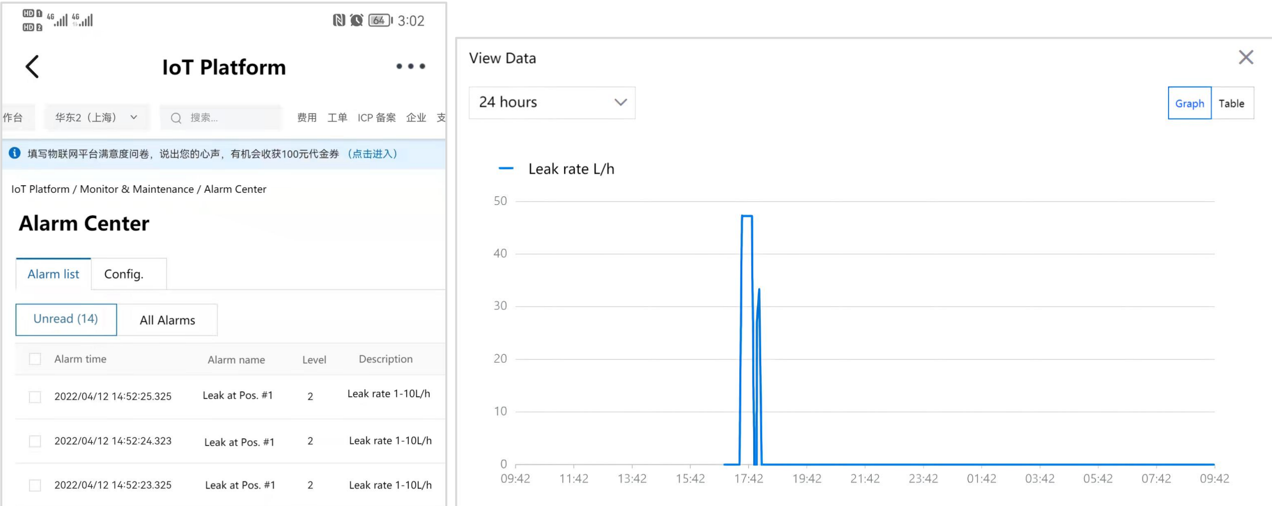

Figure 6: IoT alarm system displays

## 3.3 *Pressure Vessels Structural Cracks Monitoring*

When the pressure vessel is in long-term operation, its inherent defects or defects generated in operation expand with the progress of loading, and then the energy is released inside the structure, part of which is emitted in the form of elastic waves. RAEM system can reflect the active changes of the defects by collecting the acoustic emission signals during the operation regularly, and based on the trending calculation and characteristic analysis of the data to notify the personnel in the form of alarm results, and pay attention to or deal with the abnormal signal location zone. The regional localization method is used to determine the dynamic changes of the hazardous defects such as active defect expansion and medium leakage that may exist in the operating state of the container, and to monitor the dynamic changes of the operating state in the case of acoustic emission data anomalies.

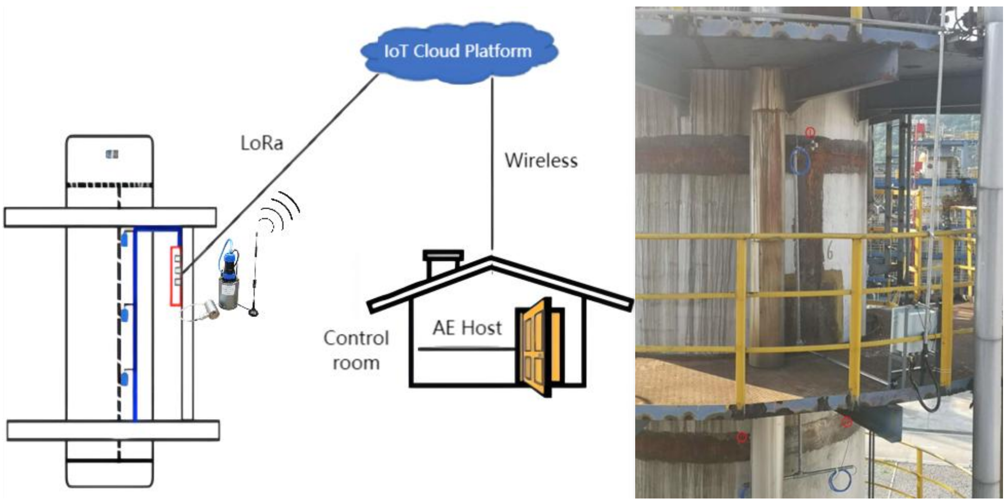

Figure 7: Container IoT AE scheme and installation

## 3.4 *Rotating Machinery Condition Monitoring*

RAEM online monitoring can be used to monitor wear, damage and lubrication of various rotating mechanical equipment such as wind turbine bearings and amusement facilities. The RAEM system has been used in a wind turbine by a wind power company to monitor the running status of bearings. The sensor is installed on the inner shaft wall of the bearing and continuously collects the acoustic emission signals generated by the wind turbine in the running state. The collector uploads and sends the collected signal data to the cloud server through the 4G network. Using the analysis software of Qingcheng to display and analyze the running state of the bearing, we can even calculate the cycle speed of the wind turbine.

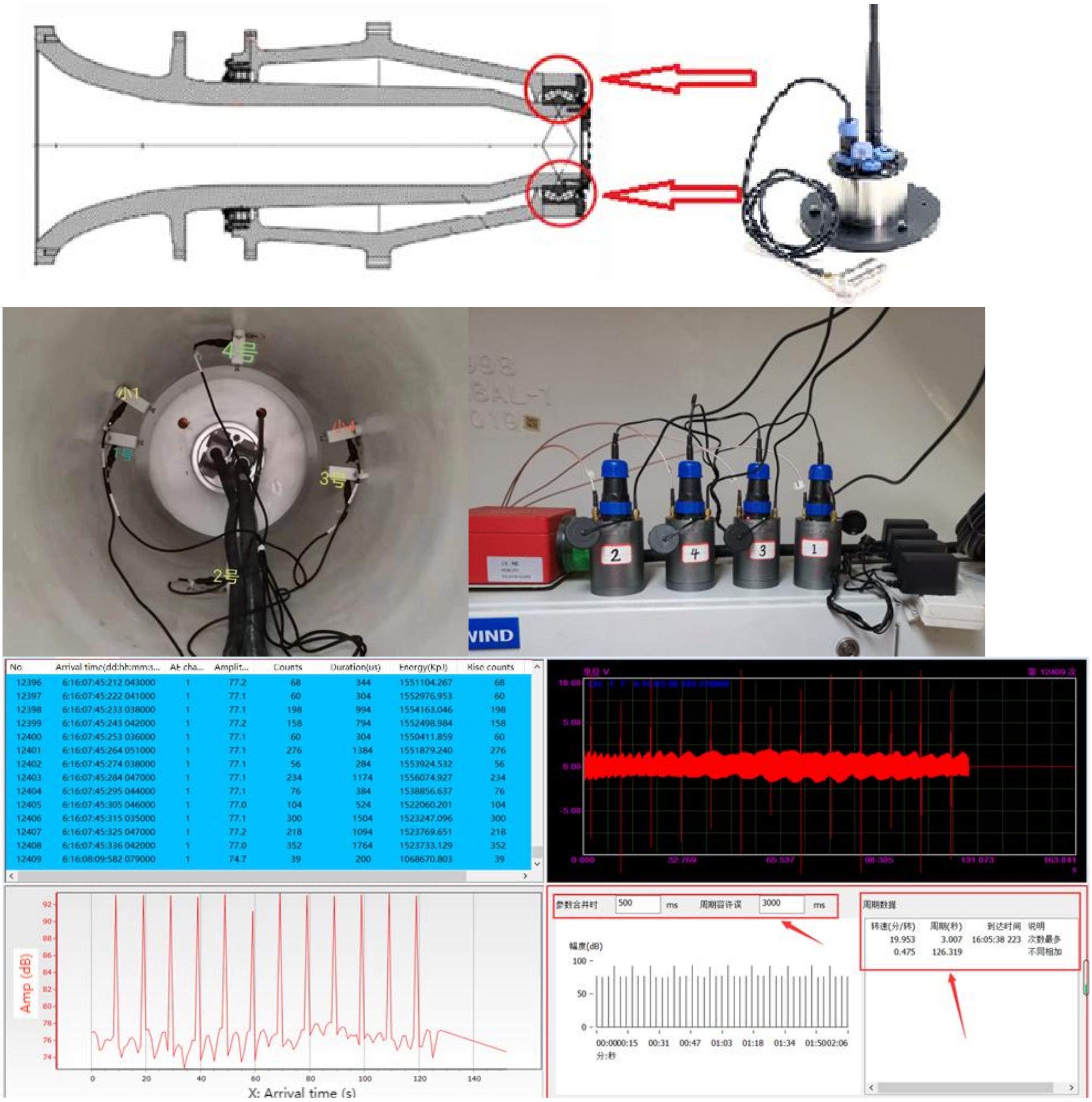


Figure 8: RAEM Installation on Wind Power and Data analysis

## 4 CONCLUSIONS

RAEM Internet of Things acoustic (acoustic emission) online monitoring system has been applied in some fields, such as bridge suspension wire breakage monitoring, valve pipeline leakage monitoring, pressure vessel crack monitoring, tank bottom corrosion monitoring, and rotating machinery condition monitoring. Compared with other existing AE devices, the RAEM system has the advantages of flexible installation, wireless data transmission, real-time cloud data display, wireless synchronization clock for locating AE sources, no need for professional analysis of results, and automatic result rating reporting. However, RAEM still has some shortcomings and can be improved. For example, when setting up for the first time, connection setup and configurations may not be straightforward enough. If the device is powered by batteries, it can only be used for periodic intermittent collection, and cannot be used for a quite long-term continuous collection. With the further development and promotion of the Internet of Things technology, the Internet of Things acoustic emission technology is a big trend and has a great demand in the industry. As a product of acoustic emission in the Internet of Things, RAEM system is expected to be applied and promoted in more fields and cases while being further improved.

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