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ACOUSTIC MONITORING AND ANALYSIS OF ONSHORE WIND TURBINES OPERATING IN THE PONDS

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Wind power is one of the key drivers of global renewable energy development and construction to achieve the goal of zero net emissions by 2050. In this study, the acoustic measurements of the onshore wind turbine operating conditions in the ponds are analyzed. First, the maximum response location of the onshore wind turbine was analyzed as a reference point for measurement. Then, 10 points were planned by taking the plane of the ponds as the X-axis and Y-axis, and the depth as the Z-axis. Taking the land-based wind turbine as the center point, measurements were made at ±4m and ±8m in the left and right directions, at 2m and 3m in the front, and at 0.2m and 0.4m in the depth of the pond, and the three-axis accelerometers and hydrophones (also known as underwater acoustic microphones) were applied to synchronously measure the impacts of low-frequency vibrations of the land-based wind turbine on the ponds in the process of its operation. After analyzing the measurement signals, the underwater acoustic measurement data of the ponds were used to observe the frequency response of the operational vibrations of the land-based wind turbines, and to preliminarily confirm the feasibility of the hydroacoustic measurements in the ponds. The preliminarily results of acoustic monitoring and analysis are expected to serve as a reference for the future development of hydroacoustic devices in related industries.

Keywords: Onshore wind turbine, hydrophone, ponds.

1. Introduction

In recent years, wind power generation technology has grown rapidly in the development of renewable energy power generation technology. Wind turbines can convert wind energy into mechanical energy, and then convert mechanical energy into electrical energy. The impacts of wind power generation on the environment and ecology mainly include: 1. Noise, 2. Glare and flicker, 3. Birds. Offshore wind power generation may increase underwater noise and vibrations generated during construction, thereby affecting the habitats of fish, benthic organisms, and marine mammals. [1]

At present, there are few studies on the impact of acoustics and vibration on breeding ecology. Chang et al. [2] studied the long-term physiological effects of offshore wind farms (OWF) underwater noise on fish. They tested black sea bream (*Acanthopagrus schlegelii*) in two types of simulated wind field noise test sites: quiet (QC: 109 dB re 1 μPa / 125.4 Hz; about 100 meters away) and noisy (NC: 138 dB re 1 μPa / 125.4 Hz; close to the turbine) for a period of 2 weeks. The fish in the NC group showed higher plasma reactive oxygen species (ROS) content than the control group in the second week. The study showed that continuous OWF operation noise is a potential stressor for fish that deserves investigation.

Barrett and Oppedal[3] studied the biological impacts of noisy machines (workboats, well boats, pumps, compressors) on Atlantic Salmo salar and conducted underwater sound pressure level (SPL) measurement studies on 10 farms, including 4 open sea cage farms, 2 closed sea cage farms and 4 land-based farms. The results showed that typical sound levels in ponds had little risk of causing significant hearing loss or acoustic damage to farmed salmon. However, potential responses to short-term and/or chronic stress from sound exposure warrant further investigation, both in the context of predictable and unpredictable sound exposure.

This paper focuses on the acoustic measurement and analysis of the operating status of onshore wind turbines in ponds, and uses a three-axis accelerometer and hydrophone to observe the relevant operating vibration frequency response of onshore wind turbines. Through on-site measurement and analysis, the feasibility of using hydrophones for the ponds measurement was confirmed.

2. Introduction to hydrophone characteristics

Underwater sound sensors, also known as hydrophones, are mainly used to detect underwater sound wave devices and are widely used in ocean monitoring, sonar systems, underwater communications and other fields. The operating principle of the hydroacoustic device is based on the Piezoelectric Effect or the Piezoresistive Effect. When sound waves propagate in water and act on piezoelectric materials, tiny mechanical deformations will occur. Deformation caused by pressure will cause the charge within the material to be redistributed, resulting in a voltage change. The voltage signal is related to the amplitude and frequency of the sound wave, so it is converted into readable data through circuit processing. The appearance of the hydrophone is shown in Figure 1.

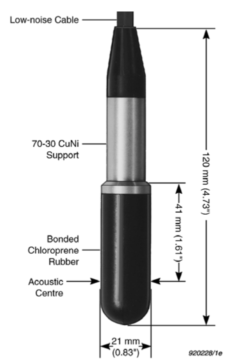


Figure 1: Hydrophone appearance (B&K 8104) [4]

Sound pressure is the physical quantity that causes local pressure changes when sound waves propagate in a medium (such as water or air). It is usually expressed in Pascals (Pa) or microbars (μbar). The underwater of sound pressure level (SPL) is a logarithmic representation of the sound pressure in decibels (dB re 1 μPa):

$$\mathrm{SPL} = 20\log_{10}\frac{P_{rms}}{P_0} \quad (1)$$

where P_{rms} is the measured sound pressure (Pa), and P_0 is the reference sound pressure, which is 20 μPa = 2 x 10^{-5} Pa in air and 1 μPa = 1 x 10^{-6} Pa in water.

3. Experimental measurement in ponds

This study mainly discusses the acoustic measurement and analysis of the operating status of onshore fans in the ponds. The measurement experiment flow chart, as shown in Figure 2, is the complete experimental process: before each experiment, the accelerometer and hydrophone are calibrated separately; secondly, the relevant experimental instruments and equipment are set up. The measurement was carried out using the Sound and Vibration Measurement System (SVM) software. The fan vibration and underwater sound signal information obtained from the measurement were calculated using fast Fourier transform and short-time Fourier transform (STFT) to obtain their spectrum and time-frequency diagrams for analysis. The regularity was observed to complete the overall experimental process. The setup of experimental measurement instruments at the farm is shown in Figure 3.

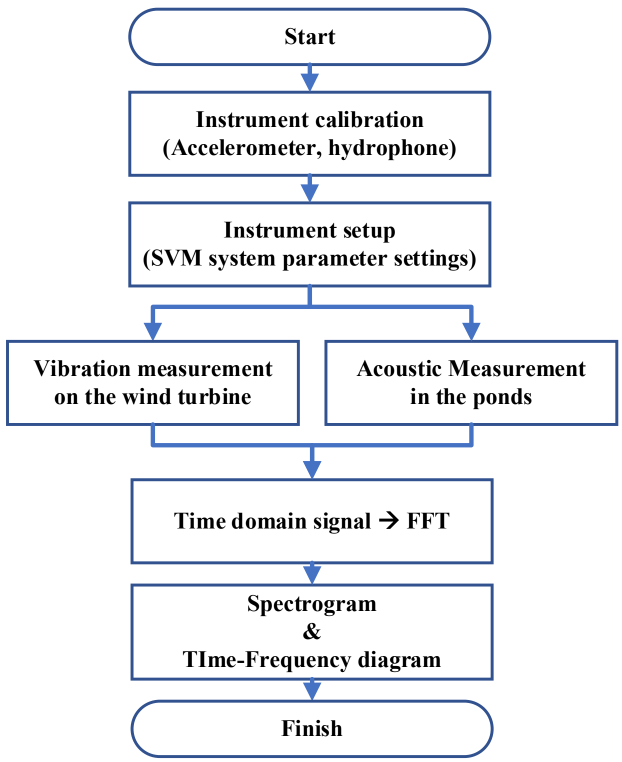


Figure 2: Experiment measurement flowchart

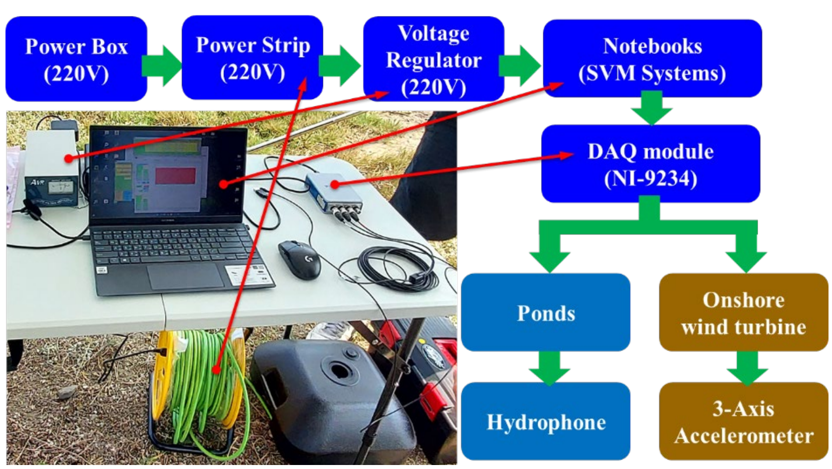


Figure 3: Experiment measurement connection diagram

In terms of accelerometer measurement planning, the accelerometer is pasted at three locations: 1.0 m, 2.0 m, and 2.5 m from the ground of the wind turbine to determine the best measurement response point, as shown in Figure 4. In addition, in terms of hydrophone measurement planning, the horizontal side of the ponds plane is planned as the X-axis, the vertical side is planned as the Y-axis, and the depth is planned as the Z-axis. With the onshore wind turbine as the center point, the left and right sides of the ponds are ±4m and ±8m away, and the front is 2m and 3m away, as shown in Figure 5. The depth of the ponds is planned to be measured at 0.2m and 0.4m, as shown in Figure 6. The planned 20 measurement coordinate points are listed in Table 1. Finally, the three-axis accelerometer and hydrophone simultaneously measure the impact of low-frequency vibration of onshore wind turbines on the ponds during operation.

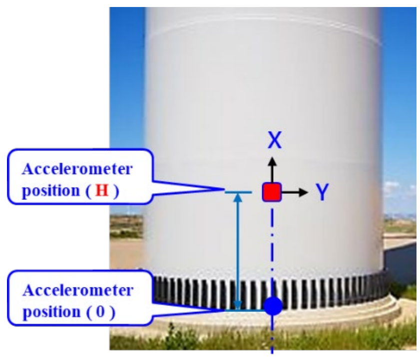


Figure 4: Measurement position of accelerometer

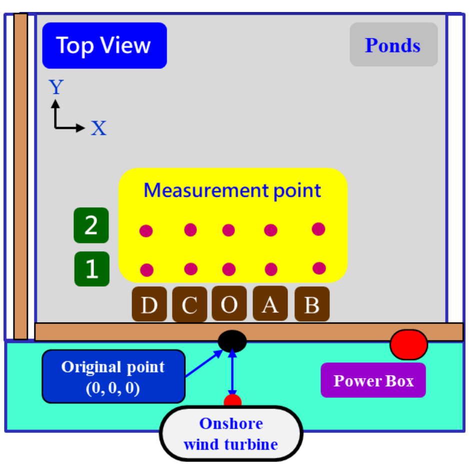


Figure 5: Schematic of hydrophone measurement (top view)

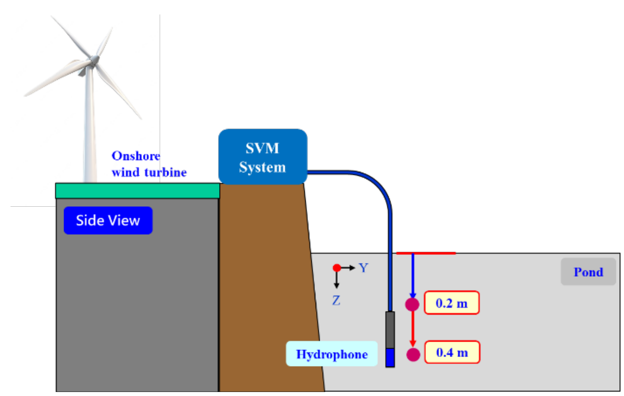


Figure 6: Schematic of hydrophone depth measurement (side view)

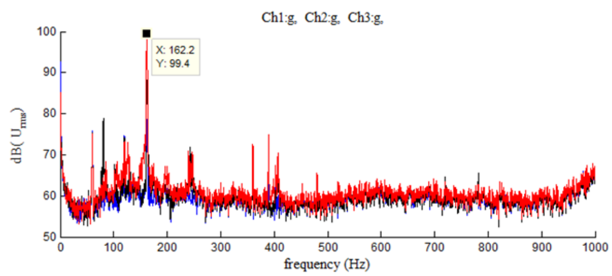
Table 1: Summary of hydrophone measurement points (unit: m)

No.	Name	Coordinates			No.	Name	Coordinates			No.	Name	Coordinates		
		X	Y	Z			X	Y	Z			X	Y	Z
1.	D1_1	-8	2	0.2	9.	O1_1	0	2	0.2	13.	A1_1	4	2	0.2
2.	D1_2	-8	2	0.4	10.	O1_2	0	2	0.4	14.	A1_2	4	2	0.4
3.	D2_1	-8	3	0.2	11.	O2_1	0	3	0.2	15.	A2_1	4	3	0.2
4.	D2_2	-8	3	0.4	12.	O2_2	0	3	0.4	16.	A2_2	4	3	0.4
5.	C1_1	-4	2	0.2						17.	B1_1	8	2	0.2
6.	C1_2	-4	2	0.4						18.	B1_2	8	2	0.4
7.	C2_1	-4	3	0.2						19.	B2_1	8	3	0.2
8.	C2_2	-4	3	0.4						20.	B2_2	8	3	0.4

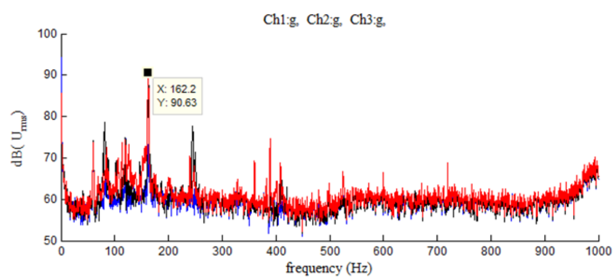
4. Results and Discussion

4.1 Confirmation of measurement response point

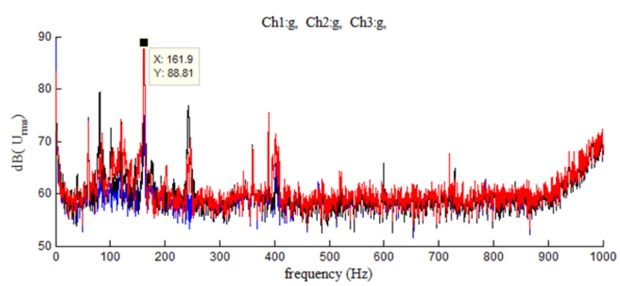
The onshore wind turbine measures the vibration signal. The accelerometer measures the vibration signal at three positions: 1.0 m / 2.0 m / 2.5 m. The measurement signal is analyzed by SVM software to obtain a spectrum diagram, which is shown in Figure 10. It can be seen from the figure that the maximum response of the accelerometer occurs at 1.0 m, and the fan measurement response point is confirmed here.



(a) 1.0 m



(b) 2.0 m

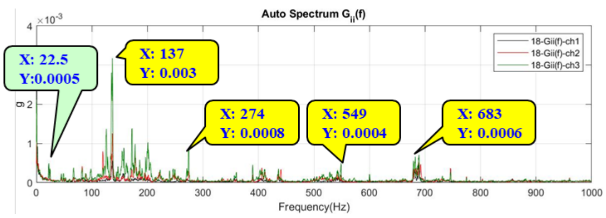


(c) 2.5 m

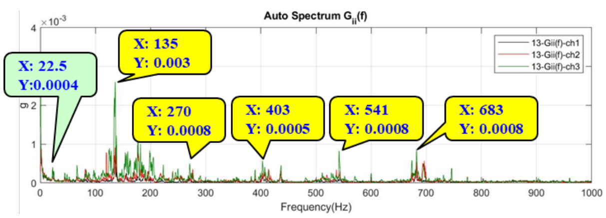
Figure 10: Response of the accelerometer at different heights of onshore wind turbines

4.2 Hydrophone measurements in ponds

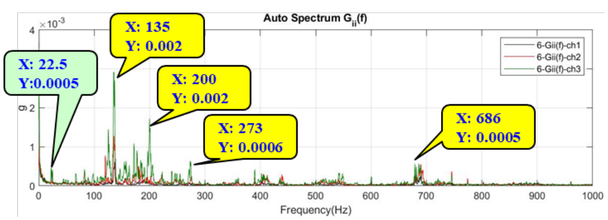
The experimental measurement data analysis results are summarized in Figures 11-13. Figure 11 shows the spectrum analysis results at point D. The vibration frequency of the onshore wind turbine mainly occurs in the frequency band below 500 Hz, and a periodic frequency of 137 Hz is generated in the Z-axis direction. The vibration frequency of the onshore wind turbine changes to 137 Hz, 135 Hz, 135 Hz, and 137 Hz. It is speculated that the frequency change of the onshore wind turbine vibration is caused by the weather and wind speed. The vibration frequency of onshore wind turbines in the Y-axis direction also increases significantly. Figure 12 is the spectrum of underwater sound signals in the ponds. The spectrum diagrams of the four monitoring points at point D all have a periodic frequency of 60 Hz, and the generator frequency of the power generation system next to the fan is transmitted to the bottom of the ponds. The time-frequency diagram of the underwater sound signal from the ponds shows an obvious 60 Hz periodic frequency, as shown in Figure 13.



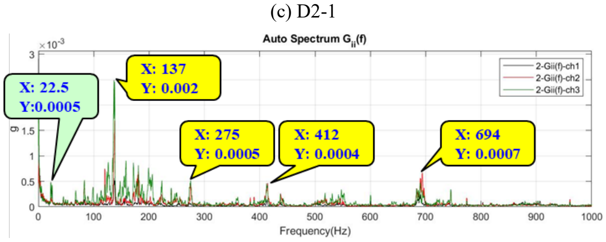
(a) D1-1



(b) D1-2

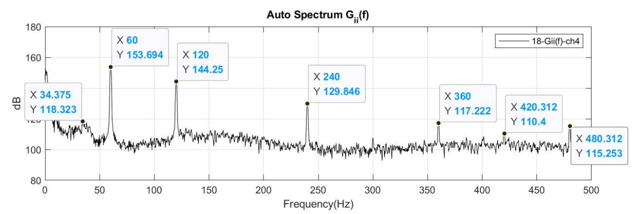


(c) D2-1

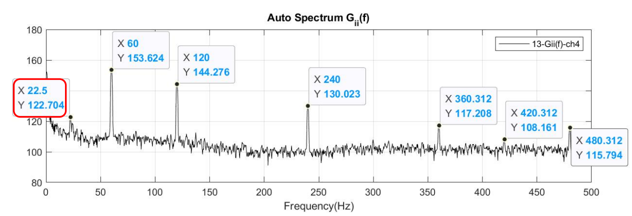


(d) D2-2

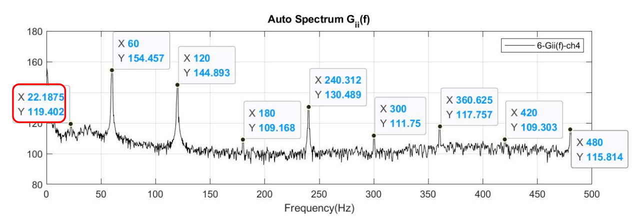
Figure 11: Spectrogram of onshore wind turbine vibration signals (point D)



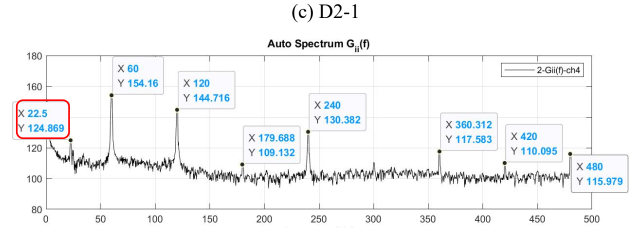
(a) D1-1



(b) D1-2



(c) D2-1



(d) D2-2

Figure 12: Spectrum of hydrophone signals in ponds (point D)

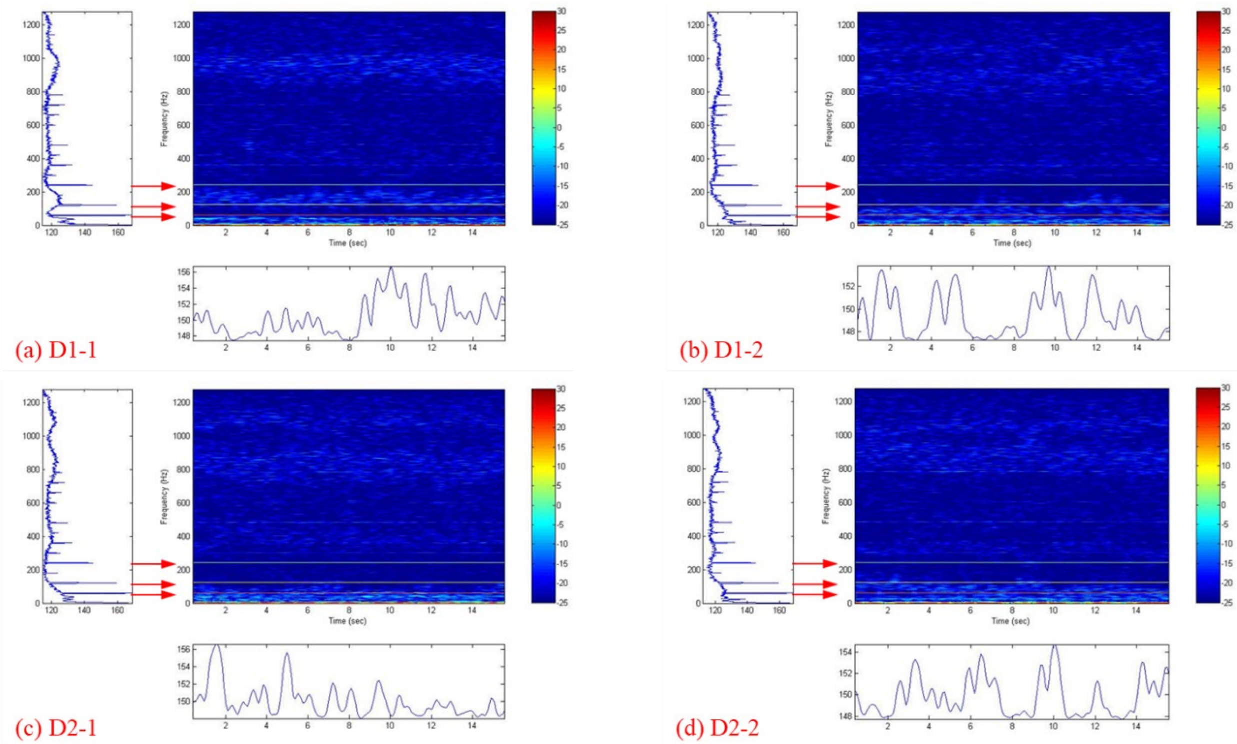


Figure 13: Time-frequency diagram of hydrophone signals in ponds (point D)

Based on the above signal analysis chart results, the 60Hz and 22.5Hz sound values of the underwater sound in the ponds are summarized and discussed. Figure 14 shows the summary of hydrophones measurements in ponds (60 Hz). The higher sound value obtained at the farthest point of the fan (point D) at the measurement point is 154 dB re 1μPa / 125.4 Hz. It is speculated that this is caused by the larger operating sound on the forward fan side. Similarly, the smaller sound value at the measurement point (point B) is 150 dB re 1μPa / 125.4 Hz. It is inferred that the side is facing away from the fan, so the operating sound is relatively small. In addition, Figure 15 is a summary of hydrophones measurements for ponds_22.5 Hz. From the observation map, the vibration frequency of the wind turbine was observed to be 22.5 Hz at all measurement points. The sound value close to the middle side of the land turbine (point O) was 127 dB re 1μPa / 125.4 Hz. Similarly, the sound values at the measurement points deeper from the water surface (points 1-2 and 2-2) were relatively higher than those at the measurement points shallower from the water surface (points 1-1 and 2-1).

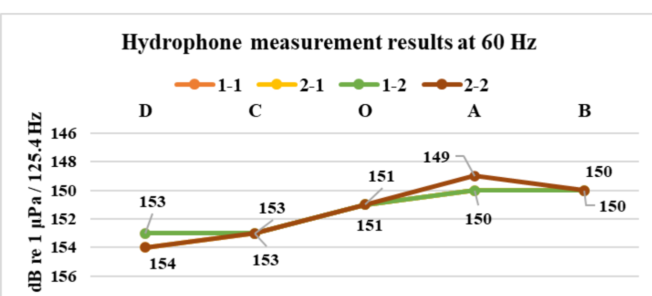


Figure 14: Hydrophones measurement results at 60 Hz

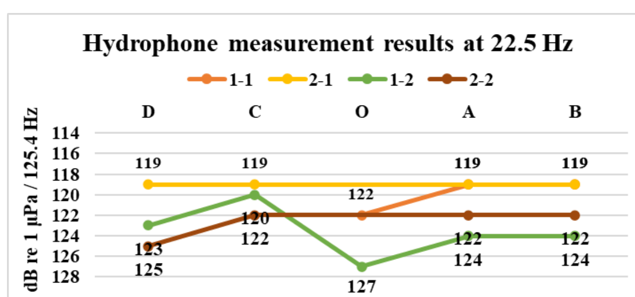


Figure 15: Hydrophones measurement results at 22.5Hz

5. Conclusion

This article focuses on the acoustic measurement and analysis of the operating status of land-based wind turbines in ponds, and uses three-axis accelerometers and hydrophones to observe the relevant operating vibration frequency responses of land-based wind turbines. Based on the on-site measurement and preliminarily analysis results, the feasibility assessment of hydrophone measurement in ponds was confirmed. Based on the above preliminarily analysis results, the following conclusions are:

1. Analysis of wind turbine measurement response points: The vibration response of land-based wind turbines occurs on the Y/Z axis, which represents the left-right/front-back swing phenomenon of land-based wind turbines. Its maximum frequency occurs at 162.2 Hz, and there is a natural periodic frequency located around 81 Hz. The frequency change is mainly caused by the weather and wind speed.

2. Land wind turbine vibration and underwater sound measurement: Observe 5 points (D/C/O/A/B), the wind turbine vibration periodic frequency is 22.5 Hz frequency multiplication relationship; the hydroacoustic device observation period frequency is 60 Hz, and the maximum sound value is 154 dB re 1μPa / 125.4 Hz. In addition, the vibration frequency of the fan was observed to be 22.5 Hz, and the maximum sound value was 127 dB re 1μPa / 125.4 Hz.

3. Based on the measurement signal analysis results, the underwater sound measurement data in the ponds was used to observe the relevant operating vibration frequency response of the land-based wind turbine, and the feasibility of hydrophone measurement in the ponds was preliminarily confirmed. The expected acoustic monitoring and preliminarily analysis results serve as a reference for the application and development of hydrophones in related industries.

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