# Analysis of Infrasound and Generation Mechanism

Yasumasa UYAMA

Personal member of Japan Wind Energy Association.

## Abstract

This document provides the results of analysis of the sound from wind turbine, and the mechanism of infrasound generation.

The part of the infrasound near the wind turbine is described as wind noise and the frequency is not examined in detail. However, when this feature is investigated, it becomes clear that the directivity of the wind turbine sound, the shaking of the top of the tower, and the vibration around 40 m above the ground of the tower are related, and it is found that the wind turbine generates directional infrasound.

For wind noise, "Low-frequency wind noise is caused by wind hitting the microphone. This noise has a louder component as the frequency decreases. In the frequency range of about 5 Hz or less (in some cases about 10 Hz or less), it is difficult to eliminate wind noise." It is said,

Even if the wind is strong, the component of 10 Hz or less in a place where there is no wind turbine has an extremely low sound pressure and no regular wind noise. Even if the wind is not so strong, near the wind turbine, the sound pressure of the component below 10 Hz is high, and wind noise with regularity appears.

This is either to think that there are two types of wind noise: "wind noise in places where there are no wind turbine" and "wind noise in places where there are wind turbines", or to think that infrasound with high sound pressure is generated from wind turbine.

Keywords: infrasound, wind noise, lift vector, rotation moment, tower vibration

## 1. Introduction

The component of sound of 5 Hz or less is considered "wind noise" and "if this is removed, the original wind turbine sound can be obtained. However, by analyzing the frequency and clarifying the cause of the vibration of the wind turbine, it is shown that this sound is "infrasound caused by the wind turbine".

## 2. Measurement equipment and analysis target

Measuring equipment: NL-62, NX-42WR, analysis target: Wind turbine with horizontal rotation axis in Kaze-no-oka, Tateyama City, Chiba Prefecture*1

## 3. Noise comparison

Compare frequency spectra to show features. (Frequency hertz [Hz] on the horizontal axis, sound pressure pascal [Pa] on the vertical axis)

Fig.1:Sound in J FE steel mill (0~5000Hz)

Fig.2: Sound measured near the wind turbine (0~5000Hz)

Fig.3: Sound measured near the wind turbine (0~25Hz)

Fig.4: Sound in the precincts of Nagao Shrine (0~25Hz)

Fig. 1 Fig. 2 is a comparison in the range of 0~5000Hz, and the sound in the steelworks is wideband, but the wind turbine sound is concentrated near 0.8Hz in the left corner and is not a broadband sound.

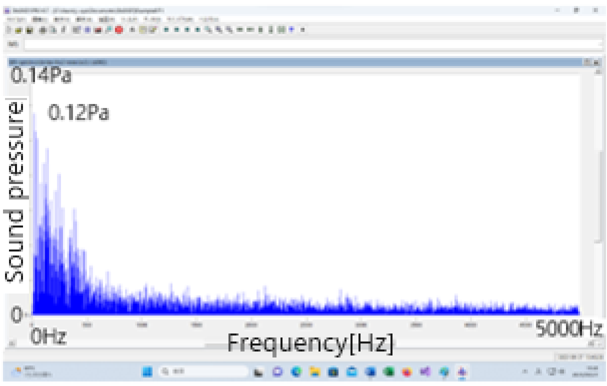


Fig.1 JFE iron mill ; Max 0.12[Pa](12Hz)

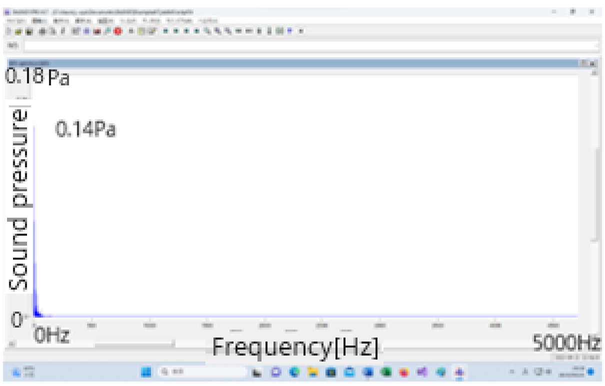

Fig. 2 Wind turbine noise ; Max 0.14[Pa](0.8Hz)

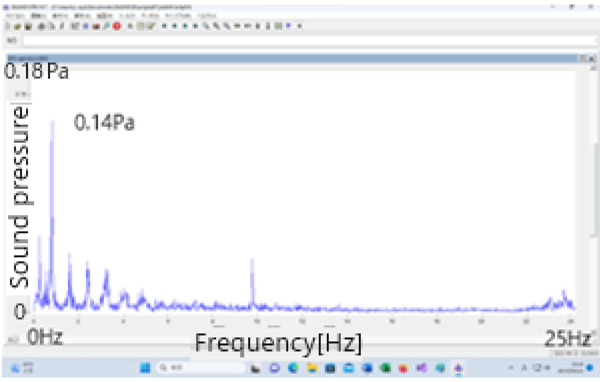


Fig. 3 Wind turbine noise (0～25Hz)

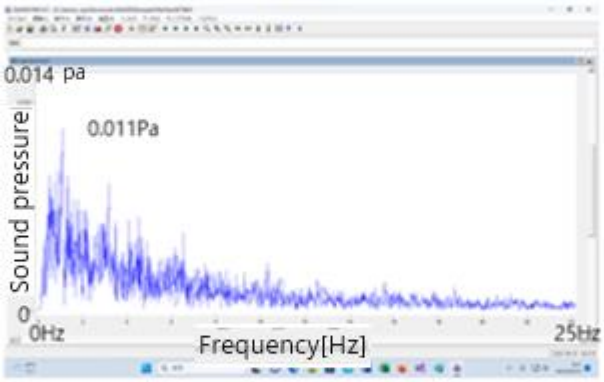


Fig. 4 Nagao shrine (0～25Hz); 0.011[Pa](1.1Hz)

Fig. 3 Fig. 4 shows the sound measured by placing equipment in the car near the wind turbine and opening the leeward window (maximum sound pressure 0.14 [Pa] (0.8 Hz)) in the range of 0~25 Hz) and the sound measured with a microphone placed on the stairs of the nearby Nagao Shrine and being exposed to the wind (maximum sound pressure 0.011 [ Pa] (1.1 Hz)). Table 3 describes in detail the regularity of "wind noise" near wind turbine. From FIG. 4, it can be seen that in places where there is no wind turbine, the sound pressure is low and there is no regularity in the frequency. It is necessary to distinguish between these "wind noises".

Table 1 Table 2 shows the energy distribution for each frequency band.

| Energy distribution | 0～20Hz | 20～5kHz |
|---|---|---|
| Wind turbine | 93% | 7% |
| Iron mill | 12% | 88% |

Table 1 Energy distribution (0～5000Hz)

| Energy distribution | 0～1Hz | 1～20Hz | 0～20Hz |
|---|---|---|---|
| Wind turbine | 61.3% | 38.7% | 100.0% |
| Iron mill | 0.04% | 99.96% | 100.0% |

Table 2 Energy distribution (0～20Hz)

From Table 1, if wind turbine sound is considered as noise (frequency 20 Hz or more), 93% of the sound energy is ignored. As a result, the proportion of people who complain of discomfort is compared with the value excluding the part that causes discomfort such as pressure, and there is a large error compared to the case of traffic noise.

From Table 2, it can be seen that the 0.8 Hz portion accounts for 61% of the sound energy of 0 ~ 20 Hz. Therefore, infrasound should not be limited to 1~20Hz.

## 4. Wind turbine sound and playback sound

Figure 5 shows the sound of a wind turbine recorded by NL-62 for 60 seconds. Figure 6 shows the sound divided using FFT, with blue as 0~20Hz, green as 20~200Hz, and red as 200~24kHz components. Figure 7 shows the sound of Fig. 5 played back on a PC speaker, and then the sound recorded by NL-62 again divided in the same way as Fig. 6.

In Fig. 6, amplitude modulation can be seen in the 200Hz~24kHz component, but the influence on the room is weak considering the extremely low sound pressure and air attenuation and energy transmittance. Conversely, the energy of infrasound is large and its effects should be carefully investigated.

Except for the feeling of pressure, the difference between the sound heard near the wind turbine and the sound from the speaker could not be distinguished by hearing.

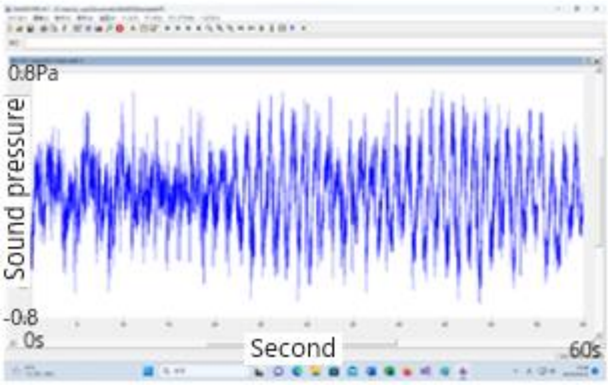


Fig.5 Wind turbine noise

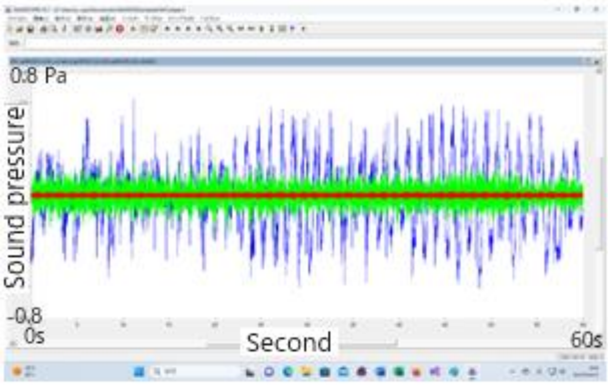


Fig.6 Separated Wind turbine noise

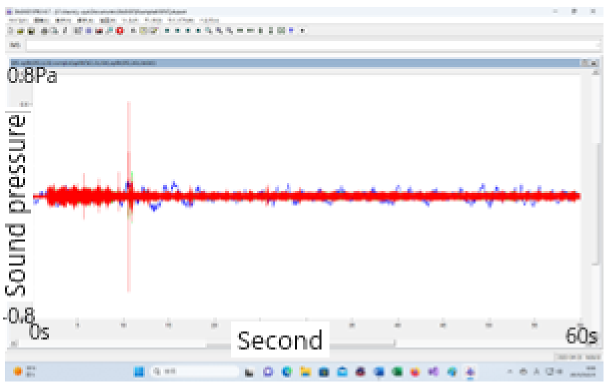


Fig.7 Separated sound from speaker

From FIG. 7, it can be seen that the speaker sound does not include infrasound sound. Even large speakers cannot reproduce sound below 1Hz. This is the cause of the difference in pressure between the sound of the wind turbine and the sound played by the laboratory. If you want to do an experiment, you have to build a laboratory on the bed of a trailer and go near the wind turbine.

## 5. Detailed characteristics of wind turbine sound

Table 3 shows the correspondence between the peak value of the sound pressure in FIG. 3 and the frequency at that time.

| Frequency at peak[Hz] | Rate(1) | Rate(2) | Sound pressure[Pa] |
|---|---|---|---|
| 0.2667 | 1.0000 | | 0.0560 |
| 0.5333 | 2.0000 | | 0.0309 |
| 0.8167 | 3.0625 | 1.0000 | 0.1405 |
| 1.5833 | 5.9375 | 1.9388 | 0.0436 |
| 2.4167 | 9.0625 | 2.9592 | 0.0242 |
| 3.2167 | 12.0625 | 3.9388 | 0.0317 |
| 4.0000 | 15.0000 | 4.8980 | 0.0177 |
| 4.8667 | 18.2500 | 5.9592 | 0.0173 |
| 5.4667 | 20.5000 | 6.6939 | 0.0101 |
| 6.2667 | 23.5000 | 7.6735 | 0.0098 |

Table 3 Frequencies of the peak values

The frequency of 0.8 Hz when the maximum sound pressure is achieved corresponds to f = RZ / 60 [Hz] when the number of blades is R (rpm) and the number of blades is Z (sheet). If we elucidate the mechanism by which sound is produced, including other frequencies, we can understand the reason why infrasound is generated.

## 6. Fine fluctuations in frequency

From f = RZ / 60 [Hz], the frequency varies with the number of revolutions. From the Wavelet graph of FIG. 8, it can be seen that the frequency changes between 0.73 Hz and 0.87 Hz.

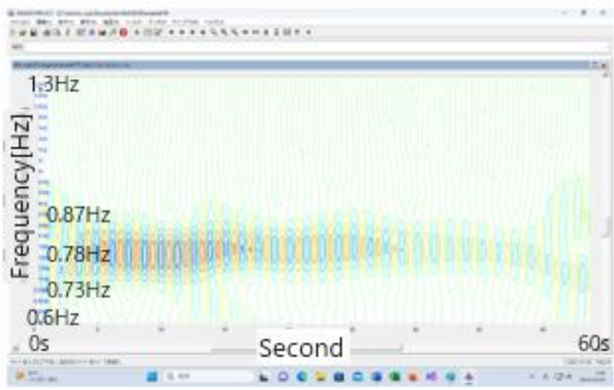


Fig.8 Fine fluctuation nearby 0.8Hz

| Rotation (7times), a part of large table | | |
|---|---|---|
| Brade pass | Time(second) | Frequency[Hz] |
| 21 | 28[s] | 0.75[Hz] |
| 21 | 22[s] | 0.95[Hz] |
| 21 | 28[s] | 0.75[Hz] |
| 21 | 28[s] | 0.75[Hz] |
| Average | | 0.8 [Hz] |

Table 4 Fine fluctuation from video

Table 4 shows a part of the frequency calculated from the state of rotation captured on video. The frequency changes finely in response to changes in wind speed, coinciding with changes in Figure 8.

In FIG. 8, the darker part indicates that the sound pressure is high, and since FIG. 8 is the measurement result for 60 seconds, it can be seen that the state of high sound pressure continues for about 20 seconds. From the measurement results for 10 minutes, it can be seen that the sound pressure of the frequency component close to 0.8 Hz is 0.10 [Pa] when the wind is weak, 0.37 [Pa] when the wind is strong, and the average is about 0.18 [Pa].

## 7. Tower vibration direction and wind turbine sound directivity

Consider the direction and magnitude of vibrations on the nacelle and the sides of the tower 40 meters above the ground, as well as the directivity of the sound, while paying attention to the direction of the lift vector. (1.6Hz is because it is a small wind turbine with a high rotation speed.) )

"Vibration Analysis of Wind turbine Nacelle Tower" 1)

Then, regarding the nacelle portion, ″In the rolling direction of FIG. 3, an increase in gain can be confirmed to 0.8 Hz, 1.6 Hz, and 2.7 Hz, and the eccentricity of the rotor does not appear remarkably, and instead the number of blades × rotation speed oscillations appear at 1.6 Hz. This is caused by blade deformation vibration due to the wind speed and the number of blades up, down, left, and right″Figures 4 and 5 show the 210 degree direction and 300 degree direction spectra of nacelle vibration. ″In the 210 degree direction, the rotor rotation frequency of 0.5 Hz appears slightly, and the number of wings × the rotation speed of 1.6 Hz is remarkably displayed″, and furthermore, from FIGS. 6 and 7 of 1), it can be seen that a component of 1.6 Hz appears in the 210 degree direction and the 300 degree direction even in the vibration of 40 m in the tower.

"Effect of wind speed on wind turbine noise directionality"2)

Then, "The level at 200 degrees is high, which is the position where the cancellation mechanism works and the level decreases, and the opposite phenomenon of directivity appears. It can be seen from FIG. 6 of 2) that the sound pressure is high in the direction of 20 degrees, 110 degrees, 200 degrees, and 290 degrees.

Referring to "Studies on the elasto-plastic pure bending collapse of cylinders" 3), the variation of the side of the tower is shown in Fig. 9, Fig. 10.

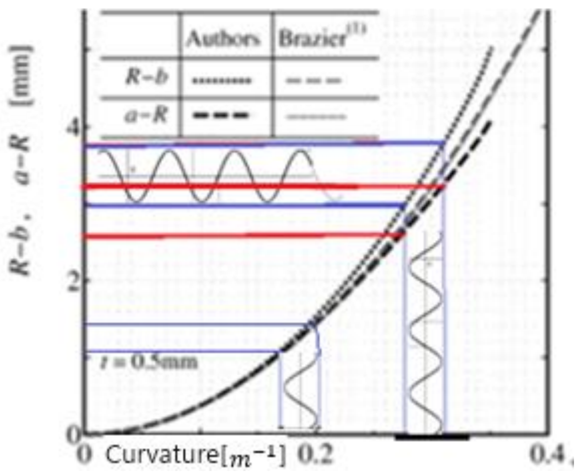


Fig. 9 Force fluctuation and side vibration

FIG. 9 shows that the side of the tower vibrates in response to a change in the force applied to the tower. The vibration width of the side is larger on the right.

The cross section of the tower becomes elliptical when the cylinder bends as shown on the right side of FIG. Lateral vibrations in the direction of the applied force and side vibrations in the direction perpendicular to it occur. As a result, the wind turbine sound is directional, and the frequency coincides with the frequency of the force applied to the tower. Furthermore, if the cross section changes from a circle to an ellipse, the volume in the tower decreases because the area decreases. Conversely, if the cross section approaches the circle, the volume increases. The deformation of the tower also causes fluctuations in air pressure inside the tower.

## 8. Forces exerted on wind turbines and their effects

According to "Fluid Dynamics (Part I)" 4),

The lift force L acting on the wing is、Kutta-JopukowskiFrom the theorem of、

$$L = \rho U \Gamma = 4\pi \rho U^2 \lambda \sin(\alpha - \delta) \qquad (1)$$

, the lift force is proportional to the square of the uniform flow velocity U.

Considering the close distance between the blade and the tower, if we investigate the magnitude of the lift L and the periodic change in the rotational moment with respect to the tower, we can understand the deformation of the tower and the cause of the wind turbine sound, and also know the frequency of the wind turbine sound and the degree of sound pressure.

In "Vibration Analysis of wind turbines" 5), after describing the lift L, the force applied to the wind turbine is discussed.

"Wind speed varies with height, so as the blades rotate, these forces change periodically, resulting in cyclic excitation forces on the blades and tower."

"Each frequency component of the force applied from the blade to the tower is multiplied by several times, and as described above, a lot of excitation force with a frequency nP n times the rotational speed is added." It states.

"A lot of excitation force with an frequency nP n times the rotational speed" lacks consideration of the directivity of the windmill sound, and does not lead to how the tower is deformed and produces sound.

"Aeroacoustics"6) describes how sound is generated from a vibrating object.

In order to consider the vibration of the side of the wind turbine, it is necessary to shift the viewpoint to the rotational moment hanging on the tower from the viewpoint of the force applied to the tower. The deformation of the tower is similar to the case of a fishing rod bending. The deformation of the fishing rod is determined by the moment of rotation relative to the fishing rod. The shaking of the upper part can remain circular, but the shaking of the side is accompanied by deformation of the cut.

The wind turbine rotates by lift, and the rotation speed is adjusted by changing the angle of the blades. At the start of rotation, the direction of the blade is adjusted so that the component in the rotation direction increases, and when the rated output operation Set the direction of the lift vector to 200~210 degrees to suppress blade rotation. As a result, the component of the lift force in the direction of the rotation axis increases.

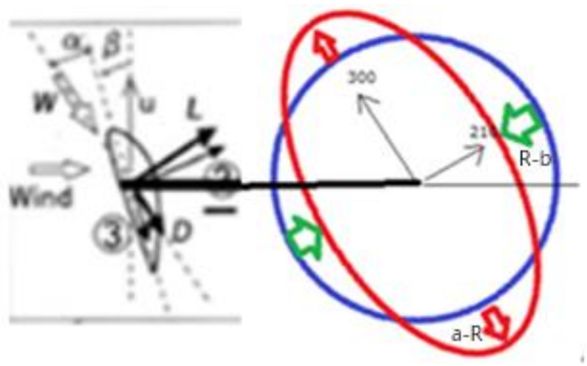


Fig. 10 Lifting vector and modification

## 9. Force and rotational moment on the tower

(Calculated with a 9-digit number and rounded to the end.) )

Regarding the swing of the nacelle and tower, emphasis should be placed on the direction of the lift vector when the blade is directly overhead, but here we consider the component of the lift vector in the direction of the axis of rotation.

Simplifying, the height of the tower is 100 m, and instead of the blade, a plate shaped like a round sign is attached 50 m from the center, and the frequency is calculated.

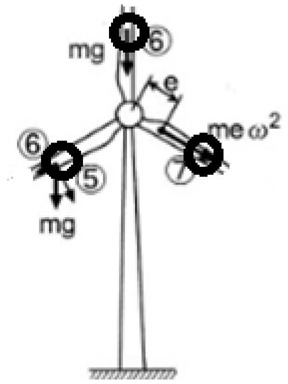


Fig. 11 Wind turbine in balance

The height of the disk above the ground is m$100 + 50 * \sin(\omega t + \theta)$
Become.

Winds blow stronger in the sky than near the surface. There are several formulas for predicting wind speed in the sky, but the following prediction equation is used here.
Wind speed at$Z_{h1}$ height$V_{Zh1}$
Predicted wind speed at$Z_{G(V)}$ height$V_{ZG(V)}$
Power index α according to ground surface roughness classification V (v)
and the following equation

$$V_{ZG(V)}/V_{Zh1} = (Z_{G(V)}/Z_{h1})^{\alpha(V)} \quad (2)$$

In the countryside, it is.$\alpha(V) = 0.15$
In rural areas, when the wind speed is 7 [m/s] at 10 m above the ground,
The wind speed at 100+50*sin(ωt+θ) m above the ground is

$$7 * ((100 + 50 * \sin(\omega t + \theta))/10)^{\wedge}0.15 \quad [\mathrm{m/s}] \quad (3)$$

Become.

If the air density is 1.23 [kg/m^3], the wind force coefficient Cd = 1.2, and the wind speed V [m/s], P: the wind load [N/m²] is

P＝（V^2／2）×1.23×1.2　[N/m²]　(4)

Then, when the area of the sign is 10 [m²], when a wind of 7 [m/s] blows 10 m above the ground, the force on the round plate attached to the windmill is

$$P = \frac{\left(\left(7 * \left(\frac{(100 + 50 * \sin(\omega t + \theta))}{10}\right)^{0.15}\right)^2\right)}{2} * 1.23 * 1.2 * 10 \quad [N] \quad (5)$$

Become. This force is proportional to the square of the wind speed.

The force that tries to knock down the windmill caused by this force is the moment of rotation when the axis of rotation is a straight line shared between the ground surface and the rotating surface of the blades.

$$P * (100 + 50 * \sin(\omega t + \theta)) = k * (100 + 50 * \sin(\omega t + \theta))^{\wedge}1.3 \quad [\mathrm{Nm}] \quad (6)$$

(k=181.24). Here

$$(100 + 50 * \sin(\omega t + \theta))^{\wedge}1.3 \quad (7)$$

Let's focus on the part.
Since the angle of the blade is 2π/3, the rotation moment M is
When ω=2π・0.8/3,

$$f(t) = (100 + 50 * \sin(\omega t))^{1.3} + (100 + 50 * \sin(\omega t + 2\pi/3))^{1.3} + (100 + 50 * \sin(\omega t + 4\pi/3))^{1.3} \quad (8)$$

If so

$$M = k * f(t) = 181.24 * f(t) \quad [\mathrm{Nm}] \quad (9)$$

It becomes. McLoughlin deployment

$$(1 + x)^{\alpha} = 1 + \frac{\alpha}{1!}x + \frac{\alpha(\alpha-1)}{2!}x^2 + \frac{\alpha(\alpha-1)(\alpha-2)}{3!}x^3 + \cdots \quad (10)$$

to calculate. (The calculation in SIN is shown, but the same applies to cos.) )

1. Approximate calculation on the calculator (basis of 0.8 Hz)

$$(100 + 50 * \sin(\omega t))^{1.3} = (100^{1.3})(1 + (1/2) * \sin(\omega t))^{1.3} \quad (11)$$

If we substitute (1/2)sin(ωt) into the expansion equation,

$$(100 + 50 * \sin(\omega t))^{1.3} = 398.11 * \{1 + 0.65\sin(\omega t) + 0.05sin^2(\omega t) - 0.006sin^3(\omega t) + \cdots\} \quad (12)$$

Become. Calculate by paying attention to the following equation.

$$\sin(x) + \sin(x + 2\pi/3) + \sin(x + 4\pi/3) = 0 \quad (13)$$

$$sin^2(x) + sin^2\left(x + \frac{2\pi}{3}\right) + sin^2\left(x + \frac{4\pi}{3}\right) = \frac{3}{2} \quad (14)$$

$$sin^3(x) = (3\sin(x) - \sin(3x))/4 \quad (15)$$

So, out of the sum of the cubes of sin, the sum of sin(x) is 0, and the sum of sin(3x) is

$$\sin(3x) + \sin\left(3\left(x + \frac{2\pi}{3}\right)\right) + \sin\left(3\left(x + \frac{4\pi}{3}\right)\right) = 3\sin(3x) \quad (16)$$

Because it becomes

$$sin^3(x) + sin^3\left(x + \frac{2\pi}{3}\right) + sin^3\left(x + \frac{4\pi}{3}\right) = -(3/4)\sin(3x) \quad (17)$$

consequently

$$f(t) \approx 1223.43 + 1.70\sin(3\omega t) \quad (18)$$

Become.

When the three blades rotate according to SIN (ωt), SIN (ωt + 2π / 3), SIN (ω t + 4π / 3), The rotational moment on the tower is

$$M = k * f(t) \approx 221734.19 + 307.78\sin(3\omega t) \quad (19)$$

If the rotation frequency of the blade is 0.26666 Hz, the moment applied to the tower changes at a frequency of 0.8 Hz.

It can be seen that the rotation moment changes at a period of 1/3 of the rotation period of the blade.

(2) Uneven case (0.27Hz, 0.53Hz grounds)

Next, consider the case where only one of the blades is slightly larger than the other two.

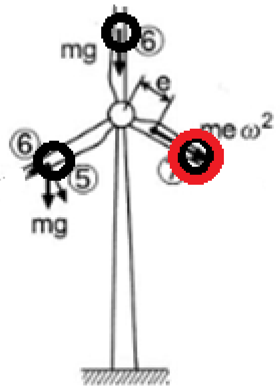


Fig. 12 Wind turbine imbalance

If the area of the large part is 10*1.003=10.03 m², the force received by the red circle at this time is

$$P = \frac{\left(\left(7 * \left(\frac{(100 + 50 * \sin(\omega t + \theta))}{10}\right)^{0.15}\right)^2\right)}{2} * 1.23 * 1.2 * 10 * 1.003 \quad [N] \quad (20)$$

than

$$P * (100 + 50 * \sin(\omega t + \theta)) = k * ((100 + 50 * \sin(\omega t + \theta))^{1.3} + 0.003 * (100 + 50 * \sin(\omega t + \theta))^{1.3}) \quad (21)$$

Become. Assuming that θ=0 is large,

$$g(t) = f(t) + 0.003 * (100 + 50 * \sin(\omega t))^{1.3} \quad (22)$$

Think. (I used equation (8).) )

$$0.003 * (100 + 50 * \sin(\omega t))^{1.3} = 0.003 * 398.11\{1 + 0.65\sin(\omega t) + 0.05sin^2(\omega t) - 0.006sin^3(\omega t) + \cdots\} \quad (23)$$

Then, if we calculate by expressing the power term in double angle,

$$M = k * g(t) = 221955.93 + 139.77\sin(\omega t) - 5.28\cos(2\omega t) + 308.08\sin(3\omega t) + \cdots \quad (24)$$

Get. This is the basis for the appearance of 0.27 Hz and 0.53 Hz components in extremely low frequency sound.

(3) 0.8Hz、1.6Hz、2.4Hz、...Grounds for the appearance of

Note the following proposition:

can be expressed by a constant and a linear equation of (m=1~n). ($(sinx)^n$ $\sin(mx)\cos(mx)$The same applies to COS)

If n=1, then $(sinx)^1 = \sin(1x)$ is correct.

Assuming that it holds when n = k,

$$(sinx)^{k+1} = f_k(x) * sinx \quad , \quad (25)$$

The constant *sinx satisfies the condition,

$$\sin(mx) * sinx = -(\cos(mx + x) - \cos(mx - x))/2 \quad (26)$$

$$\cos(mx) * sinx = (\sin(x + mx) + sin(x - mx))/2 \quad (27)$$

Therefore, equation (25) can be expressed by a constant and a linear equation of (m = 1 ~ k + 1).$\sin(mx)\cos(mx)$

Therefore, it can be written in the following form.$(sinx)^n = f_n(x)$

$$f_n(x) = c_n + \sum_{m=1}^{n} a_m \sin(mx) + \sum_{m=1}^{n} b_m \cos(mx) \quad (28)$$

Therefore

$$(sinx)^n + (\sin\left(x + \frac{2\pi}{3}\right))^n + (\sin(x + \frac{4\pi}{3}))^n \quad (29)$$

To think about the sum of the first order equations

$$\sin(mx) + \sin\left(m(x + \frac{2\pi}{3})\right) + \sin(m\left(x + \frac{4\pi}{3}\right)) \quad (30)$$

It would be good to find out.

m=3k、m=3k+1, m=3k+2 (k=0, 1, 2, ⋯)

Let's divide the cases of.

If m=3k,

$$\sin(3kx) + \sin\left(3kx + \frac{6\pi k}{3}\right) + \sin\left(3kx + \frac{12\pi k}{3}\right) = 3 * \sin(3kx) \quad (31)$$

If m=3k+1,

$$\sin((3k+1)x) + \sin\left((3k+1)x + \frac{6\pi k + 2\pi}{3}\right) + \sin\left((3k+1)x + \frac{12\pi k + 4\pi}{3}\right) = 0 \quad (32)$$

(The same applies to m = 3k + 2). consequently

$$f_n(x) + f_n(x + 2\pi/3) + f_n(x + 4\pi/3) \quad (33)$$

Only terms and constants of the form , remain. This issin $(3mx)\cos(3mx)$ why it peaks at frequencies greater than 0.8 Hz, 1.6 Hz, 2.4 Hz, 3.2 Hz and 4.0 Hz.

(8) For equation (9), even if the expansion formula of (10) is lengthened,

Only the constant term and the , term remain.sin $(3m\omega t)\cos(3m\omega t)$

In addition to the force of the lift of the blades, the tower also bends slightly downwind due to the force of the wind blowing on the tower itself. Since the wind speed varies depending on the height, the lift force of the blade periodically changes the force on the tower. Even if the three blades are perfectly even and the wind is stable, in addition to 3*R/60[Hz], 2*3*R/60[Hz], 3*3*R/60[Hz]、4*3*R/60[Hz]、...Tremors occur.

In addition, if one blade is only slightly larger, or if the angle to the wind is only slightly different from the other two, In addition to R/60 [Hz], fluctuations of 2 * R / 60 [Hz] and 3 * R / 60 [Hz] are also included in the fluctuation of the wind turbine.

If this force acts on the tower, the cut edge of the tower becomes an ellipse, and the tower Vibration occurs on the side of r. As a result, an extremely low-frequency sound with directivity in the direction in which the side vibrates greatly is generated.

The sound generated by the vibration of the tower, which has a regular frequency and is caused by the rotation of the blades, should not be called "wind noise". "Infrasound is generated from wind turbines."

FIG. 4 represents "wind noise", but FIG. 3 represents infrasound from a windmill. It is characterized by the directivity of sound and the regularity of frequency.

Figure 13 shows an image of a musical instrument with two drums on the body and a flute on the top. This is a schematic diagram showing the mechanism by which sound is generated from a wind turbine after considering the characteristics of the wind turbine sound, including the fluctuation of air pressure in the tower.

Fig. 13 Image of Wind turbine noise

## 10. Indoor measurement and chaos theory

"Modeling a House Filter for Low-Frequency Noise"7) states, "The indoor sound field is complex and contains many physically difficult problems, especially in the low-frequency range. It is written.

Analyzing sound in a room is difficult, but chaos theory can overcome the difficulty. FIG. 14 is an analysis for finding a faulty machine from the noise in the steel mill.

The first stage is a noise graph, the second stage is the frequency spectrum, and the third stage is Wavelet analysis. The characteristics are unknown in the analysis so far, but if you use "Average Wavelet Coefficient-Based Detection of Chaos in Oscillatory Circuits" 8), you can get the fourth graph.る。

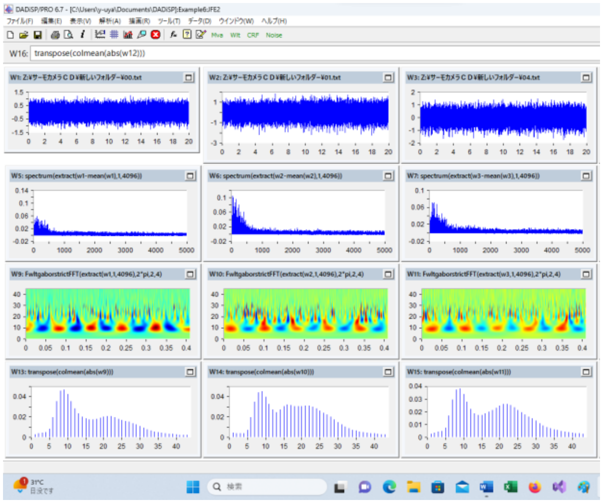

Fig. 14 Effect of Chaos theory

The fourth row is a graph that looks like a camel sitting, with one hump representing the vibration of two objects with one natural frequency, and two humps representing the vibrations of two natural frequencies. The graph in the middle shows that it is caused by a square sieve with two natural frequencies.

## 11. Things to keep in mind when it comes to wind turbine sounds

In order to investigate the relationship between sound pressure and oppressive feeling, it is necessary to treat the maximum sound pressure as it is at the Pascal value. In addition, regarding fluctuations in sound pressure, it is necessary to consider the possibility of bubble generation due to acoustic cavitation. If small bubbles form in the body, it is the same as diving sickness and headaches occur. Even the slightest possibility should be examined in detail. ("Foam Engineering"9))

## 12. Conclusion

Although the horizontal-axis wind turbine has been shown to be the generator of infrasound, the Eiffel Tower in Paris still has a beacon of hope. There, a vertical axis wind turbine with quiet sound and little vibration generates electricity. There is no factor that generates infrasound from a vertical-axis wind turbine

(In February 2015, two wind turbines were installed in the Eiffel Tower about 120 meters above the ground.) )

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