Reduction of aerodynamic noise radiated from Wells turbine

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Abstract. This study focuses on the reduction of aerodynamic noise radiated from a Wells turbine. A Wells turbine is composed of a cascade of blades arranged around the rotational axis. As a fundamental study, we measured the aerodynamic sound radiated from an airfoil with a plasma actuator mounted near the trailing edge of the two-dimensional airfoil. At a normal airfoil, discrete frequency noise is clearly observed at small attack angles. The peak level of spectra for working plasma actuators decreased compared with the normal airfoil. The plasma actuator was effective in reducing the discrete frequency noise radiated from the airfoil. This noise radiated from the airfoil depended on the electrode position, geometry of the electrode, and applied frequency. The effective geometry of the plasma actuator to reduce this noise was clarified.

1. Introduction

Low-noise level is an important sales point of various kinds of machines, as is high performance. The Wells turbine is a self-rectifying air turbine that is expected to be widely used in wave-energy devices with oscillating water columns (OWCs) [1-4]. The Wells turbine is composed of a cascade of blades arranged around the rotational axis. The noise may well be a serious problem when large-scale versions of these machines are operated in coastal banks or gullies because they rotate at high speeds, and this will be an important planning consideration. The noise evaluation will become an inescapable problem to put wave power plants to practical use. Takao et al. showed the noise characteristics of a variety of designs of turbines suitable for use as wave power converters [4].

In contrast, it is generally known that tonal noise is generated from a two-dimensional airfoil at certain flow conditions at a discrete frequency of approximately 30 dB above the background broadband level [5-7]. There are many studies involving the reduction in aerodynamic noise radiated from the airfoil [8-14]. Fukano et al. reported that fan noise decreased by changing the profile of the rotor blade [9]. Polacsek et al. showed that the wavy leading-edge was effective in reducing the noise [10]. Nishimura et al. observed that the fan noise reduced by affixing a fur material around the leading edge on the surface of the wing of a cooling fan [11]. Hamakawa et al. showed that local porous material on the surface of the airfoil was effective in reducing the aerodynamic noise [14]. However,
the effect of the plasma actuator on the aerodynamic noise radiated from the two-dimensional airfoil was not clear.

The purpose of the present study is to clarify the effect of the plasma actuator mounted near the trailing edge on the aerodynamic sound radiated from the two-dimensional airfoil to reduce the aerodynamic sound radiated from a Wells turbine. The influences of the electrode position, geometry of the electrode, thickness of electrode, applied frequency, applied current, and applied voltage on aerodynamic noise were investigated experimentally.

2. Experimental Apparatus and Procedure

Our experiments were performed in a low-noise wind tunnel, which is described in detail elsewhere [15]. This wind tunnel is an open circuit with wing-type silencers in the diffuser located at the outlet of the blower, and splitter-type silencers at the inlet of the blower. The test section was placed in an anechoic room, which is 3 × 3 × 3 m. The collector was downstream of the test section. Noise-absorbing fluffy materials were attached to the surface of the collector to reduce the interaction noise between the open jet and the collector. The background noise was approximately 63 dB(A) at a freestream velocity of 50.0 m/s.

Figure 1 shows a schematic view of the test-section and a test airfoil. The cross-section of the nozzle exit was a 0.5-m-wide and 0.25-m-high square. A test airfoil was installed in the test section 100 mm downstream of the nozzle exit. The freestream velocity ranged from 5 to 45 m/s at the test section inlet. The Reynolds numbers, based on the chord length, Re, and freestream velocity, \( U_\infty \), ranged from \( 3.1 \times 10^4 \) to \( 3.4 \times 10^5 \). The flow past the nozzle was uniform, and the drift of the freestream velocity was less than approximately 0.9%. The freestream turbulence level was less than 0.5% of the freestream velocity. In addition, no peak velocity fluctuation spectrum formed at the test section without the test airfoil at this velocity range. Two end plates were placed at the top and bottom of the test section, and a test airfoil was placed vertically and rigidly supported between them. These were 900-mm-wide and 450-mm-long acoustically non-reflecting end plates, which were large enough to cover the jet edge region. The downstream distance from the test airfoil to the edges of the end plates was 350 mm. These end plates were composed of a 25-mm-thick polystyrene and 25-mm-thick glass wool backed with a punched steel plate to reinforce the plate rigidity [15]. It was clearly observed that the results for the non-reflecting end plates were almost the same as the attenuation characteristics of the free field.

Figure 2 shows a schematic of the test airfoil with a plasma actuator. Figure 2(a) is the schematic of the plasma actuator. The electrode thickness was 0 (flush-mount) and 0.37 mm. Figure 2(b) shows a photograph of the plasma actuator. The electrode of the plasma actuator was mounted near the trailing edge of the test airfoil. The pitches of the plasma actuator, \( b \), were 6.3 mm and 12.6 mm. The depths, \( a \), were 13 and 20 mm. The airfoil has a NACA0015 profile, chord length, \( l \), of 100 mm, and span length, \( h \), of 250 mm. We measured SPL at an attack angle of \( \alpha=4^\circ \). The features and symbols are presented in Table 1.

Figure 1. Schematic of test section of wind tunnel.
The aerodynamic sound in the far field from the test airfoil was measured at $X=0\;\text{mm}$, $Y=-500\;\text{mm}$, and $Z=0\;\text{mm}$ using a microphone. When the observation location is far enough to be considered as the far field, the effect of the near field can be neglected. In this measuring position, the near field component attenuates, and the far field component is approximately 16 dB larger than the near field component for phenomena that occur above 700 Hz. The microphone output was sampled by an FFT analyzer and the statistical parameters were calculated.

### 3. Results and Discussion

We measured the aerodynamic sound radiated from the two-dimensional airfoil with a plasma actuator. The thin black line in Figure 3 shows the baseline spectrum of the sound pressure level (SPL) at an attack angle, $\alpha$, of 4º. The discrete frequency noise was clearly observed.

Figure 3 shows the variation in electrode position on the spectra of SPL. Case 1 is the result of the plasma actuator mounted on the surface of the pressure side of the airfoil; small peaks formed in the spectrum. The maximum peak level of the plasma actuator is approximately 30 dB lower than that of

![Schematic of plasma actuator.](image1)

![Photograph of plasma actuator.](image2)

**Figure 2.** Schematic of test airfoil with plasma actuator.

**Table 1.** Geometry of electrode of plasma actuator.

| Case  | $a$ (mm) | $b$ (mm) | Location of electrode  |
|-------|----------|----------|------------------------|
| Case1 | 13       | 6.3      | Pressure side          |
| Case2 | 13       | 6.3      | Suction side           |
| Case3 | 13       | 6.3      | Pressure side, Suction side |
| Case4 | 20       | 6.3      | Pressure side          |
| Case5 | 20       | 12.6     | Pressure side          |
| Case6 | 20       | 6.3      | Pressure side, Flush-mount |
| Normal| -        | -        | -                      |

**Figure 3.** Effect of variation in electrode position on spectra of SPL ($\alpha=4^\circ$, $Re=0.9\times10^5$; 7 kHz; 8 kV).
the normal airfoil. It is clear that the plasma actuator is effective in reducing the discrete frequency noise radiated from the airfoil. Case 2 is the result of the plasma actuator mounted on the surface of the suction side of the airfoil. The discrete frequency noise was clearly observed to be the same as that of a normal airfoil. Case 3 is the result of both sides of the airfoil. The peak levels of Case 3 are larger than that of Case 1.

Figure 4 is the effect of the variation in chordwise electrode distance, $a$, on the spectra of SPL. The peak levels of $a=20$ mm (Case 4) are smaller than that of $a=13$ mm (Case 1). However, as the chordwise electrode distance increased, the broadband noise at the higher frequency component increased slightly.

Figure 5 shows the effect of the variation in spanwise electrode distance, $b$, on the spectra of SPL. The peak levels of $b=6.3$ mm (Case 4) are smaller than that of $b=12.6$ mm (Case 5). As the spanwise electrode distance decreased, SPL decreased. It is clear that the discrete frequency noise radiated from the airfoil depended on the spanwise electrode distance.

Figure 6 shows the effect of the variation of the applied frequency on the spectra of SPL. The peak SPL for the applied frequency of 7 kHz is the smallest in the range of applied frequency of 4–7 kHz. It is clear that the discrete frequency noise radiated from the airfoil depended on the applied frequency.

Figure 7 shows the effect of the flush mount electrode on the spectrum of SPL. Case 4 is the result of an electrode thickness of 0.37 mm, and Case 6 is the flush mount of the plasma actuator electrode. The effect of the electrode thickness on the spectrum of SPL was small.

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**Figure 4.** Effect of variation in chordwise electrode distance on spectra of SPL ($\alpha=4^\circ$; $Re=1.1\times10^5$; 7 kHz; 8 kV).

**Figure 5.** Effect of variation in spanwise electrode distance on spectra of SPL ($\alpha=4^\circ$; $Re=1.1\times10^5$; 7 kHz; 8 kV).
4. Conclusions
To reduce the aerodynamic sound radiated from a Wells turbine, the effect of a plasma actuator on its sound radiated from a two-dimensional airfoil was investigated experimentally. As a result, the following conclusions were obtained.

(1) The plasma actuator mounted near the trailing edge of the pressure side of the airfoil is effective in reducing the discrete frequency noise radiated from the airfoil. As the spanwise electrode distance decreased, the peak SPL decreased. The peak SPL for the applied frequency of 7 kHz was the smallest in the range of applied frequency of 4–7 kHz.

(2) As the chordwise electrode distance increased, the peak SPL decreased. However, as the chordwise electrode distance increased, the broadband noise at a higher frequency component increased.

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