Technical Note

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MUSICAL RHYTHM, VIBRATO AND WIND TURBINE NOISE

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The nature and origin of frequency and amplitude modulation in music and other related human activities is examined and particular neural sensitivity is identified in the frequency range 1 to 10 Hz. It is surmised that amplitude modulation as the vanes pass the tower may be a major factor in wind turbine annoyance, and suggested that an electro-acoustic system to reduce this modulation might be effective in reducing noise annoyance.

INTRODUCTION

Electrical power is of increasing importance to the survival of human civilisation, and many of the energy sources used to produce it, such as coal, gas, oil, and even nuclear energy, have limited future availability. Everything therefore comes down to solar power in some form, particularly solar-electric, tidal, and wind power. Of these, wind power alone presents acoustic problems because of the noise produced by the rotating turbine blades. This noise is not very loud but it has led to problems for communities living several kilometers away, though the basis of this noise annoyance is far from clear.

The present short paper examines some aspects of wind turbine noise and relates them to particular acoustic and psychoacoustic features, some of which might perhaps be remediable. Some of these things have doubtless been discussed before in the published literature, but here I adopt the approach of famous philosopher Ludwig Wittgenstein, who wrote in his *Tractatus Logico Philosophicus* “I quote no sources. It is a matter of indifference to me whether what I have thought has been thought by others before me.”

RHYTHM

The notion of rhythm probably derives from the periodic nature of leg motion during walking, which has a repetition rate of about 1 Hz. This is also about the beat rate of the human heart and is a feature of sound that is readily perceived. From it comes the music of a march, which links together the leg motions of all those involved to create a communal feeling. While simple marches use just a percussion instrument such as a drum to control synchronism, musical marches also evolved more than a thousand years ago and are now commonly used in military ceremonies.

This is, of course, not the only human rhythm of importance, for we also have many dance rhythms that are widely used, again with a repetition frequency of about 1 Hz. While a march has a simple left-right-left-right. . . repetition, dances can have more complex structures. A waltz, for example, has a three-fold rhythm with three beats to a bar, though the actual motion is six-fold because of transfer between the two feet. Again, music is common for leading dances and the interaction between dancers can be either communal or two-fold. Musical dance compositions sometimes create an additional striking effect by a structure called a hemiola, in which the bar-length remains constant but instead of being divided into three beats it is divided into two longer beats for just one or two bars.

No more discussion of rhythm is needed here, the main point being that human perception of rhythm is very acute near a frequency of 1 Hz.

VIBRATO

While music may be thought of as made up from combinations of simple tones, either sequentially to form a melody or simultaneously to form a harmony, or both, there are some psychophysical subtleties that turn out to be very important in the present context. Some instruments, such as the pipe organ, produce notes that are steady in sound after an initial brief transient, while in the piano the notes simply decay slowly after initial production. This is different, however, from the sound of a violin or cello, where the player purposely rocks the finger defining the string length backwards and forwards to produce a periodic small variation in pitch. The finger motion is typically less than about 1 cm for a string of length about 30 cm, so that the total pitch variation is about 1/30 which is about half a semitone and the repetition rate of this vibrato is about 5 Hz. For a solo instrument, this adds interest or “warmth” to the sound, while for a large group of string instruments playing together as in an orchestra, the sound becomes narrow-band noise because the variations are not synchronised. This gives a modern string orchestra a rather different sound from that of an orchestra from baroque times, where the string instruments had frets to fix the string lengths and there was no vibrato.

Wind instruments operate in a very different manner from strings, but the player has some control over pitch, loudness and timbre (spectral envelope) by varying blowing pressure, mouth shape, or other parameters. Here the performance is, however, ruled to some extent by tradition, so that some instruments are played without any vibrato while others us it constantly. The pitch variation is generally quite small – only about a tenth of a semitone – but there can be a considerable periodic variation in both loudness and timbre. As with other instruments, the rate of this variation is typically about 5 Hz.

When we come to consider human singers, however, things become much more extreme. While a few singers, such as choir boys, sing pure notes without any vibrato, most adult singers do use vibrato, some to extreme. Operatic sopranos, in particular, can have very wide frequency spread in their vocalisation, typically as much as, or even more than ± 1 semitone. The amplitude and intensity of the vibrato is increased purposely in dramatic or emotional scenes in the opera.

A persuasive explanation of the role and importance of vibrato can be seen in the behaviour of neural rhythms in the human brain. In a normal brain in a relaxed state, neurons tend to oscillate in a state called the "alpha rhythm" which has a frequency in the range 8–12 Hz. This is surprisingly close to the typical 6 Hz frequency of vibrato in both instrumental playing and in singing, particularly emotional singing. It is therefore reasonable to surmise that there is a close relation between vibrato and the alpha rhythm of the human brain. Taking things to an extreme state, it has been shown that visual stimulus from flashing lights can actually cause epilepsy in susceptible individuals.

WINDFARM NOISE

So how does all this relate to the effect of wind turbine noise on listeners who are not very close, so that the sound is barely audible? A typical generator in a wind turbine has a rotation speed of about 0.3 Hz and, since it normally has three vanes on the rotor, this means that the frequency at which vanes pass the support tower is about 1 Hz. Most of the sound of the generator is produced by air flow over the rotating vane, so that this will be modulated in amplitude at a frequency of about 1 Hz. While this is a bit low to interact strongly with the alpha rhythm of the brain, it will have higher frequency components because the space between the vanes is large compared with their width. Even without such interaction, an amplitude modulation frequency of order 1 Hz would be readily perceivable and could cause much more annoyance to a listening human than would a steady sound of the same amplitude. The fact that 1 Hz is about the frequency of the sound involved in other human activities, such as marching or dancing, also leads to the surmise that such a modulation frequency might be more readily noticed by the listener than other much lower or much higher frequencies.

So where does this lead us? Obviously a simple reduction in the wind turbine noise level would reduce its impact upon not-too-distant listeners, but such a further improvement would be difficult to make. Perhaps, however, the solution is not to reduce the total sound level but to reduce the level of the amplitude modulation caused by vanes crossing the supporting tower. It is to be hoped that an aero-mechanical solution to this problem might be found, but another possibility would be to sample the radiated sound field at a moderate distance from the tower and then to provide an electrical signal that could drive a loudspeaker system mounted on the tower and with an appropriate directional radiation pattern so as to reduce the level of the amplitude modulation.