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Skating on thin ice - And the acoustics of infinite plates

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Abstract

A tone is radiated when people are skating on thin, black ice. The phenomenon is well known to the experienced skater. In fact he estimates the thickness of the ice by listening to the tone. It is easy for most people to hear the frequency shift when the thickness of the ice changes. A person with ”gold ears”, absolute pitch, can estimate the thickness of the ice with an uncertainty of 5% just by listening.

Measurement results of the frequency of the tone and the thickness of the ice are presented together with sound recordings.

The basic physics, the coincidence frequency of mass loaded infinite plates, which explains this phenomenon is discussed. Infinite plates are very common in the acoustic world and ice on a large lake is probably the best example of an infinite plate in the real world.

A high, intense tone indicates thin, dangerous ice. Is it just by chance that the sensitivity of the ear increases when the thickness of the ice decreases, and becomes very high when the ice tends to crack under human weight?

1. Introduction

Tour skating on natural ice is a very popular sport in Sweden, and might interest an international audience of acoustic engineers. The tour skating club in Stockholm, SSSK, has more than 10.000 members. Skating on natural ice can be a dangerous activity. Necessary safety equipment is floating aid, ice-prods, ice-pike (a heavy ski stick), rescue rope, company, and good ears.

Figure 1. Tour skating on thin ice.

2. Observations

When you skate on thin black ice you can hear a tone from the ice when the thickness is less than approx. 100 mm. The pitch increases when the thickness of the ice decreases. When the thickness is less the 60 mm you will hear an intense jeremiad from the ice. It is a warning from Nature. If you neglect this warning it is easy to get into big trouble.

However, you can not hear the tone from yourself. You can hear it only from skaters that are more than approx. 20 m from you. The tone that you hear is the coincidence frequency of the ice plate. The propagation speed of the bending wave of the plate is the same as the speed of sound in the air at this frequency. The power radiated by the various parts of the ice along the propagation direction "pile up" to a sound wave parallel to the ice surface.

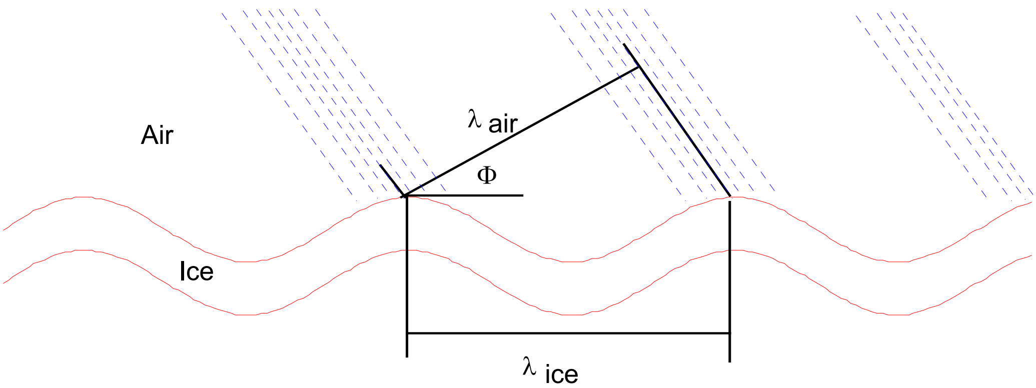

Figure 2. Coincidence frequency. $\Phi=0$. $\lambda_{air} = \lambda_{ice}$

The excitation of the wave is caused by the light impact from the skates. All frequencies are generated in the ice, but only the coincidence frequency is radiated into the air.

Thin ice on a big lake is the best example of an infinite plate in the real world. In the acoustic world you can see infinite plates of different sizes, down to 1 x 1 m or less.

3. Measurements

I have measured the "ice frequency" at different thickness of the ice. My assistant, my little lightweight son, has hit the ice with an ax and I have recorded the sound with a microphone and a mini-disc at a safe place. The recordings were analyzed with a FFT-analyser in Time mode afterwards. The frequency, f, is calculated from the period time, T, f= 1/T [Hz].

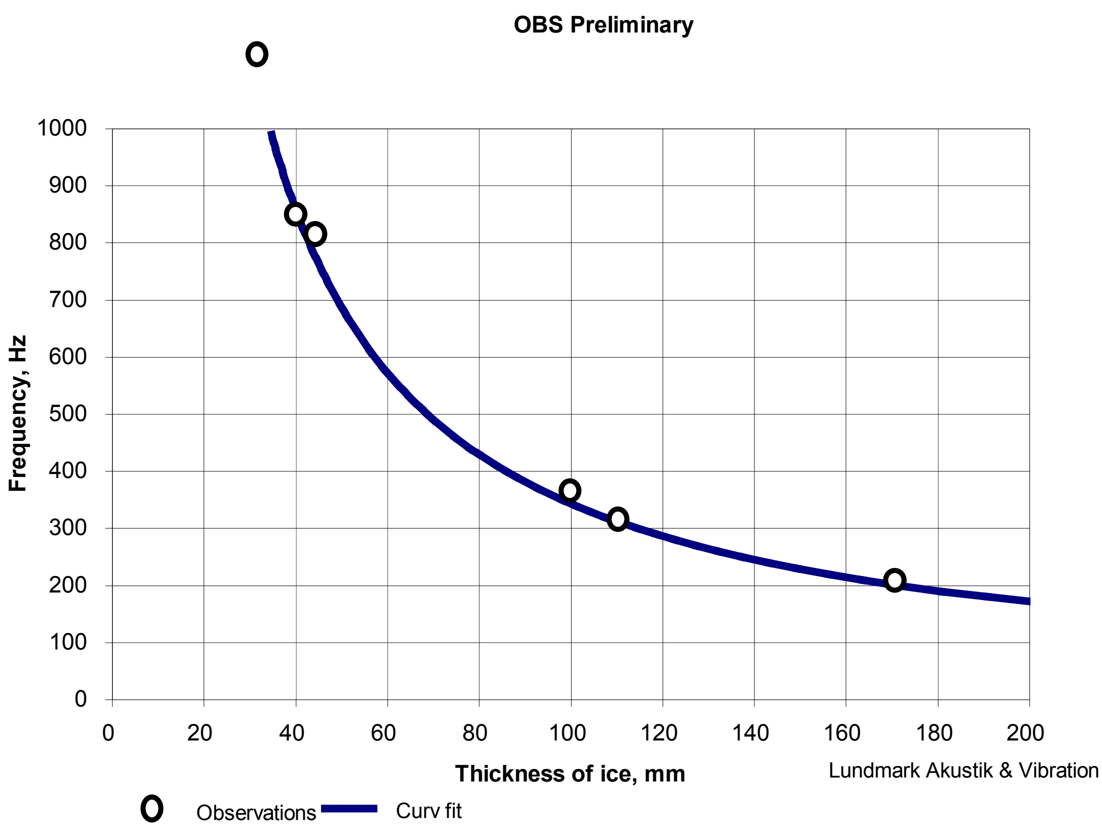

Figure 3. Coincidence frequency of hard, black ice.

4. Theoretical background

The formula to calculate the coincidence frequency of an infinite plate in air can be found in many textbooks of acoustics. The water under the ice gives a mass loading of the plate, decreases the speed of the bending wave, and makes it a little bit trickier to find the coincidence frequency. However, it is possible to find numerical solutions with a computer but the modulus of elasticity of ice is not known. Some hard work is necessary to take measurement of the modulus, and this has not been done.

I have made it the easy way. The curve fit is made with the function:

$$f = \frac{34300}{t}$$

$$f = coincidence\ frequency\ of\ the\ ice, Hz$$

$$t = thickness\ of\ the\ ice,\ mm$$

Measurements have not been taken on salt ice. The mechanical loss factor of salt ice is higher and the tone ice less intensive. When spring comes then the ice becomes softer, the loss factor increases, and you can not hear the tone from thin ice. Skating on "spring ice" is very dangerous.

5. Conclusions

The results are and will be preliminary. Skating on ice with the tone a1 (normal a, 440 Hz; 78 mm) is in most cases "safe". The ice is too thin when you hear e2 (660 Hz; 52 mm) or higher. A person with "absolute pitch" can estimate the ice thickness within 5%; hear if the ice is 55 or 50 mm. Most people can easily hear the frequency shift when the ice decreases from 55 to 50 mm.

It has here been proven that it is a good idea never to skate first. It is safer 20 m behind the leader — then you can hear the tone.

6. Questions

Is it just by chance that the sensitivity of the ear increases when the ice thickness decreases?

Is it just by chance that the ice is too thin when you hear an intensive wailing from the ice?

No, human beings have been adapted to a life on ice with good friends!