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Ice detection on a road by analyzing tire to road friction ultrasonic noise

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Abstract

A preliminary investigation of black ice on a road detection technique was performed. This technique is based on the assumption that it might be possible to judge about the presents of the ice from tire to road friction ultrasonic noise. The system was built and installed in a test car to measure the ultrasonic noise in a 20 to 120 kHz spectrum range. Multiple experiments were performed at different road conditions with and without ice at various speeds. An increase of ultrasonic noise amplitude was found on icy surface in all informative spectrum range.

Keywords: ice, ultrasonic noise, tire friction.

Introduction

Information about current road condition is vital for a driver. Most of the conditions are quite easily identified by a driver visually except for the black ice. It is a hard to see this condition and it is often left unnoticed by a driver. A system that could provide a driver with a real time data about ice on a road would significantly improve driving safety.

Background

Some commercially available cars possess systems that warn drivers about potential of black ice when air temperatures around zero are measured. However, these systems give a lot of false warnings. There were attempts to build system that monitors road surface with infrared sensors [1]. Although surface condition detection was quite precise the need for dirt-free lens to collect the reflected infrared beams is a major drawback. The same drawback stands for another detection method, which measures polarization of light reflected from a road surface [2].

Another attempt to solve the problem was to detect the road condition by processing road image captured with a CCD camera mounted on a vehicle [3]. It faced difficulties to detect black ice at different weather and sunlight conditions. Japanese inventors patented a method that detects dry or wet road conditions by measuring amplitude of an ultrasonic noise from tire to road friction [4]. It was decided to investigate this detection principle deeper with the focus on black ice.

Experiments

When the tire hits, interacts and pulls off the road surface an acoustic noise is generated as a result of friction. Hence, an assumption was made that there might be a certain differences in that acoustic noise depending on the surface condition. To confirm this assumption a measurement system according to Fig.1 block diagram was built and installed in a test car.

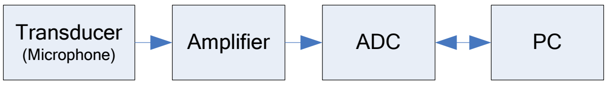

Fig.1. **Measurement channel structure**

The part of the spectrum from 50 to 100 kHz was chosen for investigation, since environment is usually filled with low frequency noise sources and the higher frequencies vanish too fast. A wide bandwidth piezoceramic transducer with a required bandwidth was selected. Pulse response of the transducer were measured using an electric spark [5]. The frequency response of the microphone was calculated using of the measured pulse response. The responses were determined before and after experimental measurements. These two responses showed a very little difference and that confirmed that the transducer was not damaged during experiments. The frequency response of the transducer is shown in Fig. 2.

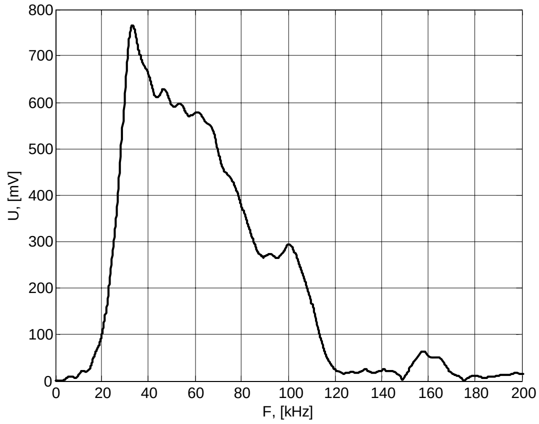

Fig.2. **Transducer frequency response**

Since a car is electromagnetically noisy environment special means like close to the source signal amplification and separate noise-free power supplies where used to minimize electromagnetic interference.

The system was installed to record acoustic vibrations aimed to the front right wheel just after the front bumper (Fig. 3). A PicoTech ADC 212/100 PC oscilloscope was used as a analog to digital converter. Measurement data collected with a laptop computer in the car.

Two sets of experiments were performed. The first set on the dry, clean and as least as possible potholed road. The second set had to be carried out on the road with the black ice. Since weather conditions did not promise any black ice it was decided to perform a test run on a frozen lake.

Fig. 3. **Transducer placement under the car**

During the test run some 30% of the lake surface area was covered with a thin layer of snow in a random manner. The rest was glassy ice. Each set of measurements was taken at five different speeds: standing still, 20 km/h, 40km/h, 60 km/h and 80 km/h. 25 signal samples in one-second period at each speed were recorded. Each signal was recorded at 781250 Hz sampling frequency for about 77ms time-span. Fig. 4 shows the signal recorded when the car is standing still, but the engine is on. Some parasitic electromagnetic interference is clearly seen. Because it is a relatively low amplitude comparing to signals at various speeds and is narrow spectrum (see peak about 40 kHz in Fig. 10), therefore, it was neglected.

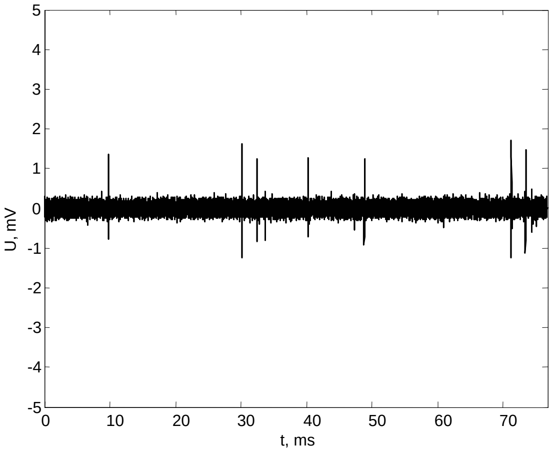

Fig. 4. **Signal example when car is standing still the engine is on**

The following five figures give noise signals acquired at different speeds. The black color signal is recorded on a dry surface and the gray color signal recorded on ice (Figs 4 - 7).

All signals were detrended and filtered with a digital pass band filter, to cancel all spectra components that are not informative. The digital filter was designed as 198th order FIR equiripple with at least 80 db attenuation for frequencies less than 20 kHz and more than 120 kHz (Fig.9) according to frequency response of the transducer.

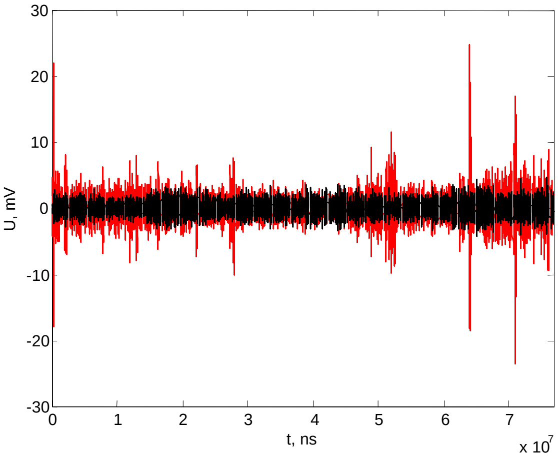

Fig. 5. **Signal example at 20km/h**

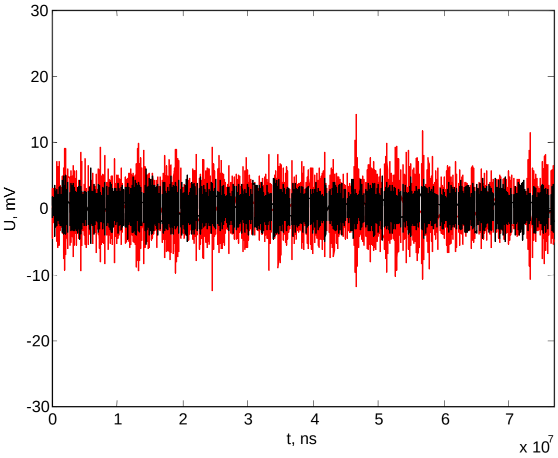

Fig. 6. **Signal example at 40km/h**

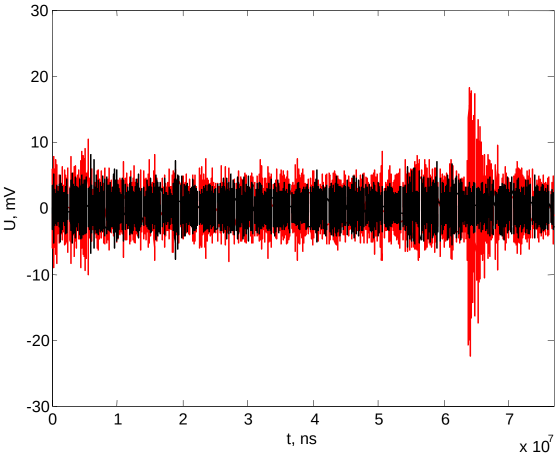

Fig. 7. **Signal example at 60km/h**

For every 25 signal set the power spectral densities (PSD) mean was calculated to get the most informative PSD of the investigated effect. PSD's were calculated using Welch's method with an overlapping sliding window.

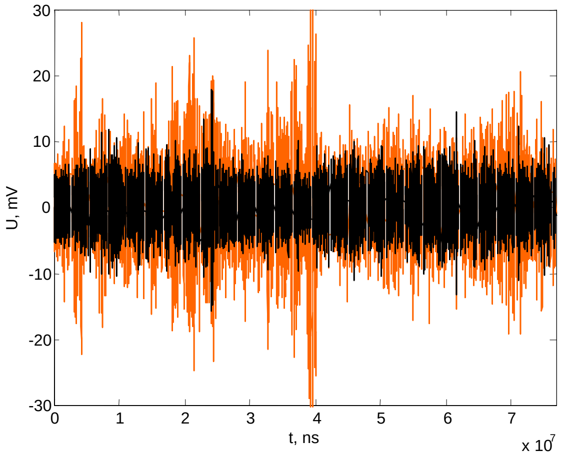

Fig. 8. **Signal example at 80km/h**

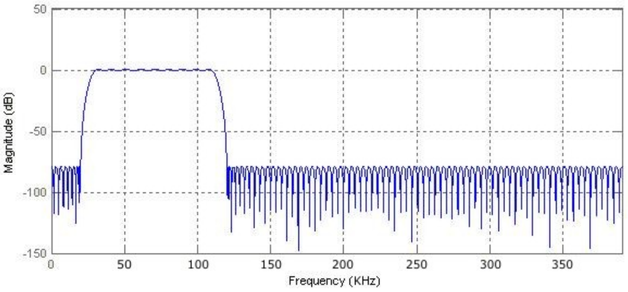

Fig. 9. **Digital filter magnitude response**

By applying these mathematical means for processing of the signal we have got the spectral characteristics of the acoustic vibrations generated by the tire friction at different conditions. Figs 11-14 plots PSD's of both ice and clear surface measurements at the same speeds. The continuous lines stand for measurements on ice and the dashed lines stand for measurements on a clear surface. We can see that there is one clear parasitic noise component in the PSD when the car is standing still with the engine on (Fig. 10).

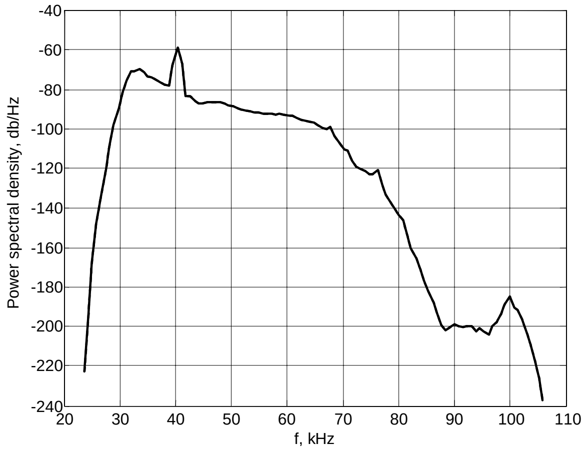

Fig. 10. **PSD, car is standing still, engine is on**

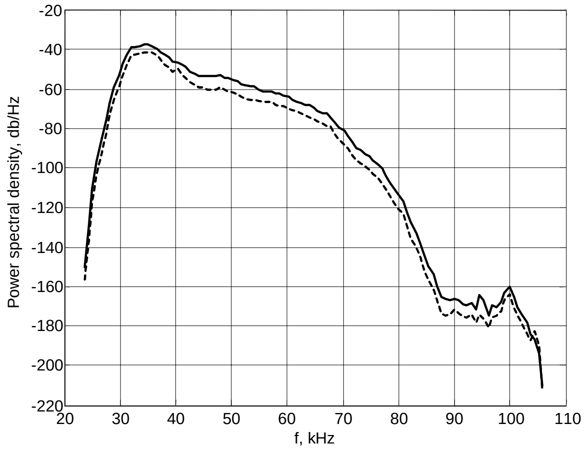

Fig. 11. **PSD at the velocity 20km/h**

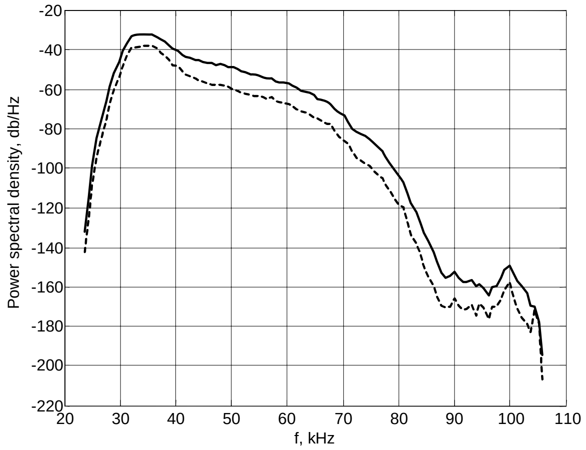

Fig. 12. **PSD at the velocity 40km/h**

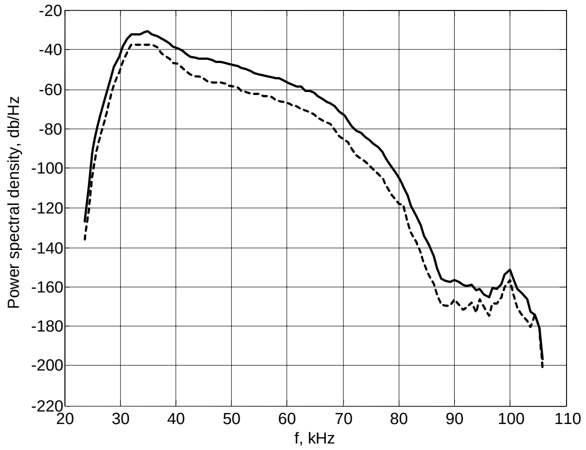

Fig. 13. **PSD at the velocity 60km/h**

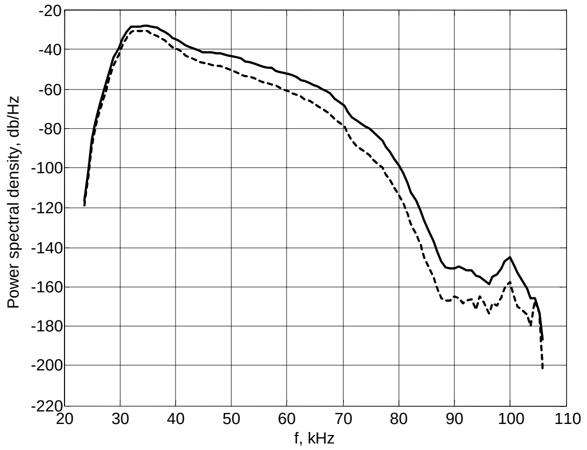

Fig. 14. **PSD at the velocity 80km/h.**

Conclusions

Although it was not discovered a certain frequency component or narrow spectrum range that apparently correlates with ice on the road, the experimental results showed a measurable amplitude shift in a wide spectrum range of acoustic noise. Taking into account other parameters like temperature or humidity that do correlate with ice and could be measured in parallel, the acoustic noise evaluation has a potential to be used as part of the ice detection system. Deeper investigation is needed with true black ice conditions. It is obvious that this acoustic noise might depend on a number of other factors like type and condition of a tire protector, wheels gather, weight of the car and so on. Hence it is needed to estimate these factors and investigate their degree of influence.

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Ledo ant kelio dangos nustatymas vertinant padangos trinties į kelią akustinį triukšmą

Reziumė

Automobilių vairuotojams labai svarbu tinkamai įvertinti kelio būklę. Dauguma kelio būklių yra lengvai atpažįstamos plika akimi. Sunkiausiai atpažįstama ir pavojingiausia būklė yra plikledis. Šiuo metu rinkoje parduodamos sistemos, perspėjančios vairuotoją apie galimą kelio dangos apledėjimą, dažniausiai remiasi oro temperatūra ir yra labai netikslios. Iškelta prielaida, jog kelio dangai apledėjus galbūt pasikeis ir padangos trinties į asfaltą keliamas akustinis triukšmas. Vertinant šį triukšmą galima būtų nustatyti plikledžio buvimo faktą automobiliui judant. Eksperimentais nustatyta, jog trinties keliamo akustinio triukšmo amplitudė, keičiantis kelio dangai iš neapledėjusios į apledėjusią, pasikeičia plačiame dažnių diapazone.

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