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An in situ method to measure the acoustic absorption of roads whilst driving

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Introduction

The acoustic properties of road surfaces correlate with the noise attenuating and mechanical properties, as well as with the maintenance related properties, such as the degree of pollution. The PU surface impedance method, measuring in situ both sound pressure and acoustic particle velocity, can be applied to measure the road surface impedance in a laboratory environment, but also outdoors on completed roads. The main advantage compared to other methods, is that it does not require the sample to be cut out and it has a low susceptibility to background noise.

Now the PU probe is used to measure while it is moved along the road surface and first results of this method will be presented here. Such measurements could be used to test large road sections during construction. And it brings the opportunity to measure whilst driving along with traffic. Normally if the acoustic impedance is measured for maintenance purposes, it is necessary to close down the road for traffic. With a special setup that is mounted behind a car it is possible to measure the impedance in a 300Hz-10kHz bandwidth, up to 40km/h, without much distortion of the sensors. At a speed of 80km/h the sensor signal is affected by wind and by the vibration due to bumps in the road, but still some parts of the signal are useful.

Traditional methods

In laboratories the acoustic properties of road surfaces are most times determined by measuring many variables to apply the Biot theory, via the reverberant room method or using the Kundt's tube testing methods.

However, laboratory results do not necessarily represent the real acoustic properties after installation of the road. The cut-out of samples from completed road surface is destructive and time consuming.

For this reason the Guardt's tube, based on the Kundt's tube principle, is sometimes used. However leakage effects at lower frequencies occur and results are deviating from the free field microphone based spot method.

This free field spot method can be time consuming, requires a large sample and is very susceptible to background noise. Both methods can only be used after the road is closed for traffic which is very inconvenient and costly.

PU in situ surface impedance

The PU free field surface impedance technique makes use of a Microflown velocity sensor and a sound pressure microphone. Both sensors are mounted in one probe that is positioned close to the material, and a sound source is positioned at a certain distance. The impedance can be derived from the ratio of pressure and velocity [1]-[10]. From this, material reflection and absorption can be calculated.

With the hand held measurement set up (Figure 1) it is possible to measure the impedance in situ, in laboratory conditions, as well as outdoors. A spherical shaped loudspeaker is used because in the free field plane waves are practically impossible to create in a broad frequency range. An image source model is used to correct for the spherical waves and calculate the plane wave impedance [2]- [4]. The loudspeaker is mounted to a grip and mechanically decoupled from the structure that holds the PU probe.

Before the measurements the setup is calibrated against the free field. The parameters of the sensors, the data acquisition system and the characteristic impedance of air, are assumed to be the same during this calibration and the measurements afterwards.

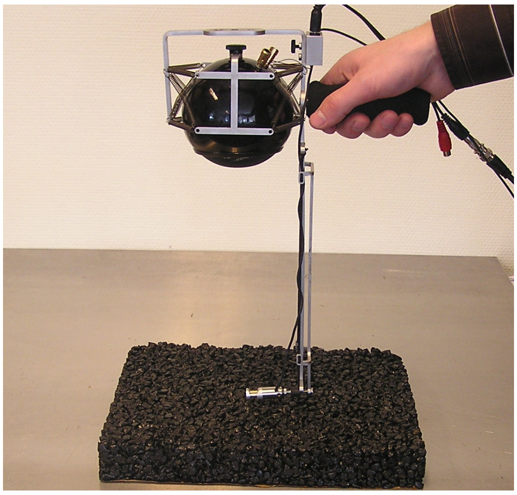


Figure 1: Handheld PU in situ impedance setup in the laboratory

Low influence to reflections

Because with this method the impedance is measured directly in one spot close to the material, it is possible to measure while having little disturbance from most reflections. The distance between the probe and the source is only 26cm so reflections at some distance are less dominant than the signal from the direct source. The method has already been applied several times inside in reverberant environments like e.g. a car [5], [6].

A moving average in the frequency domain many times gives a result similar to an anechoic measurement. A time windowing technique could also be used to filter the reflections, but the moving average is more robust. When there are many reflections the smoothed result should follow the actual impedance. However when the actual impedance has a sharp change this averaging should not be applied, so some care is required. When there is one strong reflection (e.g. from one wall near to the setup) the surface impedance measurement can be influenced [7].

Low influence to background noise

The velocity sensor measures only the contribution from its sensitive direction, perpendicular to the surface. Because only the correlated part of the pressure and velocity is used, the background noise from other directions is reduced. Also, the noise from the same direction as the direction of the source from the impedance setup would add up to the source strength, and would only improve the signal-to-noise ratio.

Normally it is possible to measure with both sensors in the whole audible range. But the lower frequency limit of the impedance method at this moment is 100~300Hz. This is due to the low sound pressure emission from the loudspeaker at low frequencies and the limited dimensions of many samples. Also close to a fully reflecting plane the particle velocity is practically zero.

Influence of wind

An unprotected particle velocity sensor already overloads at 1m/s. Several different wind caps and less sensitive sensors have been developed, with which it is possible to perform intensity measurements up to 70m/s inside a wind tunnel [11]. Mainly because the pressure sensor is less affected by wind than the velocity transducer, and because the correlated part of both signals is used, the influence of wind is reduced.

High spatial resolution

The structure of asphalt is far from homogeneous and the acoustic properties are likely to vary at each position. For research purposes and also for quality control of roads it is required to study materials in detail. Other free field methods require large samples of several square meters. The Kundt's tube and Guardt's tube method take the average value of a smaller sample, typically 8 cm in diameter. For the Kundt's tube it is necessary to cut out a sample, and there are mounting problems.

With the PU impedance method it is possible to study the material in great detail, because the distance between the sensor and the surface is small. The spatial resolution can be in the order of millimeters [8], [9].

Measurements without movement

The PU in situ method can be used on many different samples like foams, or felt, but also on materials like acoustic jet engine liners in the presence of a flow [10]. As example some absorption curves of asphalt measurements are plotted in Figure 2. At some frequencies these samples are absorbing almost 100%, while at others the absorption is very low. Because the velocity is close to zero at these frequencies absorption values below zero are present (e.g. the black curve at 6500Hz).

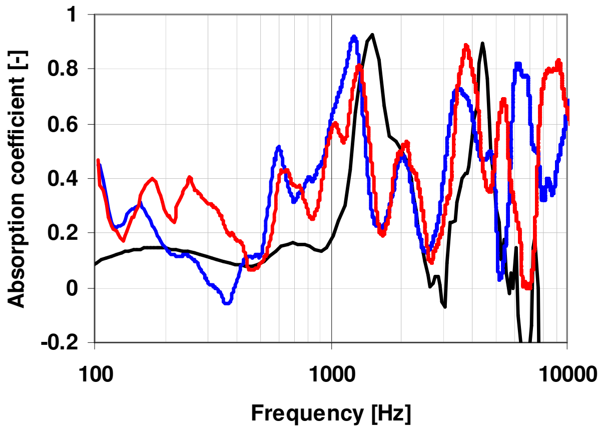


Figure 2: Examples of PU absorption measurements on asphalt

Impedance measurements whilst driving

Setup description

A special impedance measurement setup is build that can be mounted behind a car (Figure 3). A bigger speaker than normal is used to generate higher sound levels, to be able to exceed the noise from external influences like wind, vibration and background noise.

To shield the sensor from the wind the probe is packaged in porous foam that is acoustically transparent. In the turbulent area behind the car, the wind speed is less than the speed of the car itself.

To reduce the vibrations from the car engine, from the speaker through the frame, or from bumps in the road, this package is suspended in elastics. The displacement of the setup can be quite significant during driving over a larger bump. Because the sensor package is hanging it will bounce up when it touches the ground, but the sensor support will not break. To further reduce vibrations, the sensor inside the wind shielding is also suspended in springs (Figure 3, upper right corner).

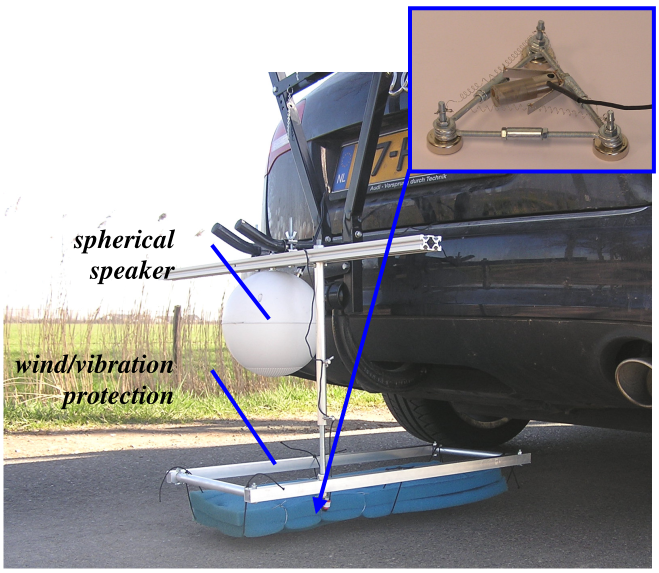


Figure 3: PU surface impedance setup mounted behind a car

Setup calibration

The setup can be turned upwards to be able to calibrate. The sensor is now pointed towards the air, and this measurement is then used as a reference with zero absorption. The road and car surfaces are quite close to the setup and reflections from these objects might result in an improper measurement.

The influence of reflections of this PU impedance method is low compared to other methods, because of the small distance between the sound source and the sensor. Most times the direct source is of greater strength than the mirror sources from reflective panels further away.

To get an impression about the influence of reflections during the calibration measurement, the calibration can be repeated with the setup at a different angle. The impedance of air remains the same, while reflections will shift in frequency. Also the sensor response can be compared to the response measured without the road and the car nearby.

Impedance measurements whilst driving

Next, the sensor is pointed towards the surface and the road impedance is measured. On an asphalt road without other traffic the speed is increased in 10km/h steps, with a maximum of 80km/h.

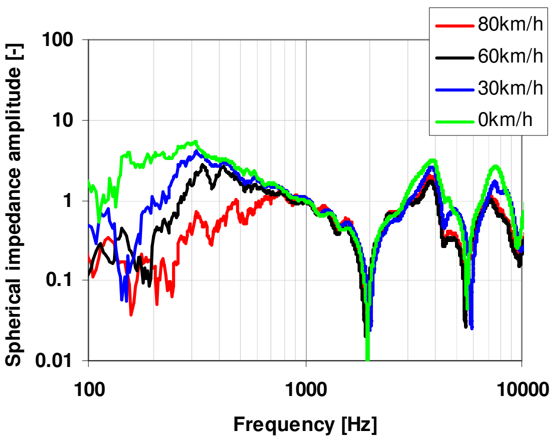


Figure 4: Measured impedance amplitude at different speeds

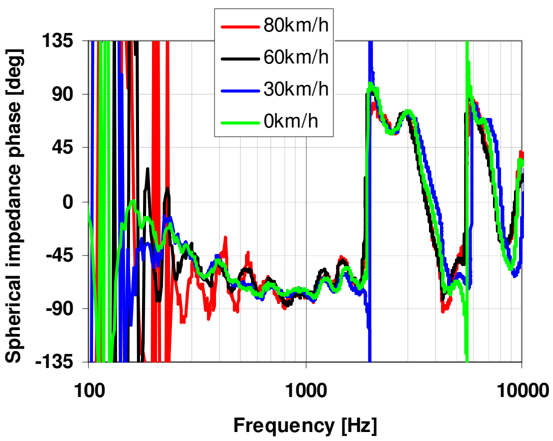


Figure 5: Measured impedance phase at different speeds

In Figure 4 and Figure 5 it can be seen that the measured impedance while driving is very similar to the impedance in the still standing situation. The road impedance is not the same on every position of this road, so this might partially explain why there are some differences.

Up to 40km/h the impedance is similar to the still standing situation from 300Hz to 10kHz. Even up to 80km/h the result is quite reasonable from 800Hz upwards. Already at 40km/h overloads of the velocity sensor can be seen in some parts of the time signal. Even though the velocity sensor was overloaded at most times during the measurement at 80km/h, still the parts without overload are usable.

Here the spherical impedance normalized to the impedance of air is plotted. For the model which is used to calculate the plane wave result from this spherical impedance, the distance between the surface and the probe should be known. Normally it can be quite difficult to estimate this distance, but here this is more easy. The distance to the surface is larger (~44mm instead of 10mm) and therefore standing waves appear at lower frequencies. If this distance is equal to a quarter of the wavelength there will be a first minimum of pressure and maximum of velocity. Around this resonance frequency the measurement is poor, but with this frequency known, the distance can be calculated accurately.

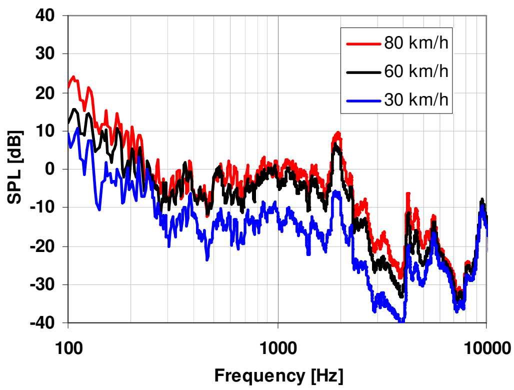
The usage of this approach is allowed, because this road surface is highly reflective. This is checked with the hand held impedance setup (Figure 1) which is used in still standing conditions.

The acoustic impedance can also be influenced by the road surface. If two sensors at different distances to the surface of the road would be used, the distance to a more absorbing material could also be determined. The material impedance is the same for both sensors, while the distance from the surface is not.

At higher speeds the influence of wind mostly affects the lower frequency response of the velocity sensor. The pressure sensor is more affected by the noise from the car, which is considerable already at low speeds. The disturbance from the noise of the car does not increase as much at higher car speeds as the wind disturbance of the velocity sensor.

The sensor responses with a driving car are also measured with the speaker turned off. In this case only the background noise, vibrations of the car and influence of wind is measured. In Figure 6 the auto-spectrum of this noise, minus the spectrum in still standing conditions (but with the speakers turned on) is plotted. If this value exceeds zero dB the external signal exceeds the speaker noise.

Even though the signals are affected a lot by noise at higher speeds, the impedance can still be measured. To calculate the impedance, the transfer-function of both sensors is used, and the noise that is not correlated goes to zero.



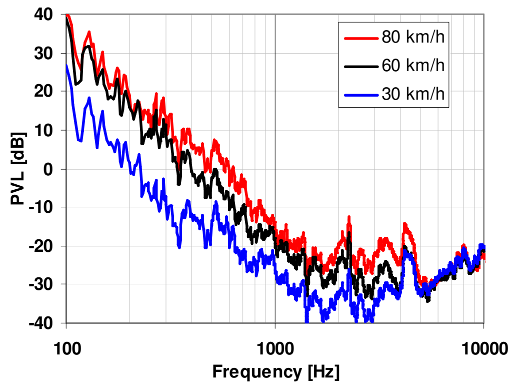


Figure 6: Autospectrum of the external noise only (speaker turned off) relative to the autospectrum at still standing conditions (speaker on). Top: pressure, bottom particle velocity response.

Recommendations

Now the maximum speed, without overloading the velocity sensor, is 40km/h. This limit is mostly caused by wind. A better wind cap, combined with a velocity sensor with a higher upper sound limit (which is already available) the velocity channel would be less affected.

During these measurements the speaker was set not too loud in order to prevent an overload of the pressure sensor. Using a pressure microphone with a higher limit the speaker volume could be turned up, and disturbances such as (traffic) noise can be reduced.

A next version of the setup will have a retracting mechanism that will prevent damage when the car drives over a large bump in the road.

Conclusion

With current methods it is only possible to measure the road impedance inside a laboratory, or when the road is closed down for traffic, which is costly and disturbing. A moving measurement technique is desired for a quick measurement of large stretch of asphalt, and for maintenance purposes.

The PU in situ impedance method has already been used in situations with relative high levels of background noise. Now a setup is build that can be mounted behind a car. With the current setup, real time acoustic impedance measurements are possible up to 40km/h, in a 300Hz-10kHz band, with high spatial resolution. At higher speeds the particle velocity signal is affected, mostly by wind. At 80km/h still some parts of the signal are usable, and above 800Hz the result is similar to a measurement without movement. Because the transfer function of two very different sensors is used, much of the non correlated external noise is reduced.

With this setup the distance between the probe and surface is larger, but it can be measured accurately. On these highly reflecting asphalt samples standing waves appear. The frequency of the maximum or minimum of the pressure or the velocity determines directly the distance.

To minimize the impact of the measurement on the traffic, the objective is to create a setup that is able to measure at speeds higher than 80km/h, and with noise of other cars.

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