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Determination of noise damping by forests

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ABSTRACT

To predict the attenuation value caused by a forest stand a model has been developed. The model depends on an attenuation coefficient for the forest and on the geometry of the forest and the positions for the source and the receiver. The attenuation coefficient has been measured by a specific test setup for several forest stands (three different pine forests and one oak forest stand) The stock of one pine stand was reduced in several steps and measured after each reduction. The results of the measurements lead not only to qualitative statements but also to quantitative attenuation values (and coefficients) for the different forest stands. The results also showed that the actual used model had to be extended because the sound path over the canopy can have a limiting effect on the maximum forest attenuation. This effect depends on the geometry of the forest and the sound and receiver positions as well as the specific forest attenuation coefficient. The extended model provides the possibility to predict the forest attenuation by forestal and geometric parameters.

Keywords: outdoor sound propagation, forest attenuation I-INCE Classification of Subjects Number: 24.5

1. INTRODUCTION

Large forest areas can be found as borderland within military training areas. An important function of these forested areas is to protect the civilian neighbourhood against negative influences from military activities. Since shooting noise from military training areas has become more and more important the influence of forests on sound propagation has been analysed with different measurement campaigns in recent years (1, 2).

Based on these measurements a technical noise damping model for forested areas has been developed (3, 4). This model contains a parameter, the attenuation coefficient K_{lin}, which reflects noise damping while moving through the forest. A measuring setup with appropriate proportions has been laid out to measure this coefficient for forest stands with typical proportions (5).

2. MEASUREMENTS OF THE ATTENUATION COEFFICIENT

2.1 Measuring method

With the measuring method, a rectangular test setup is selected in the forest (see figure 1). The measured distances were approximately 250 m for the propagation length on the edges of the measurement area. At this distance, the forest attenuation is large enough for having a significant influence on the sound propagation; on the other hand the influence of the weather at these distances is still low.

At the corners of the measurement field two microphones are positioned in 1.5 m and 5 m height. The source is located at about 10 m distance from the microphones on the diagonals. A propane gas cannon was used as source. For each propagation path a series of 10 shots was fired at the two selected heights (1.5 m and 5 m). For each propagation path the cannon was repositioned and redirected so that the microphones were positioned in a straight line in shooting direction. These multiple sound propagation directions are used to achieve a result independent from the wind direction. In addition, the wind direction and wind speed are measured outside the forest.

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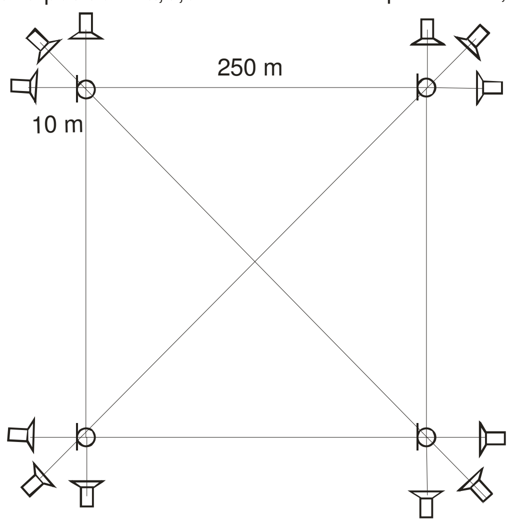

Figure 1 – The test setup with the source and receiver positions

The analyses of the measurement consist of several parts:

- Determination of the acoustical source spectrum of the sound source
- Calculation of the theoretical receiver spectrum with the propagation model of the ISO 17201-3
- Evaluation of the measured receiver spectra
- Calculation of the (absolute) attenuation value A_{forest} by the difference between measured spectra (with trees) and the theoretical immission spectra (without trees)
- Calculation of the attenuation coefficient K_{lin} by relating the attenuation value to the distance between the source and the receiver

It was found that the measurement in 1.5 m height yields to comparable results like the measurement in 5 m height. So in this paper we focus on the 5 m source and receiver heights.

The attenuation coefficient can be calculated for different level types; in this paper we focus on the calculation according to sound exposure levels for singe events and energy equivalent levels for stationary sources. So the herein presented attenuation coefficient can be depicted as $K_{lin,SEL}$.

2.2 Reduction of the stock density

In the first step we tried only to change one special parameter of the forest: the stock density. The aim was to change only one specific parameter of the forest. Therefore the measurements were performed in the same pine forest with 20 m canopy height and an age of 65 years. The stock density of the pine forest was reduced after each measurement and evaluated. The reductions of the forest were aligned to typical forestry measures. In the first step skid trails were established. The stock density was reduced by this step from 1.0 to 0.9. The next reduction was a “normal” forestal reduction with z-trees, (stock density 0.75), the third and the fourth one were evenly reductions over the whole area to a stock density of 0.6 and 0.5.

Table 1 – forestry parameters of the pine tree stand no.1

	step 0	step 1	step 2	step 3	step 4
stock density [1]	1.0	0.9	0.75	0.6	0.5
standing stock [m^3]	217.6	176.7	158.0	127.5	104.7
basal area [m^2/ha]	32.7	27.1	23.7	19.2	15.7
stem diameter [cm]	20	20	20	20	20

The attenuation coefficients were calculated as described above and figure 2 shows the result of the analysis and the corresponding parameters of the forest stands.

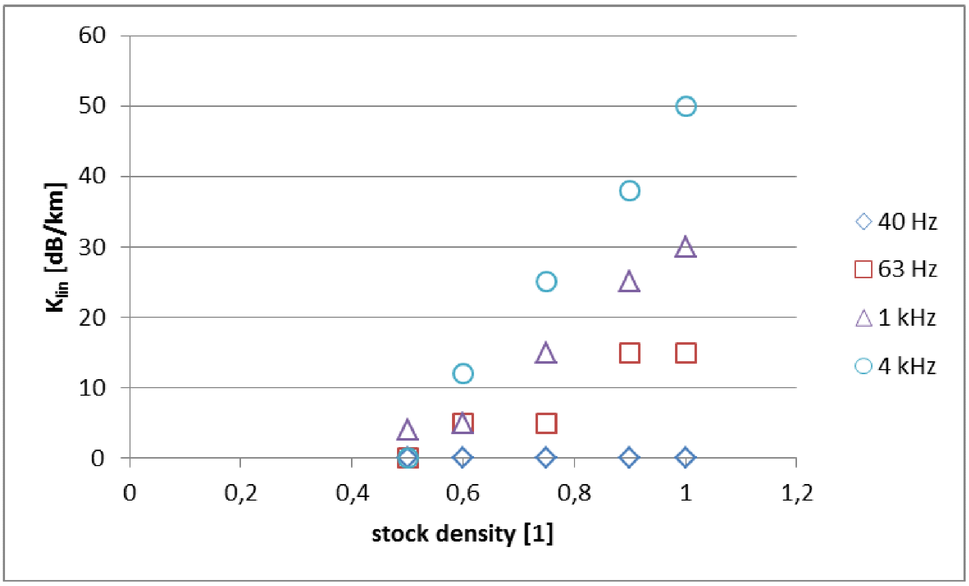

Figure 2 – attenuation coefficients for the reduced pine forest stand

Figure 2 shows that the attenuation coefficient is reduced nearly in a linear way with the reduced stock density, but has an offset with a stock density of 0.5.

After the reduction of the stock density the influence of different tree diameters on the attenuation coefficients were examined. Two different pine forests and one oak tree forest were measured.

Table 2 – forestry parameters of the pine tree stand no.2 and no.3 and of the oak tree stand

	pine tree stand no.2	pine tree stand no.3	oak tree stand
stock density [1]	1.1	0.84	1.1
age [years]	39 (2013)	103 (2013)	73 (2013)
standing stock [m^3]	183	220	228
basal area [m^2/ha]	32.2	21.6	24.0
stem diameter [cm]	10	33	18
canopy height [m]	14.5	22.3	16.0
K_{lin}(40 Hz) [dB/km]	0	2	0
K_{lin}(63 Hz) [dB/km]	5	15	5
K_{lin}(1 kHz) [dB/km]	22	12	20
K_{lin}(4 kHz) [dB/km]	50	48	20

The stock density is not suitable parameter to plot the attenuation values of different tree types against it because the stock density is a relative value for each tree type. Therefore we use a forestal parameter that reflects the density of the forest stand independent from the height of the trees, the parameter basal area, which is the sum of all stem cross section areas relative to the area of the forest stand. The results of these measurements are shown in figure 3.

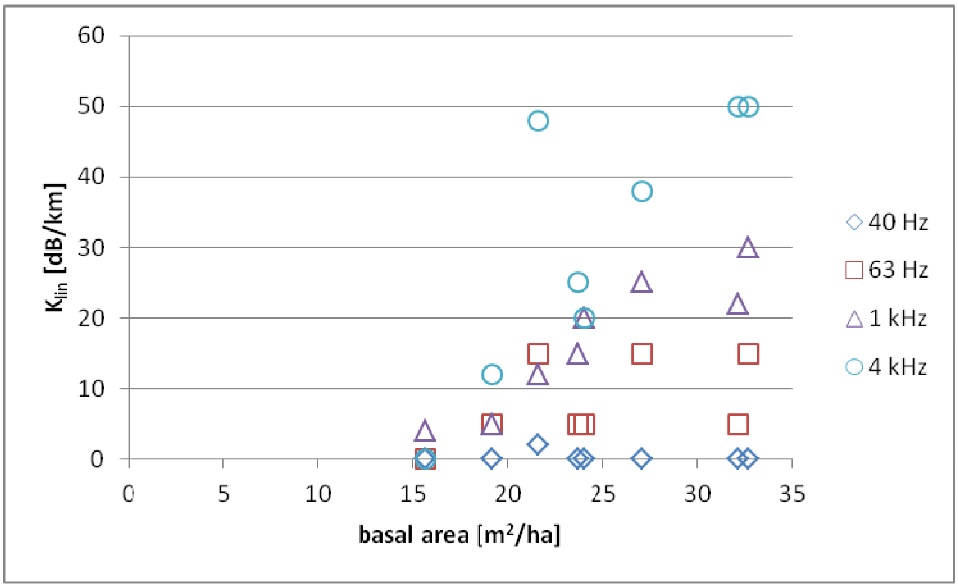

Figure 3 – attenuation coefficients for pine forest stands no. 2 and no.3 and for the oak tree plotted against basal areas

The measured attenuation coefficients show that for two forest stands with the same standing stock (pine tree no.2 and pine tree no.3) but with different stem diameters (10 cm and 33 cm) that for the low frequency at 63 Hz the attenuation coefficient is higher for the forest with thicker stems than for the one with thin stems. At 1 kHz this effect is contradicted: the attenuation coefficient is higher for the forest with thinner stems than for the one with thick stems.

The attenuation coefficient at 4 kHz and a basal area von 24 m^2/ha with a value of about 50 dB/km is much higher than the one from the other measurements. Since this forest is the only one with significantly more branches reaching to the ground, this is suspected to be the reason for it.

Below a basal area of 15 m^2/ha it can be suspected that there is no significant attenuation of the sound in any frequency.

In the forestal yield tables maximum values up to a basal area of 50 m^2/ha can be found for some forests. Therefore much higher attenuation values can be expected for those forests.

3. PATH MEASUREMENTS

3.1 Sound propagation paths in a forest

The forest model used so far assumes that for a source and a receiver located in the same forest stand, the relevant sound propagation path goes through the forest. But there are several sound propagation paths possible: the direct path, the path with reflection at the ground and the path from the source to the canopy and then by sound diffraction (or scattering) without forest attenuation over the forest canopy and then again by diffraction or scattering back in the forest and to the receiver (the canopy path).

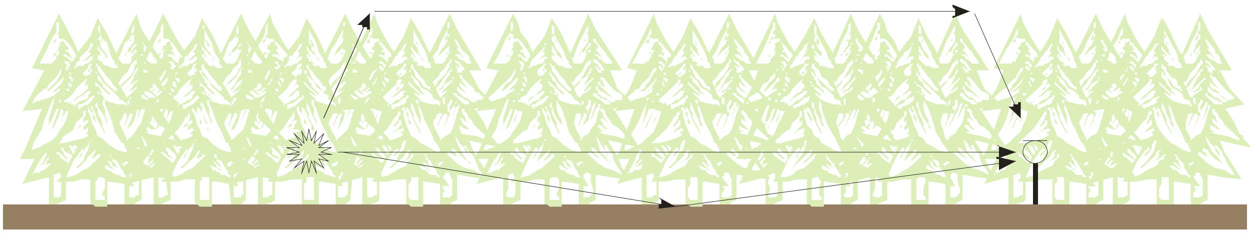

Figure 4 – sound propagation paths in a forest

The sound paths need not to be straight lines; by temperature or wind gradients in the forest the sound paths will be curved. In addition, the sound propagation path over the forest has not only one sound path to a diffraction edge on the top of the canopy but many scattering and diffraction locations. It is comprehensible that the sound propagation path over the forest becomes more important, the lower the forest height (by same source height and receiver height) and the higher the attenuation coefficient of the forest is.

To investigate this effect, a measurement was performed for longer distances up to 500 m for two forests (pine tree no. 2 and pine tree no. 3).

3.2 Results

The results for the pine forest with the thick, high trees (no. 3) with a lower basal area show a similar attenuation coefficient for all distances but for the pine forest (no. 2) with thin, low trees and a high value for the basal area, the attenuation coefficient differs with the distance between the source and the receiver (see figure 5).

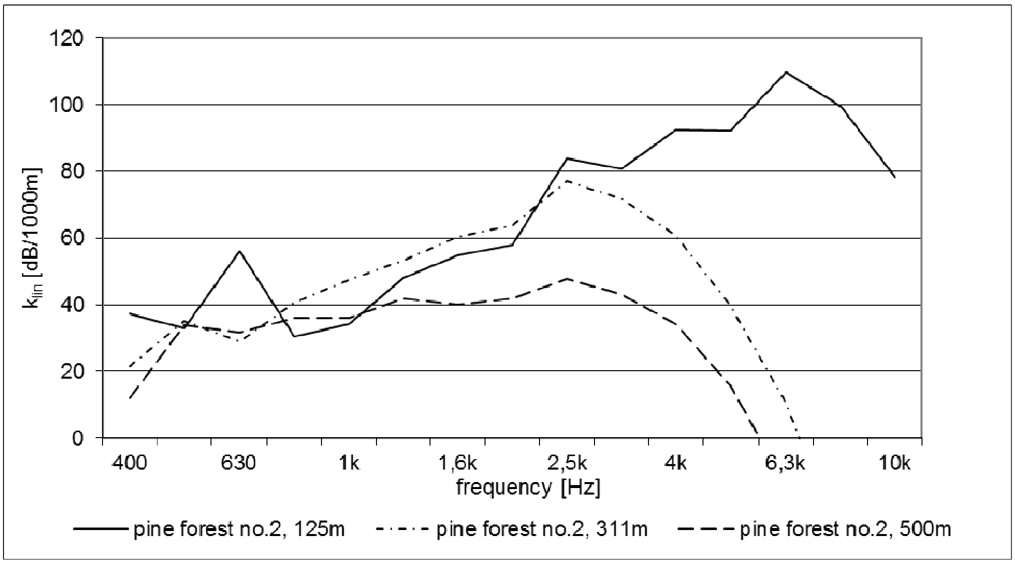

Figure 5 – attenuation coefficient for pine forest no. 2 plotted against frequency

The attenuation coefficient of the path measurement in the pine forest no. 3 is similar for a distance between source and receiver of 125 m and 311 m, but for 500 m the attenuation coefficient shows lower values at a frequency range above 1.6 kHz. The attenuation coefficient above 2.5 kHz for 500 m and 311 m distance is reduced because of the decreasing signal to noise ratio (SNR).

4. EXTENDING THE FOREST MODEL

4.1 Actual forest model

The model introduced in 2009 (3, 4) assumed that the immission level behind a forest is affected by a part of the sound energy that propagates from an acoustical source through the forest and a second part of the sound energy that propagates over the forest.

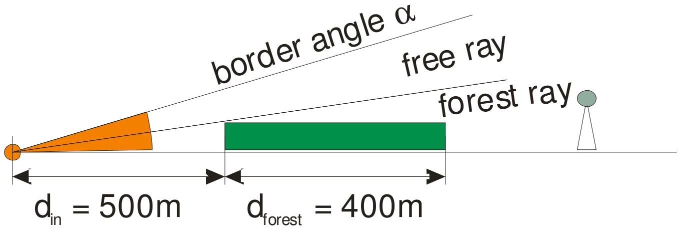

Figure 6 – The two sectors of the relevant sound energy from a source on one side of a forest to an immission point on the other side

The sector of the part propagating through the forest is limited by the ground and the line through the source location and the upper edge of the forest. The second sector above the first sector is limited by a cut off angle. The sound energy above the second sector is supposed to have no influence on the immission level. The maximum angle of the free field sector was found by a correlation method to be approximately 20°. For emission points near the forest it is possible that the angle of the first sector is greater than 20°. In that case there is no second sector with a free ray. The sound rays limiting the sectors are not straight lines but curved with a radius depending on the wind and temperature gradient on that propagation path.

When we try to simulate the path measurements as described above, the actual forest model will lead to increasing forest attenuation, linear to the distance between source and receiver. The effect of limiting the maximum forest attenuation respectively decreasing the attenuation coefficient as shown in fig. 5 could not be reproduced.

4.2 Extending the model

To reproduce the influence of the sound traveling over the forest an approach by the ISO 9613-2 (6) is done.

For a special outgoing vertical angle the length of the sound propagation path through the forest is calculated. A diffraction is supposed at an edge where the sound propagation path reaches the top of the forest canopy. Near the receiver the sound propagation path is diffracted at a second virtual edge and travels through the forest to the receiver with the same incoming angle as the outgoing angle. The diffraction at the both edges is calculated by the ISO 9613-2. The attenuation of the forest affection on the sound propagation path is calculated for the length of the path, where the sound travels through the forest by the corresponding attenuation coefficient. This is calculated for different outgoing and incoming angles. The one with the lowest attenuation sum $A_{ISO9612,min}$ (diffraction and forest attenuation) is defined to be the dominant attenuation angle.

A combined attenuation value A_{forest} for a given geometry can be defined by the (energetic) sum for the (negative) attenuation of the different sound portions (the direct sound path including the reflected path and the canopy path):

$$A_{forest} = -10\lg\left(10^{(-A_{ISO9613,\min}+\sum_{v} d_{forest,direct}{}^{*}-K_{lin,v})} + 10^{\sum_{w} d_{forest,diffraction}{}^{*}-K_{lin,w}}\right)$$

This combined attenuation value is subtracted from the expected immission level that can be calculated by sound prediction methods like ISO 9613-2 or ISO 17201-3 (7).

First calculations using the extended model to the diffraction by ISO 9613-2 give similar results as the measurement. This will be validated in detail in the further work.

If this proves true, the maximum possible attenuation of a forest, independent of its internal attenuation coefficient, can be estimated. In forests with high attenuation values and low canopy heights it is expected that the acoustic path through the forest starts at a distance of about 400 m (for source and receiver near or in the forest).

5. CONCLUSIONS

In the measurements presented here the acoustic characteristics of the forests were measured and the forestry parameters of forest stands were supplied. The wanted acoustical characteristic was the attenuation coefficient of the measured forest stands. From these coefficients the damping value for a special geometry can be achieved by multiplying the coefficient with the length of the sound propagation path from source to receiver.

The measurements show that a reduction of the stock density of a forest stand leads to the conclusion, that from a certain minimum value of the stock density the measured attenuation coefficient has an almost linear relationship to the stock density (and also to the standing stock and to the basal area).

When forests with different diameters of stems and tree heights are compared, the linear relation of the attenuation coefficient values to the basal area (but not to the other two parameters) of the forest stand is again approximately linear. The forestal parameter “basal area” reflects the density of the forest. For two forests with comparable basal area values but different diameter of the stems we found higher attenuation values for the forest with large stem diameters.

The path measurement in a dense young forest with relatively low tree heights showed that from a certain distance between source and receiver the sound propagation path over the forest can dominate the attenuation value. This effect limits the maximum attenuation of the forest no matter how high the attenuation coefficient of the forest is. For sparse forests or higher ones it is expected that this effect occurs only at larger distances. Based on these results, an extended forest attenuation model was developed. This took into account the direct sound path as well as the sound path going over the canopy of the forest. With this extension, forestal recommendations can be made for specific situations. It can be estimated, how much a forest can be reduced without reducing the attenuation value of the forest based on a specific geometry and forest parameters. Other issues related to forest development could be made, e.g. which tree type at which canopy height and which stock density leads to an optimal acoustical attenuation for a specific situation.

These optimal combinations of forestal parameters to archive a maximum attenuation value depend on the geometric situation; so there is not a simple conclusion like "High trees are the best!" or "Dense forest are the best!" but there is a different solution for each situation.

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