

Prediction of Sound Pressure Levels at Workplaces

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The sound pressure levels at work places are determined by the sound emission of the noise relevant facilities like machinery and by the acoustic properties of the room. A strategy has been developed to create virtual models of the sources by single point sources with frequency dependent directivity or by acoustically impervious cuboids covered by grids of point sources. Their emission is coupled to a hybrid propagation calculation that allows applying absorptive treatment of surfaces as well as noise reduction by screening objects. Low order reflections are calculated deterministic applying the mirror image method, while higher reflection orders are taken into account by a fast ray tracing calculation. The method is effective to develop low noise layouts in offices, machine halls or other work places on the basis of standardized emission levels according to the machine directive and for many other applications in architectural acoustics. The main advantage is the very quick creation of geometric-acoustical models and the graphical support of the final assessment.

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1 Introduction

There was much more effort in the calculation of sound propagation outside compared to sound propagation inside rooms. One of the reasons may be the broad consensus and public interest to avoid noise exposure in residential areas from traffic and industry, while the noise impact at work places inside industrial rooms occurs in a certain way “behind closed doors” and tackles only a relatively smaller group in each individual case. Additionally it is by far more complex to describe and calculate sound levels at work places in rooms at work places near machines than the sound level caused by a road at a building façade nearby if comparable accuracy shall be achieved.



Figure 1: Labeling machines in a packaging line.

Figure 1 shows an example – the machines in a bottling plant are quite large compared to the typical distance of the operators position, many different sources inside the “reference-cube” may produce a quite complex radiation pattern that can hardly be described by uniformly radiating point source. It is a challenge to simulate these complex sources accurately enough to get realistic results and simple enough to create a model of the complete work room with machinery in time frame economically acceptable.

The same is true regarding the room layout – it is not possible to invest man-days in the creation of the geometrical room model and in the definition of the acoustically relevant objects like absorption treatments, screenings and other noise protection devices. At the first glance it seems to be a non-acoustic market aspect to make a software user-friendly and effective, but in reality such properties of the noise prediction tool may influence the success of a noise reduction concept even more than the scientific detailedness of the model.

Propagation is also difficult to be treated in a way balancing the needs of technical-scientific correctness and acceptable calculation times. While many psychoacoustic parameters depend mainly on the important first reflections with an impact at the receiver during 100 ms after emission the levels caused by continuously radiating sources in highly reflecting environments typical for many industries may be influenced by reflections up to even 10th order. With the often applied mirror image method the number of rays – and therefore of calculations – contributing to the levels at a receiver position increases exponentially with the reflection order (number of reflections of one ray path from the source to the receiver) and with the number with the number of reflecting surfaces. And different to the calculation of psychoacoustic parameters when planning a concert hall in working rooms the diffraction of direct and reflected sound is important because many mitigation concepts are based on partial walls and screens.

2 Propagation calculation

While the construction of possible ray paths for sound prediction outside is based on a 2.5-D concept in typical engineering models, the calculation of sound propagation in rooms needs a full 3-D concept.

Geometrical attenuation, reflection and diffraction are the most important influences to be taken into account. As it is shown in Figure 2 for a simple line source and 10 point sources, there are a lot of rays reaching the receiver via reflection at floor and walls (ceiling is absorbent for this view).

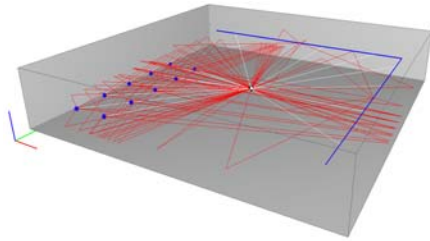


Figure 2: Direct sound rays and reflection of 1st order

The geometry of the reflected rays shown in Figure 2 where determined applying the mirror image method. In normal applications it is necessary to extend the calculation up to higher orders, but for presentation the 1st order rays are sufficient. If the ray path – direct or reflected – intersects an object, attenuation by diffraction can be taken into account. Figure 3 shows the construction of two ray paths if two objects are located between source and receiver. The objects are cutted by two planes with a 90° angle between them and the shortest polygons connecting source and receiver and lying in the planes are constructed. Based on a Maekawa formulation similar to the method in ISO 9613-2 the attenuation by diffraction is calculated. Measurements with barriers in different rooms have shown that rays up to 1st or in some cases up to 2nd order should be screened to get the best accuracy. Therefore up to a reflection order of 1 or 2 the mirror image method with diffraction around objects is applied.

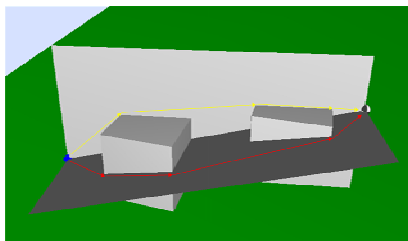


Figure 3: Construction of ray paths diffracted at 2 objects.

High order reflections are calculated with a particle method. Each source emits particles in directions randomly distributed and the geometry of each path is calculated taking into account specular or diffuse reflection at each surface hidden. This technique allows calculating the levels even in parts of a complex room where the sound ray emitted by a source needs many reflections to reach the receiver.

The complete room is logically partitioned in cubic sub-volumes (volume pixels → voxels) and each crossing of such a voxel is counted and produces a contribution.

This hybrid method allows complete calculation with mirror image method or with particle method or the calculation up to a definable reflection order with mirror

image method and diffraction and for all higher reflection orders with particle method.

3 Source modeling

Small sources like loudspeakers (PAS systems) or large and complex sources (machines) must be handled as simple as possible and as accurate as necessary. Small sources like loudspeakers, but also compressors, motors pumps and other technical facilities are simulated by point sources with frequency dependent sound power levels and – if needed – with a very detailed 3-D directivity in 5° steps and separate for each frequency band.

These detailed directivity data are generally available for loudspeakers, but for machines only very rough information for some directions is provided (see figure 4). Therefore it is advantageous to treat such rough directivity information for machinery as general input data for this source type and then to derive the general detailed format internally by interpolation and spline techniques.

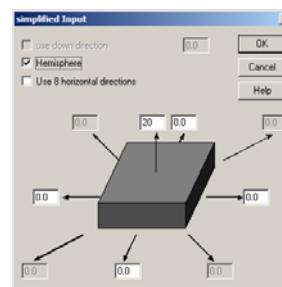


Figure 4: Input of rough directivity information

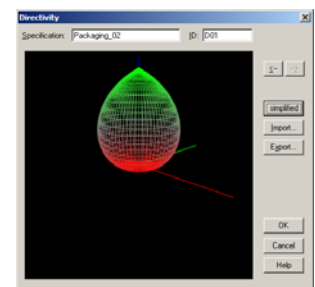


Figure 5: General format of the detailed directivity

This technique of applying different depths of detail is extremely helpful to encourage people to create such models and to check if requirements can be fulfilled.

But it is also possible to model larger machines with working places nearby more in detail – this may be advantageous for special investigations about the machine itself. Figure 6 shows the labeling machine from the plant figure 1 more in detail – the operators are protected from direct radiation by an enclosure at 4 sides, but there is free radiation by the open deck and this sound may be reflected from the ceiling of the room.



Figure 6: Enclosure of a machine with open deck.

With detailed modeling as shown in figure 7 these effects of directed radiation upwards and its interaction with the room acoustically can be studied.

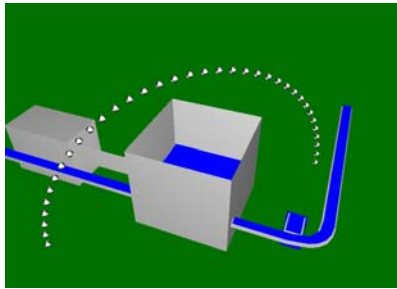


Figure 7: Detailed model of labeling machine with connecting conveyors.

The receiver points along a semi-arc vertically around the model are applied to calculate the resulting directivity.

The calculated levels are shown in the diagram figure 8 if increased orders of reflection inside the room are taken into account. The real free field directivity (lower curve) gets more flat with more reflections taken into account and all the levels increase. The curves show that the room influence (K3 at each position according to ISO 11200 series) is small where directivity is larger and gets very large where the directivity is small (or negative if normalized).

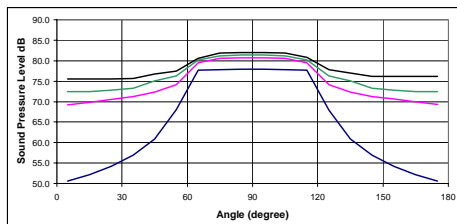


Figure 8: Detailed model of labeling machine with connecting conveyors.

The sound pressure level at the position of machine operators is calculated using the structure of declared noise emission values according to the machine directive. The direct sound from the own machine is determined using the emission sound pressure level L_{pA} and the contribution from all machines in the room is calculated from the sound power levels LWA. This technique allows to link the standardized framework of noise declarations with the room properties to get the noise levels at the workplaces.

4 Propagation Calculation

As it was mentioned above, a hybrid calculation technique is applied to cover the main important applications. It is possible to calculate the levels at grid points regular distributed on horizontal or vertical planes and to present the results as coloured noise maps or as a pattern of lines of equal noise level.

But it is also possible to subdivide the complete room volume in smaller cubic elements (volume pixels \rightarrow voxels) and to calculate the sound pressure level for all these voxels. Then the surfaces of equal sound pressure level can be shown in 3D.

With figures 9 and 10 the sound distribution produced by a point source and a simple barrier is shown that way – figure 9 are the ISO-dB-surfaces in 5 dB spacing if only the direct sound is calculated, while figure 10 shows the same surfaces if additionally 1st order reflections are calculated.

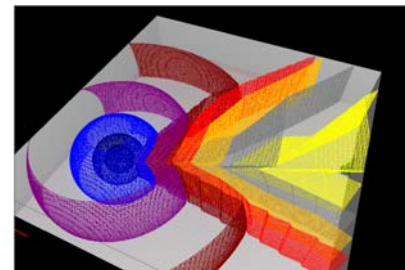


Figure 9: Surfaces of constant level calculated with point source and screen – direct sound.

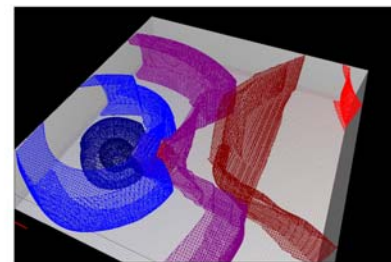


Figure 10: Surfaces of constant level calculated with point source and screen – direct sound and reflections 1st order

This technique allows to investigate the influence of special shaped rooms on the distribution of sound. The

model of the circular room in figure 11 was produced from one wall panel with a powerful transformation functionality by rotating it around the center point. Then the particle-method was applied to calculate the sound pressure level caused by a point source for all voxels with reflection orders up to 20. Figure 11 shows the horizontal distribution of sound pressure levels and from the levels at all voxel positions the ISO-dB-surfaces shown in figure 12 are derived. It is obvious that such a technique is helpful to study the influence of the layout of the room, its furnishing and many other details influencing the noise levels or the acoustic climate.

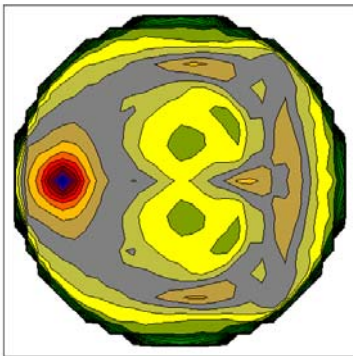


Figure 11: Horizontal distribution of sound pressure levels caused by a point source in a circular shaped room

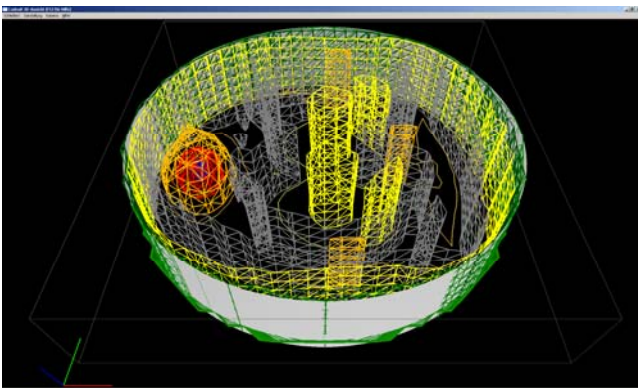


Figure 12: ISO-dB-surfaces calculated from all voxels

5 Applications

The software technique presented (CadnaR /1/) was developed to support consultants dealing with noise problems and with the acoustic design of production halls, offices and other rooms where the sound pressure levels shall not exceed certain limits or where certain requirements shall be fulfilled with respect to the sound level distribution. The main aspect is the application of modeling techniques that have been developed in the last 20 years and that are applied in software tools for sound prediction outside (CadnaA).

The combination of room design and acoustic treatment with a flexible source definition and propagation calculation may be a powerful support of all those dealing with noise abatement and acoustic treatment.

References

- [1] CadnaR, Calculation of Sound Propagation in Rooms, DataKustik GmbH, 86926 Greifenberg, Germany