New techniques in computer aided noise abatement for workplaces next to machinery

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Introduction

To protect workers from high noise levels inside industrial buildings, simplified sound propagation calculations are performed in order to meet the acoustical requirements. The VDI guideline 3760 [1] specifies the calculation of noise levels on a straight path originating from a point source using the image source method and a simplified geometry of the room. The spatial distribution of noise levels allows calculating two characteristic values: level excess above free-field level DLf and level decrease per doubling of distance DL2. If these characteristic values exceed certain limits, room acoustic measures can be recommended or enforced in noise-relevant industries. These sound decay curves were assumed to be the same for all directions of propagation paths originating from the source. The partial level of all sources in a room at a certain receiver position could therefore be derived from the sound power level of these sources and one sound decay curve characterized by the abovementioned two parameters DLf and DL2. Based on this approximation of a uniform sound decay curve characterizing the room the noise level at a workplace could be approximated by adding the partial levels of all sources energetically.

Over the last few years major improvements in acoustical planning and noise abatement were achieved by introducing the sound particle model in noise prediction procedures. This method allows to model the acoustically relevant structures more detailed and to include them in the calculation of sound propagation in working areas. This article describes the current state of acoustical modeling and calculations with the particle model using specific examples.

Methods for sound propagation calculation

Every calculation described in this article was performed with the software CadnaR [2] using the combined calculation procedure: lower reflections up to a definable order are calculated with the image source method, all subsequent orders are calculated with the particle model. It can be foreseen that the image source method will be replaced by the particle model in near future even for low reflection orders if certain problems with the inclusion of diffraction in the particle model will be solved.

Both image source method and particle model describe purely geometric sound propagation. Therefore effects based on the wave nature of sound cannot be explained. It is assumed for every example and calculation in this article that sound contributions from different sources superimpose incoherently and thus can be added energetically. Experience and verification procedures show that this simplifying assumption is valid in most cases.

In the course of these verification procedures sound decay curves SDC of approximately 150 industrial halls were recalculated and compared with those measured during a project [3,4] related to the development of the VDI guideline 3760. The spatial and acoustical parameters of the industrial halls were used as input values for calculating the SDC with various methods. As a result the method of the VDI 3760 proved to have the smallest deviation between calculation and measurement. Now in this further step the particle model in CadnaR was applied using the input data documented during the measurement campaign. From this investigation it can be concluded that the CadnaR particle model simulations are in very good agreement with the measured sound decay curves. It is planned to publish these results in detail.

Basic machine modelling

The point source is the most important and most fundamental object to model noise emitting machines and structures. It is characterized by its coordinates, the sound power level L_W of each octave frequency band and if applicable the directivity, whereas the directivity must be defined for each frequency band and with two angles as parameters. Modeling a small machine like the forging machine in Figure 1 with a point source is sufficiently accurate for the acoustical calculations.

Figure 1: Small forging machine

Therefore it is very easy to model a workshop with 4 forging machines and corresponding workplaces like presented in Figure 2.

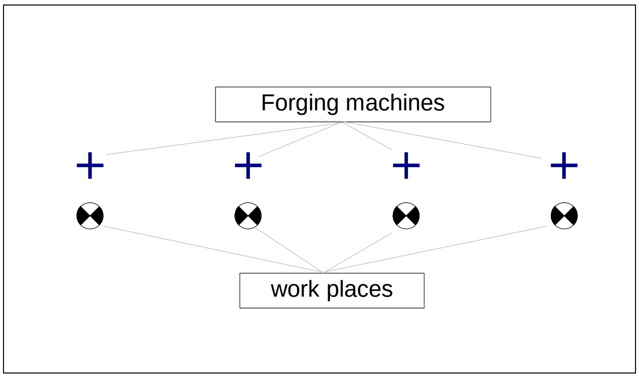


Figure 2: Model of a workshop with 4 forging machines

As it is often too time-consuming to define the directivity with two angles for every frequency band, CadnaR offers an alternate way for a simplified definition of the directivity. This definition corresponds to common noise measurements: like shown in Figure 3 measured sound pressure levels can be entered for predefined directions. In a second step CadnaR automatically calculates the directivity in steps of 5°. In this simplified model the directivity is the same for all frequency bands.

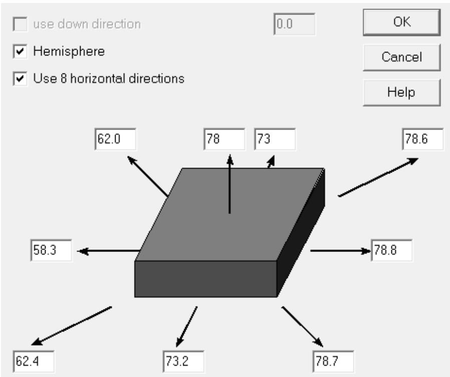


Figure 3: Simplified definition of the directivity

To validate the directivity a „virtual free field laboratory" can be used, i.e. to calculate the noise levels at receiver points positioned on a semi circle like shown in figure 4.

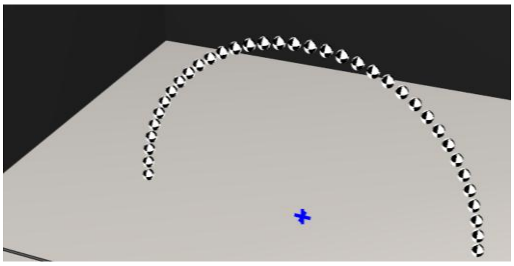


Figure 4: Setup to validate the directivity

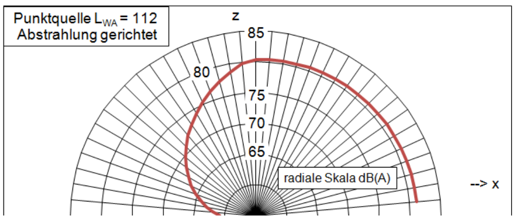


Figure 5: Directivity verified with calculated levels at receivers

For a more complex model of multiple emission sources, the resulting overall emission can be verified by placing a set of receiver points as a closed enveloping surface. The enveloping surface can be of arbitrary shape, but will be mostly be rectangular or hemispherical.

Application of emission values according to the machine directive

Figure 6 shows an encapsulated but nevertheless noisy machine. The relevant sound is emitted from a unit at the top of the machine and from the openings for material in- und output at opposite sides.

Figure 6: Encapsulated machine with three emission areas

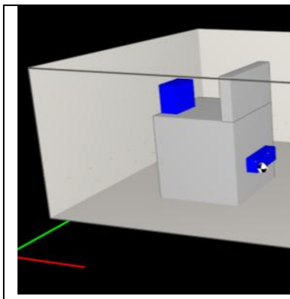


Figure 7: Simulation

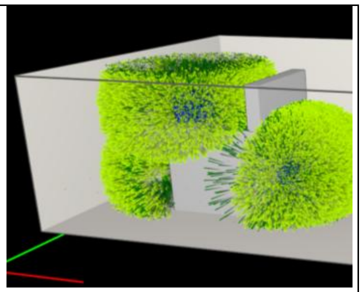


Figure 8: Radiation of sound particles

A much more detailed modeling of acoustically relevant structures of such machines (figure 6 to 8) is an essential improvement for noise calculations at workplaces. Thereby two main achievements will be described in the following:

The first achievement is the optional implementation of the emission sound pressure level L_{pA} besides the sound power level L_{WA}. The L_{pA} is a value the manufacturer has to provide due to the machine directive and describes the theoretical level at the workplace of the machine if the machine would be operated in free field above a reflecting surface without any other sources.

In some cases it is possible to model the distribution of the different sources of a machine and the nonradiating machine parts with sufficient accuracy, so that the simulation in semi free field (reflecting ground) will directly deliver the correct value for L_{pA} at the workplace.

Nevertheless it is advised not to be dependent on the accuracy of the machine modeling if official requirements about the maximal noise levels at workplaces must be fulfilled. In such cases it is the better solution to take this known free field level L_{pA} as the contribution of the direct sound. The noise calculation will then include the following steps:

1) Assignment of each receiver at a workplace to „his" machine
2) Assignment of L_{WA} for each machine and L_{pA} for each receiver point at a workplace
3) Calculation of the level at the workplaces in a free field simulation using the sound power level L_{WA} of "his" machine -> $L_{pA,sim}$
4) Calculation of the level for all receivers with all machines applying their corresponding L_{WA} and any influences of the room (room geometry, absorption, scattering etc.) → $L_{AP,sim}$
5) Calculation of the noise level L_{AP} at each workplace using the equation:

$$L_{AP} = 10 \cdot log\left(10^{0,1 \cdot L_{AP,sim}} - 10^{0,1 \cdot L_{pA,sim}} + 10^{0,1 \cdot L_{pA}}\right) dB$$

This routine may look simple but the implementation in software is quite challenging. This is especially true if the machines have several sources with different sound power levels spread over the surface area. Step 3 is a type of preprocessing being performed sequentially for one machine after the other.

This is where the second achievement comes into play: the data organization of technical facilities with any complexity. CadnaR offers a hierarchical structure called "Object Tree" similar to the Explorer which allows for example an easy switching between different operating situations of a machine: Take an industrial bottle washing machine in figure 9 as an example. The noise sources (depicted in blue) are engines at the side of the machine and conveyor belts in the front for bottle transportation.

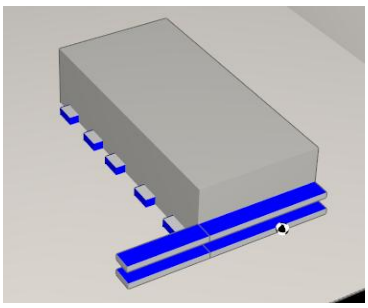


Figure 9: Model of a bottle washing machine 16m x 6m x 3,5m

It is advisable to create for each noise relevant machine three "containers" in the Object Tree like shown in figure 10: Structure, On and Off. The container "Structure" contains (in terms of data management: references) the parts of the machine model which are independent of any sources, the container "on" contains the references of source-elements and "off" contains these source elements but without emission.

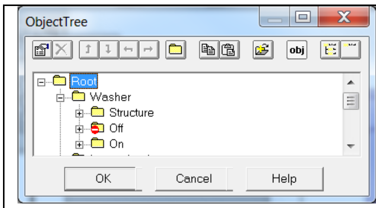
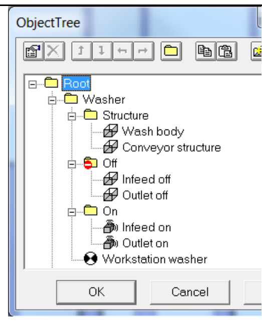


Figure 10: Hierarchical data structure for a bottle washing machine



In a further step the receiver of the workstation can be assigned to this machine. Then step 3) to 5) will be performed automatically if an emission sound pressure level L_{pA} was defined. This means that the emission sound pressure level defines the direct sound at the workplace but further contributions from e.g. other machines or reflections will be calculated using the particle model.

With the data organization provided by the Object Tree the machines have to be modeled only once. After the single (and ideally very detailed) modeling they easily can be multiplied, rearranged and copied to other industrial halls or other projects. Figure 11 sows a bottling plant which was built by import and rearrangement of individual machines.

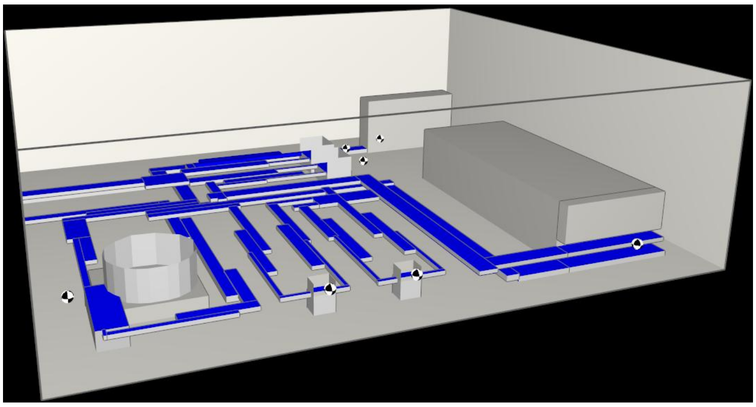


Figure 11: Model for noise calculation in a bottling plant (sources in blue)

The basic modeling elements which form the machines and the other objects in the plant are barriers and boxes which are characterized by their frequency dependant values for absorption, scattering coefficient and acoustical transparency (i.e. sound insulation value). They can also be used to model wall and ceiling cladding as well as baffle systems applying their absorption coefficients taken from official test reports according to ISO 354 [5]. The Object Tree allows to switch the wall/ceiling cladding or baffle systems on and off with just one click and therefore offers to easily calculate and compare models with and without acoustic measures. A view to such a baffle system and the corresponding CadnaR model are shown in figures 12 and 13.

Figure 12: View to a baffle system above the plant

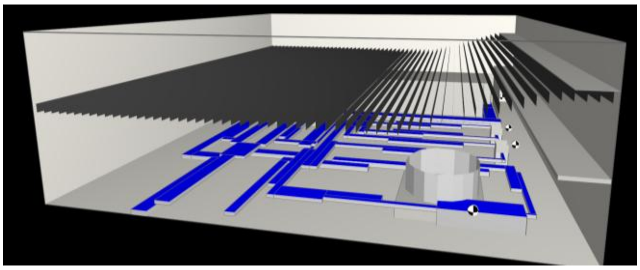


Figure 13: The corresponding CadnaR model

Due to the detailed modeling of the baffle system with each baffle as an individual object, the system is not characterized by an absorption coefficient for this geometrical lay-out, but defining absorption and transmission of the baffle-plate itself. This method to apply the acoustic parameters of the baffle-material is obvious - any other arrangement with different distance of rows or even different patterns can be taken into account by a simple geometric rearrangement. The transmission of the sound particles through the structure is simulated (see figure 14) and therefore the effect of absorption above the baffle-system, e.g. an absorbent coating of the ceiling above, is included in the simulation. The relation between structure related absorption coefficient of the complete baffle system and the absorption data of the baffle material is described in [4]. Simulations with CadnaR and the particle model proved to be in very good agreement with [4].

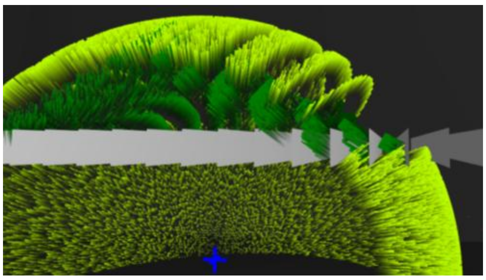


Figure 14: The sound particles emitted by a point source interacting with a baffle-system

The techniques for acoustical modeling and simulations in CadnaR allow various experiments which are difficult to perform in reality. For example it is possible to determine the resulting and finally effective sound power level using receivers distributed on a hemi-spherical enveloping surface like shown in figure 15. As shown in figure 16 with a box type enveloping surface, such "measurements" according to ISO 3744 [5] can even be simulated in the realistic industrial environment. This opens a wide field of applications to investigate the deviation of measured results due to such not ideal conditions. Applying different shapes of enveloping surfaces their influence on the determined sound power level and therefore the shape-related "angle-error" can be studied.

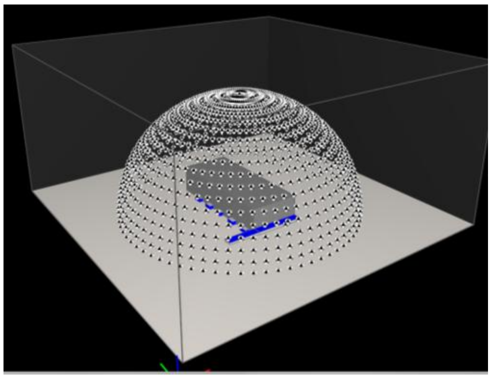


Figure 15: Receivers on a hemispherical enveloping surface according to ISO 3744 accuracy class 1

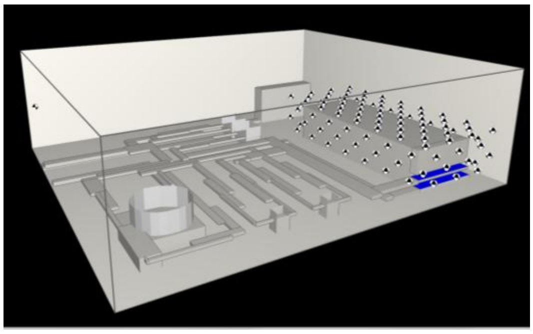


Figure 16: Receivers on a box type envelope surface according to ISO 3744 accuracy class 2

Summary

The described modeling techniques and achievements in software available open new fields in the acoustic planning of production and packaging areas and general of working areas in industry. In many fields of application like optimizing room-acoustic properties, noise prediction and abatement in working areas or even extending acoustic properties of absorbing systems measured in a laboratory for one or few layouts to many others these simulation techniques will be a powerful amplification of the acousticians expertise.

Literature

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[4] Probst W.: „Sound propagation in factory halls III - consideration of directivity, screening, big machines and coupled rooms (german language)“, Bundesanstalt für Arbeitsschutz, Fb 841, Dortmund 1999

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[6] Probst W.: „Sound absorption of baffle-systems (german language)“, ‚Lärmbekämpfung Bd.3 (2008) Nr.2
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[7] ISO 3744:2011 „Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering methods for an essentially free field over a reflecting plane“

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