Calculation of sound in workrooms to support noise control and acoustic optimization

Wolfgang PROBST

Datakustik GmbH, Germany

ABSTRACT

The calculation of sound emission and propagation inside rooms has become an important tool in the planning phase of workrooms with noisy installations like machinery where hearing loss effects shall be avoided and of offices where intelligibility, discretion and disturbance are effects shall be optimized or avoided. Due the importance of noise prediction in working areas these newer techniques shall be integrated in the existing standardization framework according to the state of the art. A main application is the calculation of noise in working areas with machinery. The technique including the modeling of sources representing even complex machines is demonstrated with practical examples. The calibration to adapt the radiation to known measurement results or to emission values declared by the manufacturer is supported by the simulation of the standardized measurement techniques according to the ISO 3740-series. Taking into account the impulse response of rooms energetically it is also possible to include the intelligibility of speech in noisy environments by calculating the speech transmission index STI. The best practice is shown with some typical examples based on industrial environments.

Keywords: Noise prediction, Workrooms, Machinery noise, Offices

1. INTRODUCTION

The prediction of noise levels at workplaces in the planning phase of industrial plants with machinery and other noise relevant facilities is – or could be – an invaluable support to ensure lowest possible noise levels according to the state of the art or achievable with a given budget. Prerequisite is the application of methods detailed enough to include the most important properties and describing parameters of the plant and the environment that can be influenced to reduce the noise.

The application of prediction methods is common practice with noise from industrial plants producing noise exposure in close-by residential areas. Gas turbine power plants, wind turbines or other noise relevant industrial facilities with critical distance to dwelling zones are generally not planned and installed in developed countries before a prediction calculation has shown that maximal acceptable sound levels will not be exceeded. If this is not the case additional measures can be taken into account and the process may be repeated.

The prediction of occupational noise – this means the prediction of noise levels at work places – is by far more difficult than to predict noise levels in residential areas outside because

- the distances between work place and machine are small relative to the extension of the source
- machines and other technical equipment are often very complex noise sources
- work places and radiating facilities are in most cases inside rooms, and full 3D-calculations of many reflected sound contributions must be taken into account.

Nevertheless an effective software strategy adapted to the problems of occupational noise is now available and shall be presented in the following.

2. CALULATION OF SOUND PROPAGATION

2.1 The energy based sound particle method SERT

The calculation of the sound pressure level at a defined receiver position caused by a single uniformly radiating point source with given sound power level is the "atom" of any noise prediction method inside rooms. Figure 1 shows the propagation of sound-particles in an empty room from the moment after radiation (upper left) till diffuse mixing (lower right) according to the application of the SERT-Method (Stochastic Energetic Ray Tracing) that has proven to be an excellent tool to support noise prediction in working areas. The SERT calculation method is applied in the software CadnaR (1).

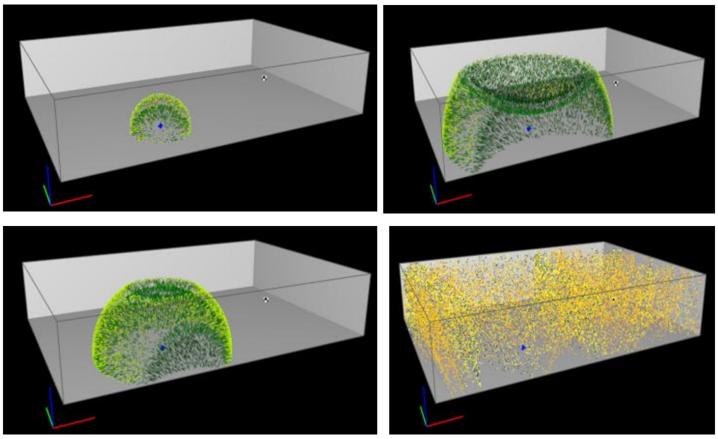

Figure 1 – Sound propagation applying the sound particle method SERT

It shall be mentioned that other methods like the mirror image method or the radiosity method can be applied. In cases where distinct modes of small rooms shall be investigated it may be necessary to take phases and coherent superposition into account. But for noise prediction at work places with technical noise sources (e. g. production halls) or in offices to optimize the acoustical climate the SERT-method offers the best adapted strategy.

2.2 Validation

To validate the method sound measurements have been performed in 122 industrial halls. A dodecahedron-loudspeaker radiated sound with a well known frequency spectrum of the sound power level and the resulting levels where measured along straight paths extended as long as possible according to the room dimensions. Figure 2 shows the loudspeaker in one of these halls.

Figure 2 – Dodecahedron loudspeaker in a production hall

Each of these 122 halls have been modeled with machinery simulated by rectangular boxes scattering the sound according to Lamberts law. In an automated process the octave band sound pressure levels were calculated at all points where measurements have been performed and the differences between calculated and measured levels have been evaluated in detail and statistically. Figures 3 and 4 show the normalized A-weighted levels related to a spectrum typical for such environments for a hall before and after installation of an absorbing ceiling.

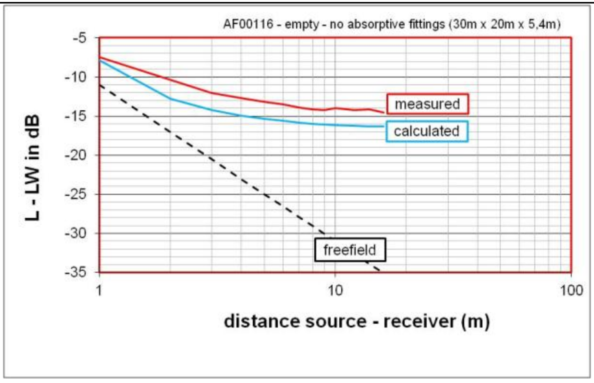

Figure 3 – Reflecting surfaces

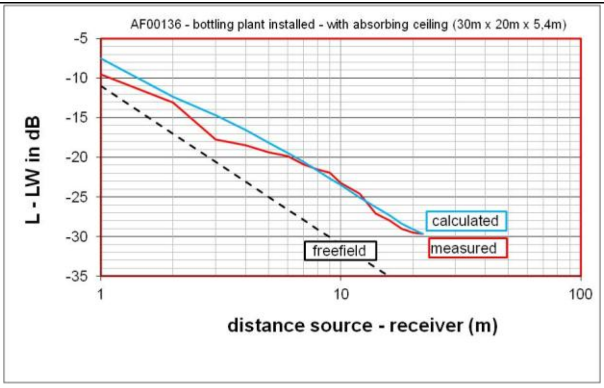

Figure 4 – With absorbing ceiling

Finally a statistical evaluation of level differences for all distances is shown in figure 5.

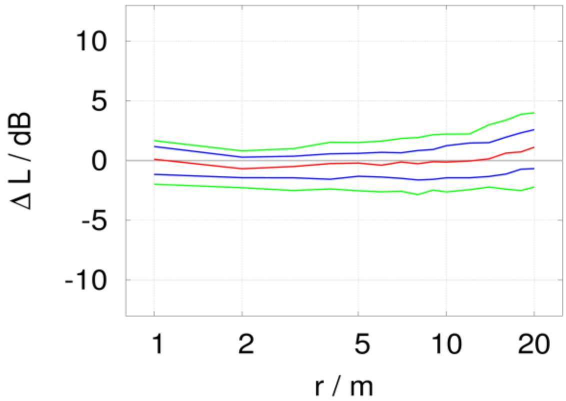

Figure 5 - Statistics of level differences calculated – measured (Red – mean, blue – 50%, green – 80%)

This final result shows excellent agreement of calculated and measured levels – the mean difference (red) is nearly zero and 50 % of all differences are smaller than ± 1 dB.

Many other comparisons of measured and calculated levels, reverberation times and other room acoustic parameters have been performed - examples are reverberation chambers or adjacent rooms coupled by an opening. The results show that the applied energy-based particle-method is well suited to calculate sound propagation in closed room with technical installations.

3. MODELING OF MACHINES AND NOISE PREDICTION FOR WORKPLACES

Small machines can simply be simulated by a point source. In more general cases a box type shape is assumed and the radiating sound power is attached with one or more of the box-surfaces.

Figure 6 shows some examples for the simulation of such larger box type machines. The box can have any size and even be elevated to allow sound particles propagating underneath.

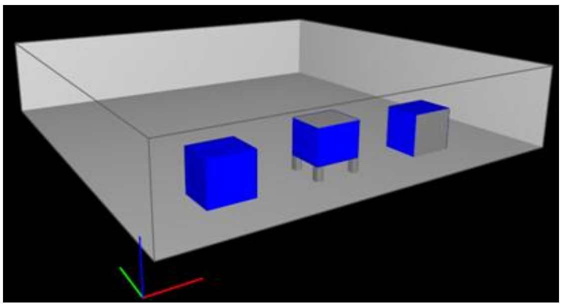

Figure 6 - Simulation of three box-type machines with different surfaces radiating sound

With the combination of point sources, line sources and such box-type structures machines of any complexity can be modeled. Figure 6a shows a large bottle washing machine in a bottling plant and figure 8 the corresponding 3D-model.

Figure 7 - Large washing machine

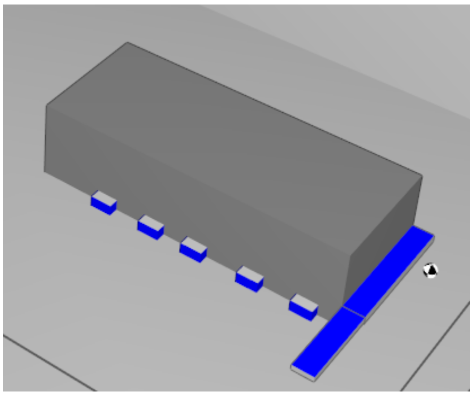

Figure 8 - Model of the washing machine

The easy assembly of such machines from basic elements is an important property of simulation software that shall be used frequently for noise prediction. The emission values L_{WA} and L_{pA} are applied as a lump information for the sound emission and the emission of all the partial sources must be adapted automatically to these input data.

The paths of the sound particles emitted from the noise relevant machine parts as shown in Figure 9 are calculated taking into account that the massive body of the machine is acoustically opaque.

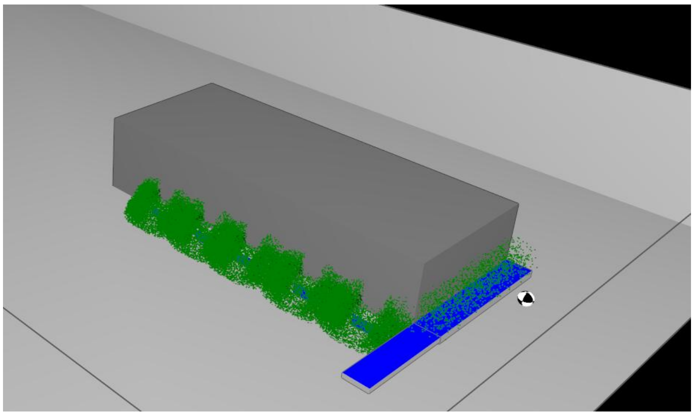

Figure 9 - Sound particles are emitted from the noise relevant parts of this machine

The distribution of sound pressure levels in a room are then calculated by counting the number of particles that cross a little control volume around the receiver.

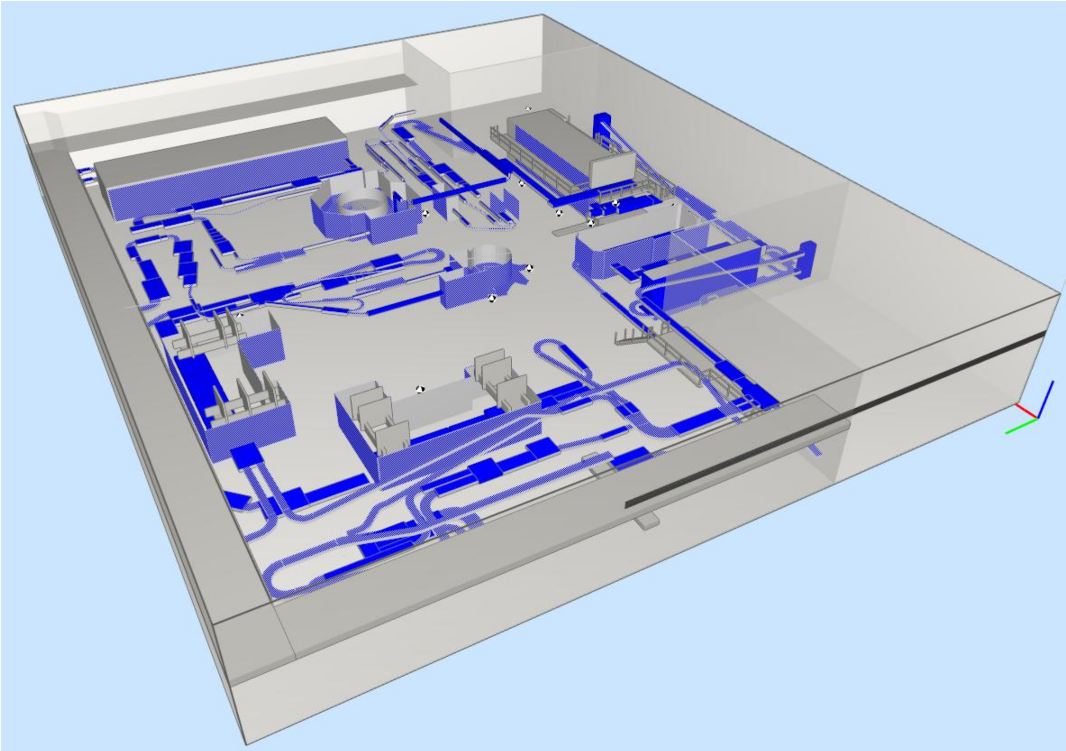

Figure 10 - Model of a bottling plant with a capacity of 50000 bottles/hour

These techniques allow the best possible and optimized approach for all parties involved. In the planning phase where different variants of possible layouts are evaluated the calculation of noise levels at the workplaces is an important part of the ranking and cost-effect evaluation.

Figure 10 shows the model of a bottling plant that was created to support this process. Starting point is a list of emission values to calibrate the different noise relevant machines and technical facilities in the model as it is shown in table 1.

Table 1 – Emission values of all noise relevant installations

1	2	3	4
Workplace/ machine	**Type**	**Emission values**	
		L_{WA} dB(A)	**L_{pA} dB(A)**
Depalletizer	O + M YC2354	102,5	80,5
Depacker	Kentus DP 78/04	101	81
Washing	Rme 2007/400	104	85
:	:	:	:
Filler	Rola 0976	105	85
Labelling	KHS 56H6	103,5	84

These values can be taken from literature or guidelines related to this type of machinery in the first step. In many cases the machine supplier knows the values from previous installations and improves this knowledge with each new case. The sound power levels are generally determined by approximating an envelope surface method according to ISO 3744 (2) and the emission sound pressure level by applying ISO 11204 (3). It is also good practice to include the declared emission levels according to ISO 4871 (4) in the contract of purchase. For machine suppliers delivering complete plants it is the economically best optimized procedure to produce such a computer model of the machines - once generated it can be imported in the future in each new planning case and after adaption to the concrete operating conditions the lowest possible sound pressure levels at the workplaces are known.

Table 2 shows in a simplified form the result of a prediction calculation and an investigation based on the emission values of Table 1.

Table 2 – The calculated noise levels at the workplaces with the plant in operation for three cases

1	2	3	4	5
Workplace/ machine	**Type**	**Levels at workplace (plant operating)**		
		V0 dB(A)	**V1 dB(A)**	**V2 dB(A)**
Depalletizer	O + M YC2354	84	81	81
Depacker	Kentus DP 78/04	86	85	84
Washing	Rme 2007/400	89	88	85
Filler	Rola 0976	90	88	85
Labelling	KHS 56H6	88	85	85

The first variant V0 (column 3) is related to the case that no additional measures are included, the second variant V1 (col. 4) is the result with absorbing measures to reduce reverberation and V2 includes additionally a well defined package of machine related measures.

It is obvious that the nowadays available and straightforward applicable noise prediction techniques will more and more be an integrated part of the plant construction process. This is effectively supported by the noise prediction software organizing the complete plant in a hierarchic structure like the object tree shown in figure 11.

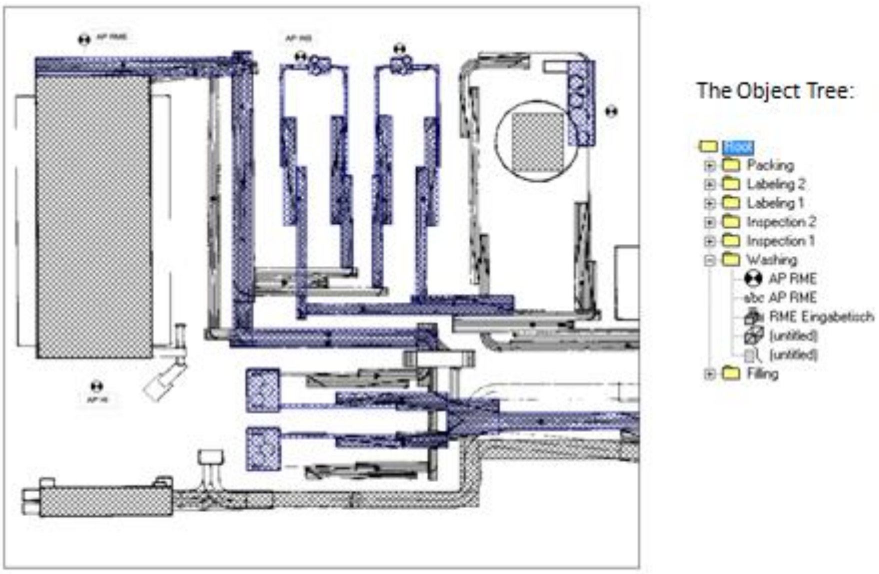

Figure 11 - Modeling a complete plant applying the “Object Tree” to organize the complete machinery

The calculation with the particle model allows to include the effect of additional measures at the machines like the protection screen in front of the washing machine as well as the detailed modeling of absorbing devices like the baffle system at the ceiling shown in Figure 12.

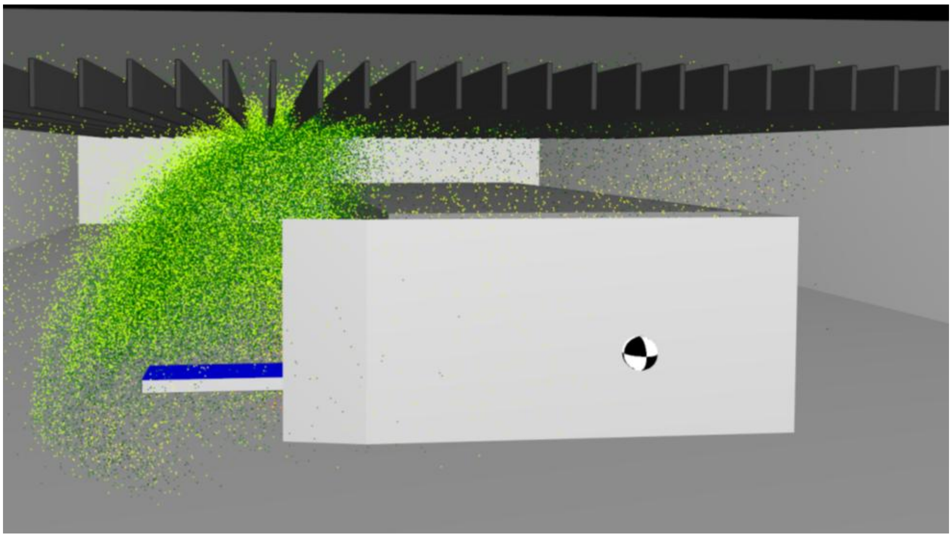

Figure 12 - Including a protecting screen in front of the machine and absorbing baffles at the ceiling

These noise prediction techniques are a powerful link between standardization of noise measurements related to emission levels of single products like machines on one side and the resulting noise levels at the workplaces with all machines operating and with all the influences of the geometry and architectural outfit of the room. It is obvious that the integration of the noise aspect in the IT based construction will be a great step to a better working environment.

REFERENCES

1. CadnaR -(http://www.datakustik.com/en/products/cadnar/)
2. ISO 3744: 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
3. ISO 11204: Acoustics – Noise emitted by machinery and equipment – Measurement of emission sound pressure levels at a work station and other specified positions applying accurate environmental corrections
4. ISO 4871: Acoustics – Declaration and verification of noise emission values of machinery and equipment