The prediction of occupational noise caused by machinery

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ABSTRACT

This is a summarizing short report about new techniques to integrate machines of any complexity as noise sources in prediction calculations. Such machines may radiate differently from different parts of their structure and cannot be simulated by simple point or area sources. Realistic models can be created by using objects like blocks and plates with well-defined acoustic properties like frequency dependent emission, absorption and transmission loss, but it is a problem to "calibrate" such models to reproduce exactly the free-field levels in the vicinity that are taken from measurements and corrected from environmental influence and background noise. The technique to determine the necessary emission of surface parts from these free field levels is shown and the control of the finally reached accuracy is performed by the simulation of a standardized determination of the final radiated sound power level. Newer techniques to implement such models of machines in extended plants with minimum effort are presented.

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1. INTRODUCTION

The prediction of noise levels at workplaces in industrial environments with partially or completely closed rooms and complex machinery is a challenging part of occupational noise control. The machines are complex noise sources and the operator position nearby is often exposed to the near field. Differently to the sound propagation outside many reflections contribute to the finally resulting sound pressure level at receiver positions and therefore the simple geometrical attenuation of 6 dB per doubling of distance must be replaced by the summation of hundreds or even thousands of sound energies propagating along many different paths. The SERT method (Stochastic Energy Ray Tracing) has proven to be well adapted to these requirements and some important aspects shall be described in the following. The examples where developed with Cadna-R /1/.

From an administrative standpoint we can distinguish two aspects. The first is to define limits for the noise levels at work places to prevent the workers from hearing impairment and other negative noise effects. The second aspect is to support the efforts to keep the emission of noise relevant equipment like machinery as low as technically possible. In Europe the machine directive requires to declare the A-weighted emission sound pressure level LpA and - where it exceeds 70 dB(A) additionally the A-weighted sound power level LWA. The strategy is therefore not to set limits for the maximal acceptable emissions but to care for transparency by this declaration system.

With the new possibilities to calculate the sound pressure levels at work places these two aspects can be linked. The declared emission values of machines are not only helpful to rate their acoustic quality but they can be applied as the basis to predict the probable noise exposure at the work places.

2. The support of standards about sound emission measurements of machines

The measurement of sound power levels is organized in the ISO 3740 series - the most important ones that allow the measurement in situ are ISO 3744 /2/ treating the measurement with an enveloping surface method and ISO 3747 /3/ dealing with the comparison method.

The measurement of the emission sound pressure level at a work station is dealt with in the ISO 11200 series - the most important one is ISO 11204 /4/ that can also be applied in situ.

For theoretical reasons the enveloping surface method can only produce correct results when measuring sound pressure levels if the measuring points are distributed on a spherical surface with a radius large compared with the extension of the source. This is not possible in real industrial environments with other technical devices in near distances - therefore smaller radii or other shapes of the enveloping surface like box or cylinder are applied. The angle-error introduced by this approximation is neglected and therefore the sound power levels L_{WA} determined from sound pressure levels deviate positively from those determined from intensity measurements even after applying the correction K_2 according to the standard.

The angle error can be determined by simulation with SERT if the receiver points are distributed on an enveloping surface with the shape under test. A simple test is a point source in the center of a cubic measuring surface - from integration the analytically derived result is a necessary correction of 0.9 dB - this is in agreement with the result obtained. The simulation is performed under free field conditions. Applying a sound power level of 100 dB for the point source as input parameter and calculating the sound pressure levels at all receivers under free field conditions - no reflections included - the sound power level determined from these calculated receiver levels is 100,9 dB.

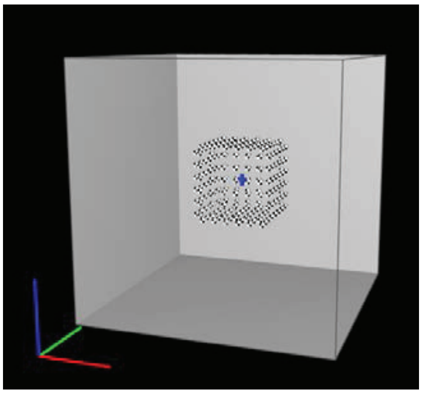

Figure 1 - Cubic arrangement of receivers - difference between L_{WA} of point source and L_{WA} determined is 0.9 dB

These "pure" cases are appropriate to validate the method - more interesting are solutions for the everyday problems arising if such measurements shall be performed in typical industrial environments.

The main problem with such measurements in Situ where emission values shall be checked - e. g. to prove the accordance with contractual assurances - is the determination of environmental corrections. The K_2 correction proposed by ISO 3744 is derived under the assumption of a diffuse sound field - a condition that is very seldom in practical situations. The SERT method has been validated /5/ to reproduce the measured sound propagation on a basis of 122 industrial halls of different shapes and with many different acoustic fittings - the deviations between measured and calculated levels are small enough to apply the method in the described sense.

To determine the environmental correction in such cases the complete situation with the machine under test is modeled and the measurement is replaced by the calculation. Figure 2 shows a typical example, where a machine is located in an edge with reflecting walls in a larger and extended flat room.

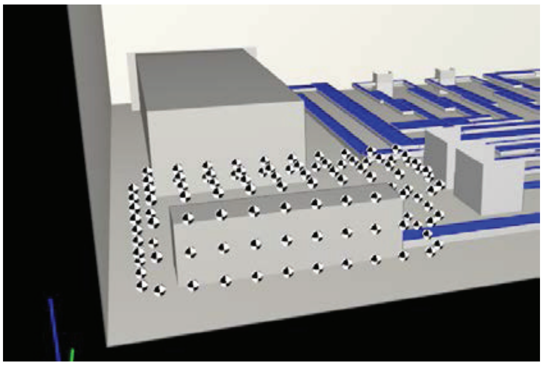

Figure 2 - Simulation of L_{WA}-determination with a box-type enveloping surface

A test value for the sound power level $L_{WA,in}$ is applied with the machine as an input parameter and then a calculation is performed only with this machine as source, but with sufficient long simulation time to get the acoustic influence of all reflections. From the levels calculated with all these receivers an uncorrected value $L_{WA,out}$ is determined following the procedure of ISO 3744 but neglecting an environmental correction. The "true" environmental correction determined by simulation with the existing environment is

$$K_2 = L_{WA,out} - L_{WA,in} \quad (1)$$

Simulations can effectively be applied to supplement measurements and to reduce the time needed for the measurements. The accuracy of the results obtained with these techniques depend on the correct modeling of the machines to get a representative distribution of radiation in different directions. Therefore it is one of the most important tasks to investigate these techniques and to integrate them in the framework of standardization.

3. Techniques to create acoustically correct models of machines

The techniques of modeling should be in line with the techniques of calculating sound propagation. It would be a waste of effort to reproduce parameters that are not used.

From noise prediction outside the techniques to model sources of any complexity with the basic types point-, line- and area-source are well known. These techniques can directly be transferred to the modeling of scenarios indoors.

Machines are often too large relative to the distance of the operator-workplace to model them with one of these basic source types. Therefore techniques must be applied to form groups each of them representing a machine.

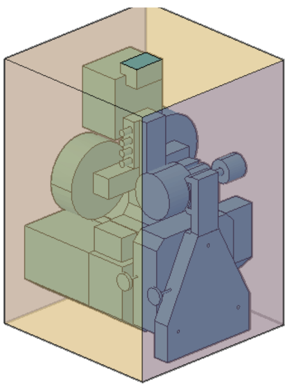

Figure 3 - The reference box enveloping the machine to be applied as machine-model

Many methods can be applied to support such a model with the correct emission values and to "calibrate" it. If the directivity can be neglected and the sound power level is known, this sound power level can be distributed uniformly on the surface of the reference box.

From measurements taken with earlier installations of the same machine type machine manufacturers may know the levels at different positions on the circumference in a given distance.

In such cases it is advantageous to apply these sound pressure levels corrected for background noise and environmental influence instead of the sound power level calculated with them not to lose the information about the directivity of the radiated sound or the different radiation of the radiating surface areas.

The following procedure allows adjusting the emission of these radiating areas so that the calculation related to the semi-free-field with the applied calculation method reproduces the K sound pressure levels known from measurements at these points.

With K measuring points and free-field levels K different radiating areas on the surface of the machine-model are defined and simulated by area sources. Their extension and position should be oriented derived from observation or with some near-field measurements. If more than K radiating areas or sources are found some of them may be grouped to get finally K groups independent from one another. If such separate areas are not found K evenly distributed but separate area sources are located in a way that the receivers are centered in front of them.

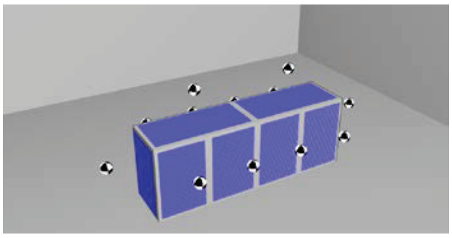

Figure 4: Machine-model with measuring points and radiating areas

Independent of their size and location the same area related sound power level $L''_{W,Test}$ is attached to these K radiating areas. An appropriate test value is the energetic mean value of the K known sound pressure levels L_m

$$L''_{W,Test} = 10 \cdot log\left(\frac{10^{0,1 \cdot L_m}}{K}\right)\ dB \qquad (2)$$

Applying the SERT - or any other intended or agreed - calculation method the partial levels $L_{n,m}$ caused by each of the K radiation areas at each of the K receiver points are determined under semi-free-field conditions. The calculation procedure must ascertain that no reflections at components not being part of the machine or at the room surfaces – beside the floor – influence the results.
These partial levels $L_{n,m}$ form the transmission matrix **M** with the coefficients

$$a_{n,m} = 10^{0,1 \cdot \left(L_{n,m} - L''_{W,Test}\right)} \qquad (3)$$

With vector Y resulting from the measured levels at the measuring points

$$Y_m = 10^{0,1 \cdot L_m} \qquad (4)$$

and the vector X formed by the quested emission values of the radiating areas $L''_{W,n}$

$$X_n = 10^{0,1 \cdot L''_{W,n}} \qquad (5)$$

this vector X can be determined by the vector equation

$$X = M^{-1} \cdot Y \tag{6}$$

where $\mathbf{M}^{-1}$ is the inverse Matrix of **M.**

The emission values $L''_{W,n}$ calculated from (6) are attached to the radiating areas respectively the area sources of the model. The calculation under semi-free-field conditions with this calibrated model may show remaining deviations that are the smaller the better the machine model is appropriate to simulate the real radiation conditions.

Negative components of the vector X resulting from this calculation show that the real radiation conditions are not good enough represented by the machine model – a negative result of (6) would require something like a "sink" of sound energy. The best strategy in such cases is to deactivate the emission of this relevant area-source and - if this is not sufficient to produce the levels with an acceptable accuracy - then to increase the directivity of the adjacent area-sources to restrict their influence on the opposing receiver point.

4. Combined constructions

Even complex machines can be modeled acoustically correct and visually realistic by combining and grouping basic sources, acoustically passive components and radiating components. The reasonable grade of detail depends on the calculation method applied – while with phase related calculation methods and mirror image methods similar to VDI 3760 /6/ calculation effort and - time may increase extremely, purely energetic models like SERT are not very sensitive with respect to the complexity of the model.

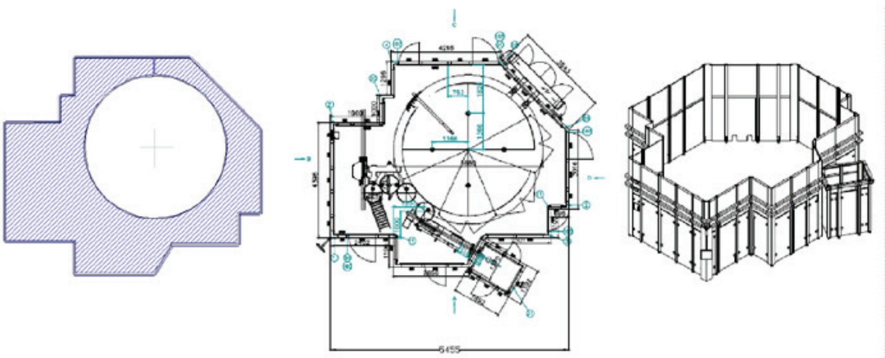

Figure 5: Model of a filling-machine (left) on basis of machine drawings (middle) and perspective views (right)

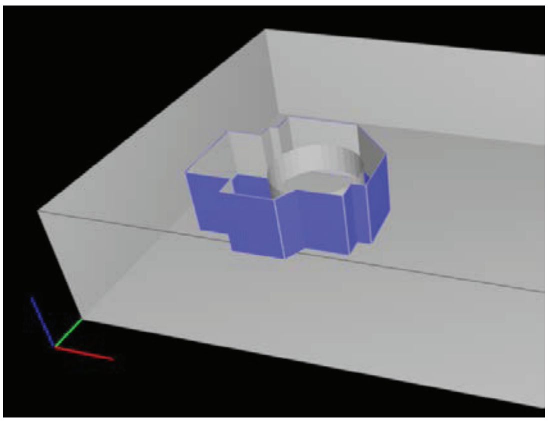

Figure 6: The model of the filling-machine

5. The emission sound pressure level L_{pA} as input parameter

In many cases the information about the distribution, directivity and intensity of radiating areas and sources is not detailed enough to determine the sound pressure level at an operator position in a small distance from the machine by applying the intended or agreed calculation method. At the other side the emission sound pressure level L_{pA} is the sound pressure level caused by the machine under semi-free-field conditions and can therefore be taken as the correct information about the direct sound including one reflection at the floor. This partial level at the operator-workplace must therefore not be calculated or - if it is included in the calculated total levels - must be replaced by the declared value.

This technique to calculate the sound exposure at work places with all the machinery in a room in full operation by using the emission sound pressure level L_{pA} of a machine as an input parameter is well approved in plants with large machines, because this L_{pA} is by far better known from earlier installations and measurements than the sound power level L_{WA}.

Independent from the calculation method applied this technique of including the L_{pA} needs the following steps:

- Calculation of the sound pressure levels $L^*_{AP,n}$ at all workplaces applying the intended calculation method

- Calculation of the sound pressure level $L^*_{pA,n}$ at all workplaces under semi-free-field conditions (only the machine under test is operating, no reflections but from the floor) applying again the intended calculation method for each machine with an operator position separately

- Finally determination of the wanted sound pressure level $L_{AP,n}$ for each machine with equation

$$L_{Ap,n} = 10 \cdot log\left(10^{0,1 \cdot L^*_{Ap,n}} - 10^{0,1 \cdot L^*_{pA,n}} + 10^{0,1 \cdot L_{pA,n}}\right) \qquad (7)$$

This is an exchange of the semi-free-field level of each machine at the own workplace calculated with the intended calculation method against the emission sound pressure level L_{pA}.

These techniques help to create models of production plants with operator positions nearby and to use the declared sound emission values L_{WA} and L_{pA} as input parameters. Existing guidelines with databases of emission values can be extended to include examples of such models. Modeling and simulation develops to be a powerful twin of the measuring techniques according to the ISO 3740 and ISO 11200 series.

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