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PREDICTION OF NOISE IMMISSION USING A ROOM ACOUSTIC CALCULATION MODEL

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ABSTRACT
For the description of the noise situation in a working room it may be useful to establish a noise map showing the noise level distribution in the room. A computer programme for the calculation of room acoustic parameters and noise maps in working rooms is presented. It is shown that the calculation can give reliable information on the noise immission and can be used for many applications. Especially the visualisation of the noise situation and of the achievable noise attenuation turned out to be of great help for the field.

1 - INTRODUCTION
In order to assess noise effects at the workplace or to recognize hazardous noise exposure an exact determination of the noise immission is required for all relevant workplaces. For the description of the noise situation in a working room it may be useful to establish a noise map showing the noise level distribution in this room. This noise map contains all necessary information which can be the basis to decide on noise control measures or necessary audiometric programmes.
Since a couple of years, BIA has been using a computer programme for the calculation of room acoustic parameters and noise maps in working rooms. This programme turned out to be a highly useful instrument for the identification of workplaces with high noise exposure, for the planning of noise control measures and for setting up a long-term noise control programme.
Experiences with the application of this computer programme for noise prediction at workplaces and with establishing noise maps for the work rooms are presented.

2 - USE OF NOISE MAPS
Usually, the noise immission at a workplace is described by the A-weighted equivalent sound pressure level L_{Aeq} for a typical working day normalized to 8 hours. If the resulting noise rating level L_r exceeds a certain limit, different engineering and administrative control measures are required. In Germany, for instance, at a level of 85 dB(A) the workplace has to be declared as noise area and all workers must have their hearing checked in periodic medical examinations. At a level of 90 dB(A) this area must be labelled as a noise area and a long-term noise control programme has to be set up.
In order to describe the noise situation in a working room it may be useful to establish a noise map. This can be realized by means of numerous noise immission measurements, for instance, in a dot matrix set out over the entire work room. Another possibility is the compute calculation based on the noise emission values of the single noise sources and the sound propagation curve of the specific room. Such a calculated noise map is shown in figure 1, where the different sound levels are indicated by lines of equal sound pressure level. Noise maps can also be presented as coloured maps, where the sound levels are classified and distinguished by the colour. Thus, areas of high sound pressure level can be represented in dark red, which changes into bright red, yellow and then green as the sound pressure level decreases.
The determination of such a noise map is useful for

- documentation of numerous noise immission data

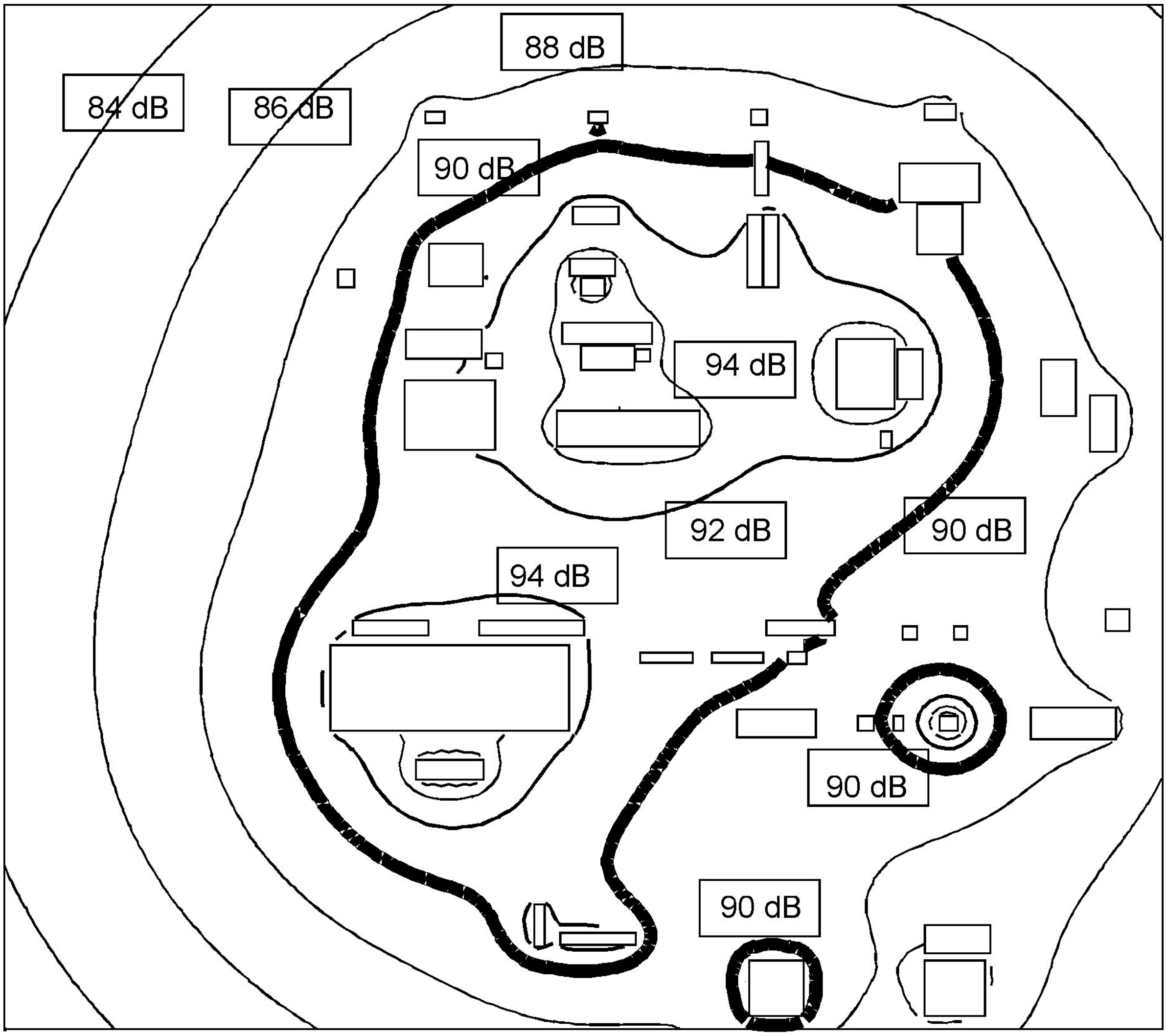

Figure 1: Example of a calculated noise map for a workroom.

- visualisation of the noise situation, for instance, as information for the workers and other involved parties
- identification of workplaces with high noise exposure
- identification and limitation of noise areas, where noise immission levels exceed the relevant noise limits (85/90 dB(A))
- decision on necessary medical examinations of the workerś hearing and selection of personal hearing protectors.

If the noise map is calculated by means of a computer programme, there are some additional applications:

- identification of the dominant noise sources, because the sound power levels of all relevant machines must be known
- determination of noise maps for different working conditions of the machines
- prediction of noise reduction by noise control measures at different machines, for instance, enclosures
- prediction of noise reduction achievable by room acoustic measures, for instance, sound absorbing ceilings
- prediction of the effect of the installation of additional machines or of the exchange of machines in a working room

- prediction of the noise exposure in new working rooms and identification of high noise areas
- visualisation of the effects of noise control measures which is very helpful for the motivation of companies.

Because of all these applications the computer programme for noise prediction and calculation of noise maps turned out to be a highly successful instrument.

3 - CALCULATION OF NOISE MAPS ACCORDING TO VDI 3760

The different calculation methods for noise prediction in workrooms are given in ISO/TR 11690-3 [1]. In Germany we agreed upon a harmonized calculation model specified in VDI-guideline 3760 [2]. The corresponding software is meanwhile offered by several companies.
According to VDI 3760 the first step consists in calculating the propagation with the distance from an omnidirectional point source for a defined sound transmission path. The resulting spatial sound decay curve is calculated using the image sound source method referred to by Jovicic in 1986. The calculation model can be described as follows:

- calculation for a room of a box-like shape
- each limiting surface is characterized by a single absorption coefficient
- mean fitting density for the total room
- specular sound reflections by six limiting surfaces
- sound attenuation due to air absorption and fitting effect
- calculation of sound distribution for octave bands and for a standardized reference spectrum (A-weighted pink noise)

This model then requires but a mean level of detail of input parameters which makes practical use relatively easy. A number of studies conducted in Germany showed that methods calling for a more complex description of the room do not necessarily provide better predictive results for usual working rooms. This is supposed to be mainly due to the uncertainty of the input parameters (e.g. the sound absorption of the limiting surfaces).
For the calculation of a noise map the sound power levels (L_{WA}) of all relevant noise sources/machines must be known. This will require appropriate noise measurements or information from the manufacturers of the machines. Account can also be taken of the directivity of noise radiation and the emission sound pressure level (L_{pA}) of single noise sources. The calculation is done in the following way:

- the sound propagation in the working room is calculated on the basis of one spatial sound decay curve which may be a calculated or a measured one
- a dot matrix is set over the entire workroom
- the sound pressure level caused by the individual machine is calculated for each dot
- the sound level distribution within the matrix is determined by adding the different sound pressure levels

In most cases the effort to calculate a noise map is relative low in comparison to the effort which would be necessary to establish a noise map by means of measurements all over the workroom. The needed sound power levels of the machines can usually be determined by measurements at some few points in the vicinity of the machines and estimation of an average sound pressure level for a measurement surface. Some experience is requested for the determination of the environmental correction (K_2) and the back ground noise correction (K_1). Often, there are several machines of the same type and noise emission in the workroom and the noise measurement is only necessary for one of the machines. Sometimes the sound power of machines can be estimated by comparison with other machines of the same size. For new machines the sound power level may be taken from the declaration of the manufacturer or the importer. When the noise map shall be calculated for an existing workroom it is essential to measure the noise exposure at different workplaces in order to get some reference values. After the first calculation of the noise level distribution it should be checked if there is good agreement between the calculated sound pressure levels and the reference values. A better approximation to the reference values can be realized by the input of corrected sound power levels or directivity corrections. In most cases it is sufficient to modify the sound power levels of single machines and to make a second calculation of the noise map.

4 - UNCERTAINTY OF NOISE PREDICTION

The calculated sound pressure levels may differ from the real noise exposure (reference sound pressure levels) because of uncertainties in the determination of sound power levels or the directivity of noise radiation of single noise sources. Additional deviations may occur because the calculated or measured sound decay curve differs from the real sound propagation in certain areas of the room or in a large distance to the noise sources. This may be caused, for instance, by areas of different sound absorption or by a different fitting density in the room.
In spite of these uncertainties the noise calculation, in most cases, will lead to a rather good approximation of the real noise situation, if the responsible engineer has a good basic knowledge of noise measurements at machines and some experience in the use of the calculation model. The quality of noise prediction shall be illustrated by three accidentally chosen examples of workrooms, described in table 1.

	kind of use and size of the room		number of machines	number of workers
A	laundry	1450 m^2	22	55
B	assembly of electrical tools	800 m^2	30	25
C	carton production	3350 m^2	26	60

Table 1: Description of working rooms for the calculation of noise maps.

Figure 2 presents the calculated sound pressure levels in relation to the corresponding reference values obtained by noise measurements at these positions in the room.
For the interpretation of these results it should be known that the noise levels were calculated with a rather low effort because the noise maps were only used for the visualisation of the effects of room acoustic measures and an exact description of the given noise situation was not needed.
The procedure for the calculation of the noise immission can be described as follows:

- determination of sound power levels with running neighbouring machines by sound pressure measurement at a distance of about 0,2 m from the surfaces
- rough estimation of the corrections for background noise (K_1) and environment (K_2)
- calculation without correction of the directivity of the noise sources
- for the workrooms A and B the calculation was repeated one time with small corrections of single sound power levels
- for the work room C only one calculation was performed and the sound power levels were determined by measurement at only two machines of different types (stripper and assembler)

In spite of these rather bad conditions for the calculation, figure 2 shows a rather good agreement of calculation and measurement. The mean deviation between the calculated level L_{calc} and the measured level L_{meas} in the rooms A and B is quite near to 0 dB because the sound immission for both rooms was calculated a second time with respect to the reference values. For the room C the mean deviation is about -1 dB which can be explained by the simplified determination of sound power levels and only one calculation. For all the rooms the maximal deviations from the mean deviation are not more than 2 or 3 dB and 50 % of all deviations differ by not more than 1 dB from the mean deviation. Other studies [3] show that the uncertainty of noise prediction is less than 2 dB in a distance up to 16 m, whereas the uncertainty may increase for the far region.
If necessary, the approximation of calculation and measurement for all rooms can be improved by one or more following calculations each with adapted sound power levels of single machines. The software allows for a more precise calculation taking into account the directivity of noise radiation and the emission sound pressure levels of single machines. Nevertheless, there may remain some deviations, especially at workplaces near to the machines surfaces. Therefore, if the calculated sound pressure levels are quite near to the established noise limits, an additional noise exposure measurement is recommended at these workplaces and the final decision should be based on these measuring results.

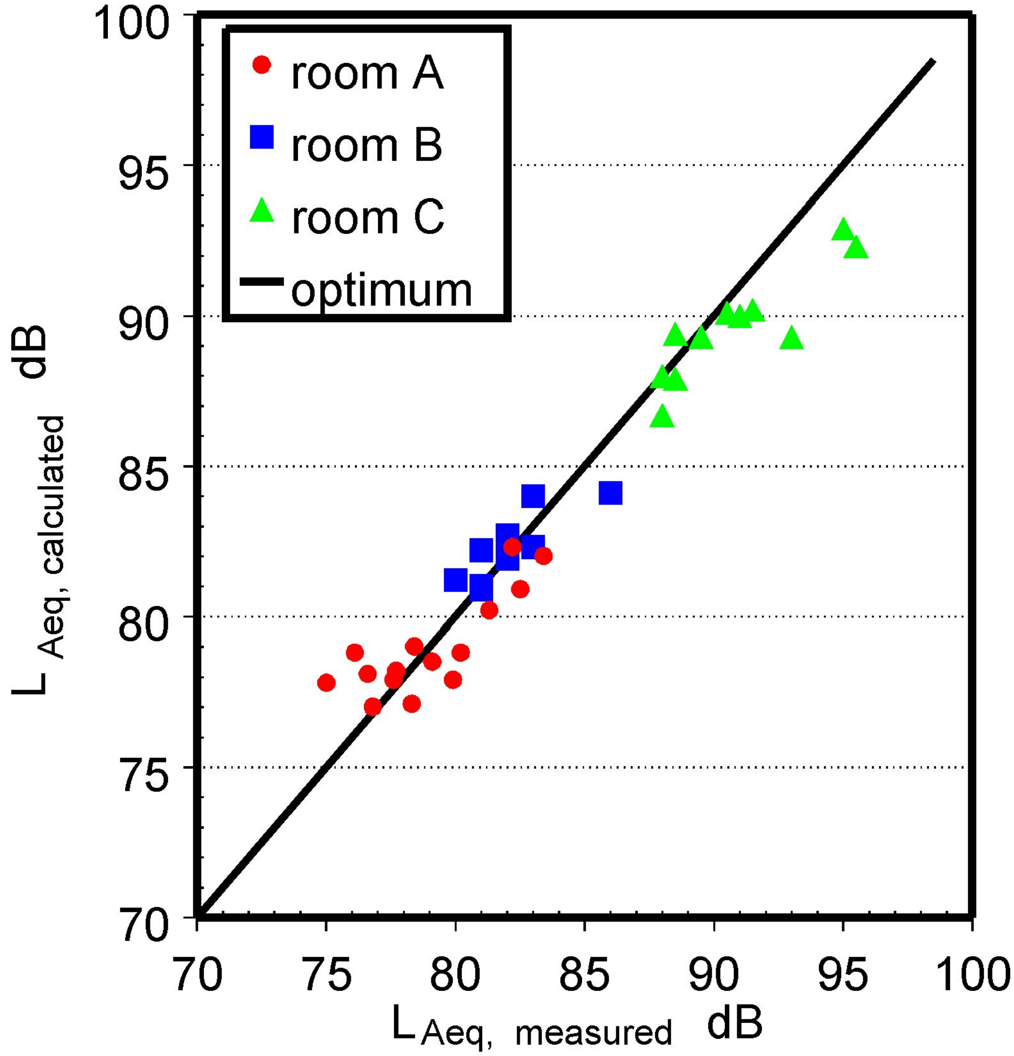

Figure 2: Comparison of calculated sound pressure levels L $_{calc}$ and measured values L_{meas}.

5 - CONCLUSIONS

Noise maps calculated according to the German VDI-guideline 3760 can give a reliable information on the sound level distribution in a working room and can thus be used for the description of the noise situation in existing rooms or for the design of new work rooms. By means of these noise maps areas of possible hazardous noise exposure can be identified and necessary noise control measures can be initiated. Because the effects of noise damping measures at individual machines and of room acoustic improvements can be calculated and visualized, the calculation programme can be used successfully for the planning of noise control measures and for setting up a long-term noise control programme. Especially the visualisation of the noise situation and of achievable noise attenuation turned out to be an important tool for the information and motivation of companies.

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