inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 7.6

PREDICTING INTERIOR FACTORY NOISE WITH RAY-TRACING MODELLING. AN EXAMPLE OF A HARDENING PLANT

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Keywords:
RAY-TRACING, INTERIOR FACTORY NOISE

ABSTRACT
Prediction of the noise levels in a factory in an early stage when it still is on the drawing-table would improve the possibilities to evaluate different solutions to reduce the noise and to find the optimum solution. Doing these calculations by hand gives very approximate results, but the big improvement in computer speed has made it interesting to use computers to predict the sound level. This project has been done on a planned hardening plant. The company has set up high demands on noise levels in the plant and is therefore interested in taking actions at the construction stage to reduce the in-plant noise. As a part of this work the plant has been computer modelled and sound level maps have been predicted over the plant. The objectives of the project have been to optimise the use of absorption material, to find a model for a distributed source (machines and steel plates) and to predict the sound reduction that can be achieved. The noise radiation from the machines in the model is based on measurements of the machines in the existing steel hardening line. As the machines are large and the computer model uses monopoles the machines have been modelled as a number of monopoles. The sound level predictions are done in octave-band from 125 Hz to 4 kHz. The computer program used for the prediction is CATT that uses the ray-tracing method to predict the sound pressure level.

1 - INTRODUCTION
In the work with noise control in factories one method to evaluate different solutions to reduce the noise is the well-known ray-tracing. The method allows testing a number of different solutions and finding the best one. Prediction of the noise levels in an early stage when the factory has not left the drawing-table would make it possible to:

- Evaluate different acoustic treatments and source solutions against each other in a cost-effective way and also lower the cost for the necessary modifications of machines and halls.
- Put more specific demands on the machine manufactures. The most effective way to reduce noise is to make sure that it never is produced in the first place.

In this study a steel-hardening plant have been modelled and one objective was to optimise the use of absorption material and to predict the sound reduction that could be achieved. The second objective was to evaluate the CPU time for modelling acoustic problems of this character.
The sound level predictions are done in octave-bands from 125Hz to 4kHz. The computer program used for the predictions is CATT©. Distributed sources where used to model the noise sources.

2 - THE MODEL
The factory modelled is a steel hardening plant and the sound pressure data used in the model are based on measurements under production. Only the hardening line and the following transportation of the plates are modelled. The factory modelled is 260m long, 54 m wide and 12 m high (figure 1). The machines modelled are a hardening furnace (L $\times$W $\times$H 71 $\times$4.7 $\times$2.5 m), a quenching system (L $\times$W

×H 13 ×5.3 ×2.5 m) and a roller conveyor (L ×W ×H 85 ×3.5 ×1 m). Two steel plates (L ×W ×H 12 ×2.5 ×0.03 m) were modelled on the roller conveyor. The first plate was put next to the cooling machine and the second plate in the other end of the conveyor. The model is built up of 37 surfaces. Absorption coefficients and diffusion coefficients of different surfaces are given in table 1 and table 2, respectively.
The machines and plates have been modelled with a number of distributed sources as the real sources are big and the program uses point sources. The sources have been modelled with a number of point sources located at their outer surface. The steel plates have been modelled with 8 point sources each and the quenching system has been modelled with 24 point sources. The hardening furnace and the roller conveyor are assumed to have at least 10 to 15 dB lower noise levels than the steel plates (100 dBA and 85 dBA, respectively) and the quenching system (80 to 100 dBA). The point sources used have the directivity of a half sphere.

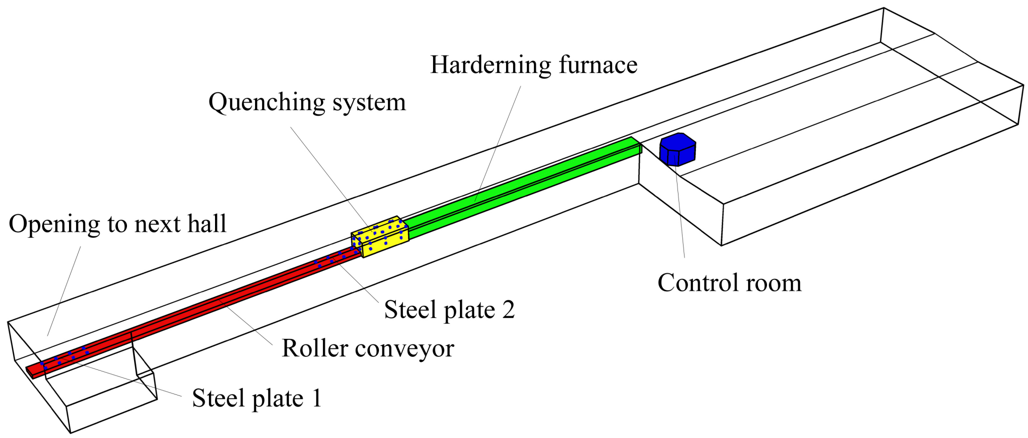

Figure 1: Plan of the model including the two steel plates modelled.

a)	Octave-band					
	125 Hz	250 Hz	500 Hz	1 kHz	2kHz	4 kHz
Ceiling	0.72	0.95	0.93	0.80	0.63	0.52
Walls	0.40	0.20	0.10	0.05	0.05	0.05
Floor	0.01	0.01	0.02	0.02	0.02	0.02
Machines	0.04	0.02	0.02	0.02	0.02	0.02
Conveyor	0.01	0.01	0.02	0.02	0.03	0.04
Steel plates	0.01	0.01	0.01	0.01	0.01	0.01

Table 1: Octave-band absorption coefficients.

b)	Octave-band					
	125 Hz	250 Hz	500 Hz	1 kHz	2kHz	4 kHz
Ceiling	15	30	50	70	80	80
Walls	10	10	20	20	30	40
Floor	10	10	10	20	20	20
Machines	10	15	15	20	20	30
Conveyor	20	40	60	80	80	80
Steel plates	10	10	10	10	10	10

Table 2: Diffusion coefficients used for the different surfaces in the model.

3 - CALCULATION TIME

The analyses have been run on a Pentium III 550MHz XEON PC. Even on this rather powerful PC the calculation time for all octave bands is long, 63 hours, with the number of rays and truncation time recommended by the software. On a slower computer the calculation time will be even higher, see table 3 where estimated calculation times for 2 computers and 4 different hall sizes are compared. This limits the usefulness for this method to evaluate different solutions against each other at big, complex halls with many sources.

Reducing the number of sources could be one solution to reduce the calculation time but would at the same time give a less accurate model of the real factory. The calculation time is directly proportional to the number of sources.
A better way to reduce the calculation time is to reduce the number of rays. For this model it is possible to reduce the number of rays with a factor of 8 from that suggested by software without getting bigger differences than 1 dB. This would reduce the calculation time with a factor of 8.

Hall size (L ×W ×H)	Number of rays	Truncation time	Estimated calculation time 1	Estimated calculation time 2
520 ×108 ×24 m	3788957	4655.3 ms	225h	536h
260 ×54 ×12 m	1044374	2327.7 ms	63h	150h
130 ×27 ×6 m	313216	1163.9 ms	19h 30m	46h
65 ×13.5 ×3 m	107920	581.9 ms	11h 30m	26h30m

Table 3: Estimated calculation time as function of the hall size; number of rays and truncation time given by auto setting in CATT; estimated calculation time 1 is for a Pentium III 550MHz XEON computer and estimated calculation time 2 is for a Pentium II 233 MHz computer.

4 - PREDICTIONS

The sound pressure distribution for the initial version of the hall is shown in figure 2a. Different solutions with shields and absorption material have been tried in order to reduce the noise levels. The major interest has been focused around the noise level next to the control room and the end of the roller conveyor (opening in to next hall). Production and other limitations have been considered and limited the number of possible noise reducing measures. The final result is shown in figure 2b, where the wall closest to the quenching system has been covered with highly absorbing material and the other side has been shielded off. Unfortunately it has not been possible to build in the roller conveyor.

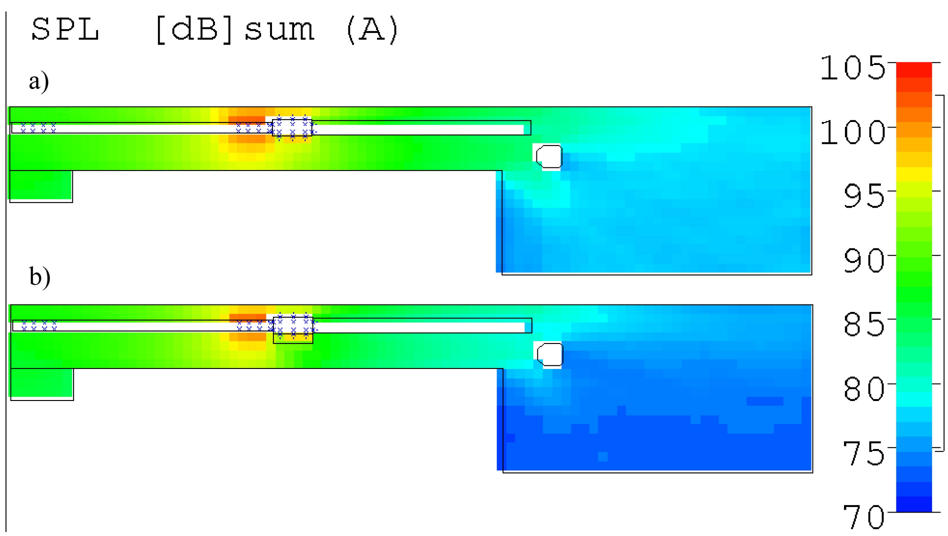

Figure 2: (a) Sound pressure distribution in the initial version of the hall; (b) Sound pressure distribution with the final sound reduction solution (shield and extra absorbent material).

5 - RESULTS

Hodgson [1] has shown with experimental validation that the ray-tracing method can give results within 2 dBA if the absorption and diffusion properties can be correctly estimated. No validation of the results presented here against measured sound levels has been done as the factory still is under construction.
From the analyses a sound reduction of 3-5 dBA in the important area around the control room have been achieved. The sound pressure level next to the opening to next hall has not been lowered as the sound in that area is mainly from the steel plate next to the opening.

6 - CONCLUSIONS

In order to be able to practically use ray-tracing as an engineering tool to find the best sound reduction solution in big halls the calculation time must be kept to a minimum. Therefore following points are of major interest:

- Try to keep the model as simple as possible.
- Use a bigger receiver size during the evaluation calculations.
- Reduce the number of rays. For this model it has been shown that the number of rays can be reduced with a factor of at least 8 with out jeopardising the result.

When the best solution has been found a calculation with higher number of rays, small receiver size and for all octave-bands where ray-tracing is suitable should be run to get a better prediction of the sound pressure distribution.

REFERENCES

1. **M. Hodgson**, Ray-tracing prediction of noise levels in a nuclear power-generating station, *Applied Acoustics*, Vol. 52 (1), pp. 19-29, 1997