A ROOM ACOUSTICAL COMPUTER MODEL FOR INDUSTRIAL ENVIRONMENTS - THE MODEL AND ITS VERIFICATION

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INTRODUCTION

This paper presents an extension to the traditional room acoustic modelling methods allowing computer modelling of huge machinery in industrial spaces. The program in question is Odeon 3.0 Industrial and Odeon 3.0 Combined which allows the modelling of point sources, surface sources and line sources. Combining these three source types it is possible to model huge machinery in an easy and visually clear way.

Traditionally room acoustic simulations have been aimed at auditorium acoustics. The aim of the simulations has been to model the room acoustic measuring setup consisting of an omni-directional sound source and a microphone. This allows the comparison of simulated results with the ones measured in real rooms. However when simulating the acoustic environment in industrial rooms, the sound sources are often far from being point like, as they can be distributed over a large space in the room and may indeed contribute surfaces to the room. Examples of such sources could be ventilation tubes or the surfaces of two turbines as presented in this paper.

CALCULATION PRINCIPLES

The basic principles applied in the ODEON program are those of geometrical acoustics namely ray tracing and Image source modelling.

Point sources. For point sources the response at a given receiver point is calculated using a hybrid calculation method combining the Image Source Method (ISM) for low order reflections (typical up to the third order) with a special Ray Tracing Method (RTM) for the late part of the response. The advantage of the ISM is the ability to handle the reflection paths as unique, whereas the same reflection path can be detected several times using ray tracing (shotgun effect). However for late reflections the ISM where reflections are handled as purely specular becomes less correct due to increasing diffraction and scattering. At this point the RTM allowing the inclusion of scattering is introduced. A directivity pattern can be applied to point sources making it relevant for modelling sources with limited size and a directivity pattern. The hybrid method used for point source modelling has been described in [1,2,3].

Line sources and surface sources. For huge and geometrical complex sources the ISM is not adequate as the sound sources are far from being point like, so rather than saying that surface and line source radiates specularly one might as well assume some kind of diffuse/scattered radiation. As a consequence ODEON uses the RTM applied for high order reflections radiated from point sources. When radiating sound from surface and line sources a number of secondary sources are distributed randomly on the ‘surface’ of the source. Each secondary source radiates a contribution to the receiving point if visible and emits a ray which is traced around the room.

The Ray Tracing method in ODEON. One of the traditional ray tracing methods is the cone tracing method where a detection radius is applied to each ray. This radius grows as the ray travels through the air, as would the wave front and each time a receiver is within the detection radius of a ray, the ray contributes a reflection to the receiver, one may say - the ray is the message. Scattering is applied in the ray tracing algorithms by making the reflected directions more or less random, typically depending on the reflecting structure.

In ODEON the rays are not used directly to model the wave, rather to detect the radiation properties of the room on may say the room is the message. A number of rays are traced around the room, each time a ray is reflected by a wall, a secondary source is created at the point of reflection. The secondary source will have a certain strength due to absorption and distance travelled and it will have a certain delay relative to the primary source. A directivity due to Lamberts law is assigned to each secondary source. Lamberts law is taken from the optics and states that radiation from a surface is proportional to the projection of the surface as seen from the receiver.

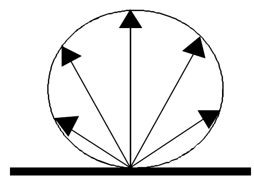

Figure 1, directivity of secondary source in Odeon. The directivity is $\cos 2\varphi$, *corresponding to the projected area of the surfaces, as seen from a receiving point.*

The reflected directions of the rays are calculated as a weighting between the specular direction and a random direction, using a user entered scattering coefficient. So assigning a scattering coefficient of 0.5 to a surface, the reflected direction is calculated as a weighted average between the specular direction calculated due to Snells law and a random direction. The random direc-tion is weighted due to the to an angular distribution function $Sin 2\varphi$, due to Lamberts law.

Collecting reflections. Having traced rays around in the room, a number of secondary sources have been located on the surfaces of the room, each with it own orientation, delay and strength. At this point reflections from the sources can be collected at a receiving point, each source contributing a reflection to the receiver if it is visible from the given receiver position. The visibility is checked by tracing the

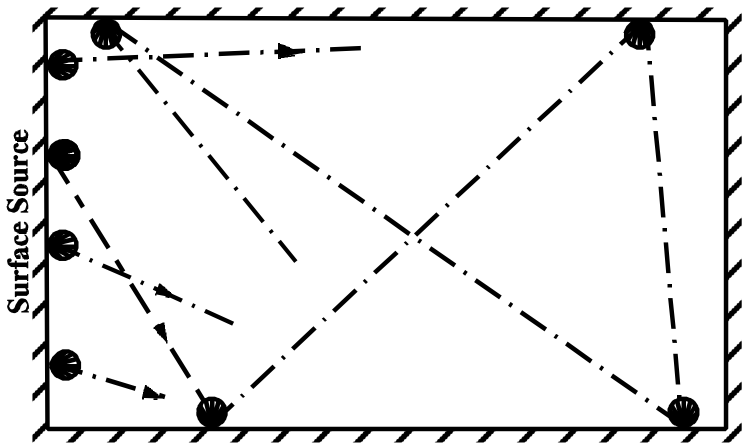

Figure 2, Surface source radiating four rays, of which four reflections are shown for the first ray.

path from the receiver to the secondary source using ray tracing.

Compared to the ordinary cone tracing one of the main advantages in tracing down the radiation patterns of the room is that rays does not necessary need to come close to the receiver to contribute reflections, if just a reasonable number of reflection points are visible from the receiver, reliable results can be obtained. As a consequence good results can be obtained with substantially fewer rays than from ordinary ray tracing (typically 1000 rays per source are used to obtain reliable results).

VALIDATION

The test case. To evaluate the validity of the calculation principles used for huge sound sources in ODEON, calculations were carried out on the third and fourth block in the turbine hall at Studstrupværket, a power plant in Jutland, Denmark. Being a turbine hall the room is a fine test case for the simulation of huge sound sources. The room is also one of the cases that often causes troubles for room acoustics calculation prog-rams, a rather simple geometry with an uneven distribution of the absorp-tion. Apart from being a good test case the room was chosen because data for radiated power was available due to an earlier noise control project dated 1991 [6]. In this earlier project noise radiated from the two turbines was measured using the intensity method, before and after some noisy ball bearings were attenuated by enclosures.

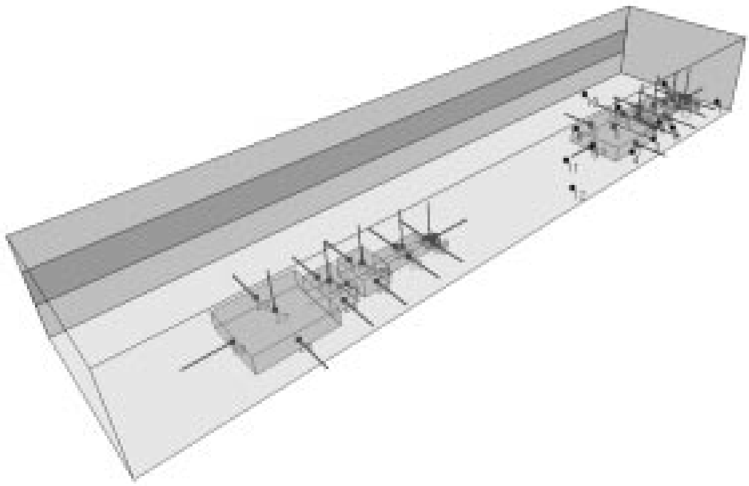

Figure 3, CAD model of turbine hall, containing two turbines. The turbines are modelled as surfaces radiating power, ball bearings are modelled as point sources. Twelve measuring points can be spotted in the rear of the hall.

The geometry. The room were modelled from 54 - 60 surfaces of which 8 are boundary surfaces and the rest of the surfaces make up the two turbines. Small details like beams and small machinery were neglected.

Sound Sources. Sound power data were known for the octave bands 125 to 8000 Hz in terms of radiated power from the following turbine parts (the two turbines being identical):

- Commutator bridge.
- Generator.
- Ball bearing 1(before and after modifications) .
- Low pressure turbine ‘South’.
- Ball bearing 2(before and after modifications).
- Low pressure turbine ‘North’.
- Middle and high pressure turbine.

The radiated sound power from the ball bearings have two values, one before casings were build and another after casings were build around the ball bearings, while the radiation from the rest of the machinery stayed the same. The modification when introducing the casings around the ball bearings made some changes to the geometry which may have some influence in the near field.

Material properties. The material properties used for the calculations were based on data provided by the manufacturer of the absorption materials and estimated values; the different materials were:

- Smooth unpainted concrete.
- Clinker concrete, no surface finish 800 kg /m^3.
- 0.9 mm Steel plate with damped cavity.
- 2 - 3 mm Steel plate with damped cavity.
- 30 mm rockphon direct on concrete, painted.
- Double glazing, 2 - 3 mm glass, 10 mm gap.

The reverberation time for the room were not available, so material properties were not fitted in order to fit best against the reverberation.

The measuring points. The receivers were distributed at 12 positions around one of the turbines in distances of 0.7 - 20 metres from the nearest sound source. Thus there are measuring points both in the near field and in the reverberant field.

The simulations. Simulations were carried out for the two cases the one where ball bearings were undamped and the other where casings were build around the ball bearings. In both cases calculations were carried out modelling the surfaces of the turbines as surface sources while modelling the ball bearings as point sources. For comparison with more traditional modelling approaches, calculations were also carried out substituting the turbines with point sources (one for each of the main part of the turbines). In the latter case calculations were also carried out modelling the sound radiated from the ball bearings by modelling these sources as surfaces source (the casings surrounding the ball bearings).

The results of the first series of simulations with undamped ball bearings are displayed in figure 4. The measured levels range from 81 to 96 dB(A). The maximum deviation between the measured levels and the levels calculated using surface and point sources is 1.6 dB(A) and the average deviation is 0.83 dB (A). The results obtained using point sources only show a maximum deviation of 4.2 dB(A) and the average deviation is 2 dB(A), so results obtained using the combination of point and surface sources are clearly better.

The results of the second series of simulations with damped ball bearings are displayed in figure 5. The measured levels range from 78.5 to 87 dB(A). The maximum deviation between the measured levels and the levels simulated using surface and point sources are 3 dB(A) at a distance of 0.7 metre from the turbines and the average deviation is 0.9 dB(A). When replacing the ball bearings (point sources) with casings radiating sound (surface sources) the maximum deviation is 1.7 dB (A) and the average deviation is 0.7 dB(A). The results obtained using point sources only show a maximum deviation of 4 dB(A) and an average deviation of 1.6 dB(A), so again we se that the best results are obtained modelling the source as surfaces radiating sound.

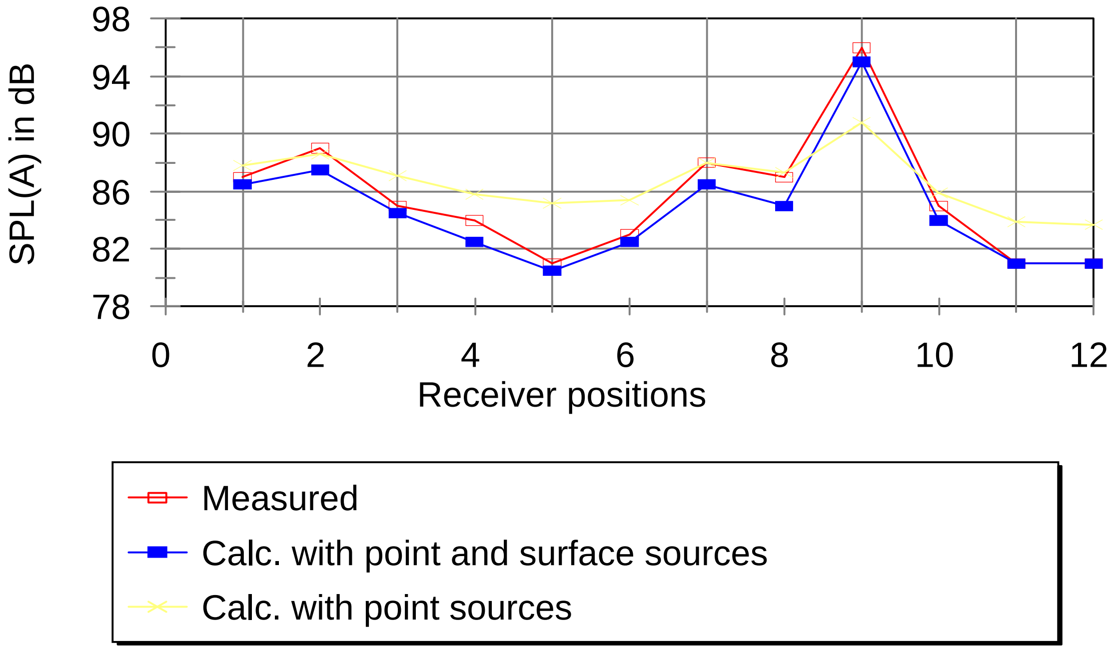

Figure 4, noise levels in turbine hall at 12 receiver points. Calculations were carried out modelling the sound sources as 4 point sources and 46 surface sources. For comparison calculations were made using 12 point sources substituting the turbines and their surfaces.

CONCLUSION

A room acoustical computer model has been extended, allowing the modelling of complex sound sources. It has been shown that it is possible to predict sound pressure levels within 1.5 dB with an average deviation below 1 dB.

Taking into account the inaccuracies in the measurement of SPL(A) itself at approx. 1 dB, the inaccuracies in absorption data and the inaccuracies in radiated sound power this is very fine. There is a tendency that estimates are lower than the measured values, this properly indicates that absorption values used in the simulation are too high.

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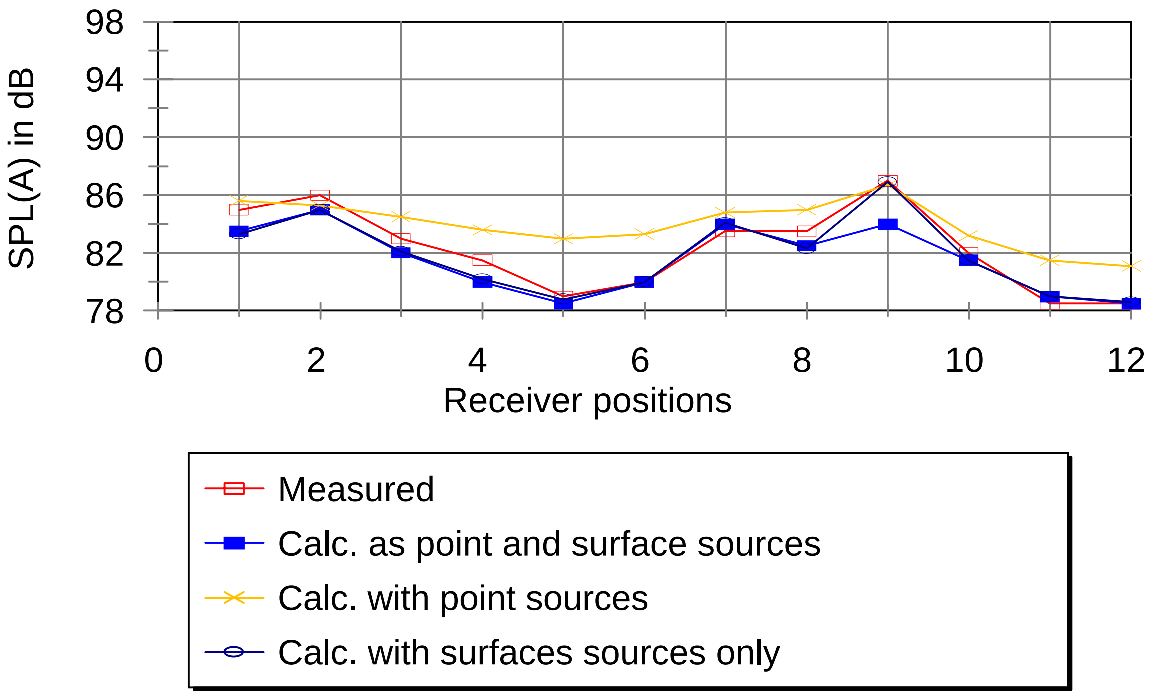

Figure 5, noise levels in turbine hall at 12 receiver points when noisy ball bearings has been insulated in casings. Calculations were carried out modelling the sound sources as 4 point sources and 46 surface sources. Two extra sets of calculations were carried out for comparison, one set where 12 point sources substituted the turbines and their surfaces and another set where the four ball bearings were substituted by 3 surface sources each.

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