ON SOUND POWER MEASUREMENT OF THE ENGINE IN ANECHOIC ROOM
WITH IMPERFECTIONS

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ABSTRACT
Engine noise is one of the most critical noises in urban noises. NVH improvement is essential in order to fulfill various noise emission regulations such as ISO 362. Reducing this noise it has been a necessity for engine developers. Measurement plays an important role beside the simulations to improve the NVH behavior, because the engine is a rather complicated mechanical system with many components. ISO 3745 is an ideal method for sound power measurement for internal combustion engines since it provides a fast measurement through many different engine speeds. However room as well as the measurement method, should comply with this standard.

Because of the size and installation situation for a running engine there is limited space for measurement; and it is difficult to reach standards requirements especially for such a directive sound source. The difficulty to meet these requirements is also applied to Scania's anechoic room. Here engine noise characteristics and the uncertainties in sound power measurement have been discussed based on both measurement and simulation. Recommendation has been made to decrease the uncertainty of sound power measurement.

Keyword: Sound power measurement, IC Engine, Anechoic room

1. INTRODUCTION
There are different noise sources in engines, categorized into three major groups [2]:
- Engine surface (surface noise) vibrations
- Pulsation (aerodynamic noise) generated by intake, exhaust and cooling systems
- Transmission of the vibrations by the engine mounts to the chassis foundation (structure-borne sound)

In the case of Pass-By-Noise, the engine surface noise plays the biggest role, and this is the subject of this study.

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Sound power is a convenient descriptor of noise emissions; because it is not depending on the distance from the source and the surrounding environment. A number of standards for sound power measurement exist, requiring different methods, tools and environments. A fast method of sound power measurement with fixed location of microphones is the first choice in engine development; which the sound power level is measured for different engine types or even different components for noise level determination and comparison purposes. ISO 3745 with stationary microphones then is the method which has been chosen, however rotating microphones are an option here.

In ISO 3745 the sound power is obtained by integrating sound intensity (or more accurately the average sound pressure) over a hypothetical spherical surface assuming plane wave conditions i.e. in sound far field.

The existing anechoic room at Scania Södertälje is using for sound power measurement of I.C. engines specifically based on ISO 3745. The requirements of standard and difficulties in meeting these requirements for this measurement room are explained later. The schematic view of the room is shown in Figure 1. The dimensions of the room are 8 × 7 × 5.35 meters; the frequency range of interest is from 80 Hz to 16 kHz. Measurement here has been carried out using stationary microphones which makes it easier to characterize the sound.

![Figure 1 – The schematic model of the engine and anechoic chamber (the scale of the engine and room are not realistic).](image)

### 2. STANDARD ISO 3745

The requirements of the Standard can be categorized in two different groups, the location of the microphones and the room qualification.

There are different arrangements for microphones in this standard. For stationary microphones which have practical preferences as well, a typical option is hemisphere and full sphere for semi-anechoic and anechoic room respectively. The location and arrangement can be found in this Standard [2]. In this paper the 20 microphone arrangements for hemisphere has been used and it is referred as ISO point’s arrangement, also shown in figure 1 which cover the top half. The hypothetical surface encompassing the noise source should be a closed surface in order to obtain the average of total radiated sound. So here in has been tried to find the best arrangement of microphones for bottom half.

#### 2.1 Requirements

The requirements of the Standard can be categorized in two different groups, the location of the microphones and the room qualification.

The microphones location or rather the hypothetical measurement surface, should be in far field where the plane wave assumption is valid. In the other word outside of the both acoustic and geometric near field. At the very least, this surface may lie within the geometric near field in which sound power levels can be obtained, although perhaps not reliable directivity would be achievable, but it should not
be inside the hydrodynamic near field [3].

According to the standard this hypothetical sphere radius should be larger than a quarter of the wavelength of the propagating wave. Also should have a radius of at least twice the major engine dimensions, but not less than 1 m. The microphones should also be at a distance of a quarter wavelengths from all room walls.

There is also limitation on minimum number of microphones. The higher the numbers of microphones are the better average of the sound intensity over the hypothetical surface. Since microphones have the same acoustic center and lying in the same hypothetical sphere, the difference between their sound pressure levels is a measure of directivity (in this case at least in top half microphones). Standards limits this value and demands more microphone for a highly directive source. However for practical reasons this number is always limited.

Room qualification has been carried out for this room based on ISO 3745 Appendix A [2]. Expect underneath the engine, shown in figure 1, the deviation from inverse power law has been within the standard limit. In the engine bottom though there are reflections below 1 KHz.

2.2 Application of standard to the case study anechoic room

Considering that major modification to the room is practically impossible the limitations and difficulties involved can be listed as follows:

1. There is reflection from the floor underneath the engine (Figure 1)
2. There is no space for a full hemisphere microphone arrangement for the bottom half (Figure 1)
3. The microphones underneath are too close to the engine surface compared to the mentioned standard criteria
4. Furthermore there are practical difficulties to increase the number of microphones.

3. SIMULATION MODEL

The simulation procedure includes the forced response simulation of the engine Dynamic model, using AVL Excite. The surface velocities have been extracted from the FEM model surface and have been used as boundary condition for Exterior Acoustic simulation in NASTRAN.

Simulation has been carried out for certain range of speeds for steady state situation as well as the measurement.

A typical model simulation model has been shown in figure 2. However FEM mesh around the engine are limited to close area near the engine, the sound pressure outside of this mesh can be requested for post processing purpose. One advantage of simulation is that the number of virtual microphones based on ISO 3745 for sound power calculation can be increased significantly.

The sound power calculation here has been divided to upper and lower hemisphere, because of special situation of the room as it has mentioned before.

![Figure 2 – The structure of the acoustic model in NASTRAN](image)
4. MEASUREMENTS

4.1 Corrections for the reflection
The floor just underneath the engine below 1 KHz doesn’t have a good absorption quality as well as the room walls. Inverse square law method with a white noise source has been applied for different distance of the source to evaluate the effect of reflection. Similarly the vertical walls which have a good absorption have been evaluated. Higher than 160 Hz third octave frequency band the effect of the reflection appears to be consistent regardless of the source distance but not close to the source [4]. The deviation from fully absorptive wall then based on inverse square law can be considered as a correction factor for reflection.

To be able to see the effect of source, i.e. engine vs. loudspeaker, same measurement, inverse square law has been carried out for engine, with six vertical paths since engine is a wider source [4]. The sound pressure has been compared for loudspeaker and engine for different third octave bands, the results for 160 Hz one third octave band has been presented in figure 3. Trend of sound pressure level is rather similar but as expected is not matching as good as the cases with two loudspeakers cases. [4].

![Figure 3](https://example.com/figure3.png)

Figure 3 – inverse square law measurement, different cases different, loudspeaker vs. Engine, 160 Hz, 1/3 Octave band

4.2 Directivity
Engine is a rather directive sound, a typical directivity for different engine speed in full load case, over third octave frequency bands has been shown in figure 4. Directivity is lower in higher frequency bands, since there is more averaging because of wider frequency bandwidth. The directivity definition is based on ISO 3745, i.e. the difference of maximum and minimum sound pressure levels in full array of microphones (the results here are only for top hemisphere) [4].
5. RESULTS AND DISCUSSION

Because of the measurement system the problem should be into top and bottom halves. However results have been evaluated for different engine and different engine speeds for brevity only results from simulation and measurements for 1500 rpm have been presented.

5.1 Reflection correction

Reflection from the limited area in the bottom will only affect the few microphones there. The deviation from free field condition has been measured using inverse square law, for loud speaker and engine source. For the microphone located in that region, depending the distance from wall, reflection correction has to be applied [4].

5.2 Choice of Acoustic Center and microphones distances

All the microphones should be located on the same hypothetical sphere i.e. same distance from acoustical center.

A sphere of 2.7 m has been shifted in different directions in the acoustic field but with fixed location of the engine. The results are shown in figure 5, indicate that the choice of acoustic center doesn’t have a significant effect on power calculation, but the important fact is that all of the microphones should be moved together.
The Microphones should be outside of the acoustic and geometric near field. Then the question is when there is limitation for location of the microphones and they couldn’t be located in far field how much uncertainty it will be introduced. For ISO points for different location of Microphones the uncertainty is not changing much with distance higher than 1.9 m as it is shown in figure 6. A part of this uncertainty however by closer look to the figure 5 is coming from high directivity since even for the distance of 5.4 m radius sphere there is still up to 1.5 dB deviation from the real power [4]. This can explain the increase of the number of microphones in ISO 3745:2012 compare to ISO 3745:2003.

Figure 6 – Deviation of power calculated based on ISO points from real power, effect of distance, 1500 rpm

5.3 Directivity
Simulation shows a rather similar directivity compare to the measurements for a top hemisphere. A comparison of this directivity in simulation and measurement has been shown in figure 7. As mentioned before there is more directivity in lower third octave bands frequency.

Figure 7 – directivity of ISO points, measurement vs. Simulation model, 1500rpm

In bottom though there is not enough space, and furthermore the numbers of microphones are limited. Different arrangement for bottom microphone has been tested; only one microphone, four microphones, one rotating microphone with radius of 75 cm, ISO 3745 points for a hemisphere and
half of these points. The uncertainty has been evaluated for different speeds and the half of the ISO points appears to be best choice with minimum number of microphones and lowest uncertainty.

Figure 7 – Deviation of power calculated for different microphones arrangement from real power, 1500 rpm

6. CONCLUSIONS

The microphones are to put as far as possible and not closer than 1.9 m to the acoustic center. Putting all microphones at 1.6 m from acoustic center will increase the uncertainty up to two dB in one third octave bands.

Reflection correction coefficient to be applied to the specific microphones located in low absorption quality area just beneath the engine.

Twenty microphones in the top and ten in the bottom will introduce 2-3 and 3-4 dB uncertainty in measurement respectively. Since the power has been calculated using integration over a surface the weight of twenty microphones in top and ten in bottom are the same. The final uncertainty is estimated to be 2-3 dB in one third Octave band results in total power which is significantly improved by the new arrangement.

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