Main achievements of the EMRP sound power project and future prospects

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ABSTRACT

An independent method for the measurement of sound power, based on a primary standard traceable to units tied to fundamental constants, has been realised and tested. The most important achievement is that the uncertainty evaluation can be deduced in a direct and (mostly) analytical way from the primary standard and measurement environment parameters, both hemi free and reverberant acoustical fields have been considered. A new traceability line to the primary standard has been established, and the validity of the already available transfer standards has been investigated. All these achievements have the revision of the sound power measurement procedures, for which developments and validation has been carried out during the project, as a goal. Dissemination has been realised by papers, participation in conferences and a seminar. Future work will focus on improvement of the frequency range and uncertainty of the primary standard, establishment of measurement capabilities by means of key comparisons in the EURAMET region, declarations of services in the CIPM database and proposed revision of the ISO standards concerning sound power. Another important task is working among the acoustic industrial and metrological community to foster the acceptance of the new methods. Applications to calibration of microphone arrays are also possible.

Keywords: Sound Power, Primary Standard I-INCE Classification of Subjects Number(s): 72.4

1. INTRODUCTION

There were many goals to be achieved in project EURAMET EMRP SIB56 “SoundPwr”. The most important was the demonstration of the feasibility of a direct standard for sound power, that is a source of acoustical energy whose power is calculable on the basis of a measurement of its velocity, independently of calibrated acoustic sensors. But there was a general plan to include this new standard in a revised process of measurement of sound power with sounder metrological basis. This included the characterisation of reference transfer sources (the primary standard is not easily usable outside laboratories in metrology institutes), the study of tonal reference sources and a general overview of the measurement procedures including the effect of spatial sampling, of the sound field in the measurement environment and the characteristics of the measured sources. Both theoretical, numerical and experimental approaches have been used. The first step was a critical verification of the definition of the quantity free-field sound power and its suitability to characterise the properties of sound sources in different outer acoustic environments (4). This theoretical study was the ground to establish a new traceability line for sound power measurements.

2. STATUS OF THE PRIMARY SOURCE

There have been four participants in the realisation of the primary source, UME, SP, PTB and INRiM. Different approaches led to different characteristics and problems (5). The concept of a rigid piston is very simple to model both theoretically and numerically but quite challenging to realise in practice: it is not a case that none of the many loudspeaker realisations in over a century of electroacoustics has successfully followed this approach! The lack of a suspension (in almost all prototypes) introduces either a friction with the surface of the cylinder that guides the piston or a leakage or a combination of both. The most important aspect to consider is the unwanted radiation from the surrounding of the piston. Even if it is possible to measure the vibration velocity of all the surface surrounding the piston (and it has been done during the experiments at PTB) and account for this effect in the Rayleigh integral, it is not desirable to have a source that requires such a complex calibration and moreover the resulting directivity and variability of the emitted sound field would render the source less usable. The unwanted radiation has to be reduced as far as possible (a 40 dB difference between piston and surrounding velocities is the minimum) and its effect should be considered in the uncertainty calculation. The problem is shown in the following figures.

In fig.2.1 the difference between piston and surrounding of the piston of an earlier version of INRiMs prototype primary source is shown: at the frequencies of the principal modes of the mounting plate (above 300 Hz in the example), there is a critical situation, that is reflected in the difference between the power calculated from the velocity of the centre of the piston and the one measured on 20 points on a 1 m radius hemisphere in hemi free field as shown in fig.2.2.

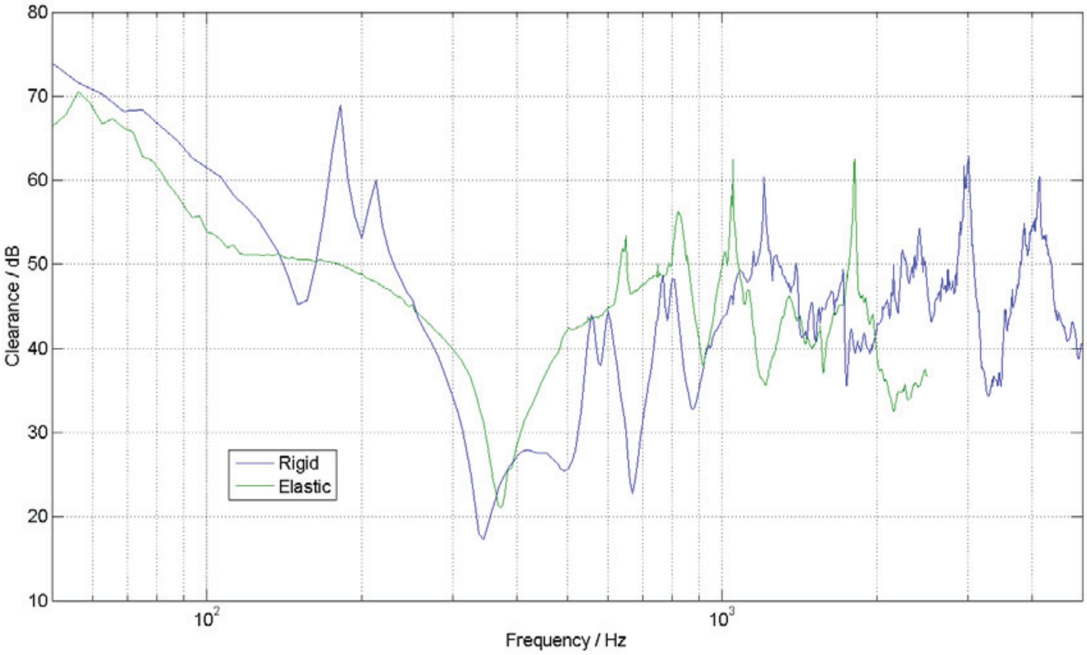

Fig.2.1 - Difference between piston velocity and velocity of the surrounding surface of an INRiM prototype of primary source

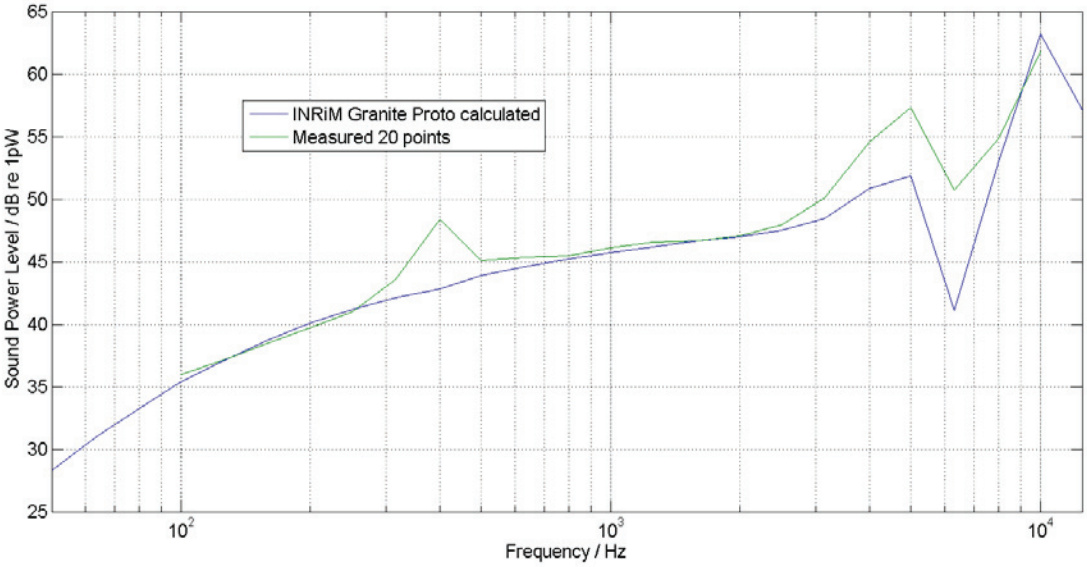

Fig.2.2 - Measured (green curve) and calculated sound power of an INRiM prototype of primary source

In order to reduce the unwanted radiation, elastic mounting of the electrodynamic driver (modified loudspeaker or vibration exciter) and a mounting system made of heavy metal plates connected by vibration reducing adhesive tape may be used. An alternative solution is to lay the vibration exciter on the floor of the hemi anechoic room (SP solution), but this makes it more difficult to obtain a reduction of the leakage between the front and the rear of the piston. Another approach is to use an elastic suspension around the piston rim, that complicates the numerical simulation and the calibration of the source. The efficiency of the source is rather low compared to that of a loudspeaker, because the moving mass is much higher than that of the moving part of a direct radiator loudspeaker (cone, dome…). To maximize power output and to fulfil the requirement of a low directivity index may lead to the use of two sources of different diameter to cover the 50 Hz to 10 kHz frequency range. The diameters of present realisations vary from 25 to 60 mm.

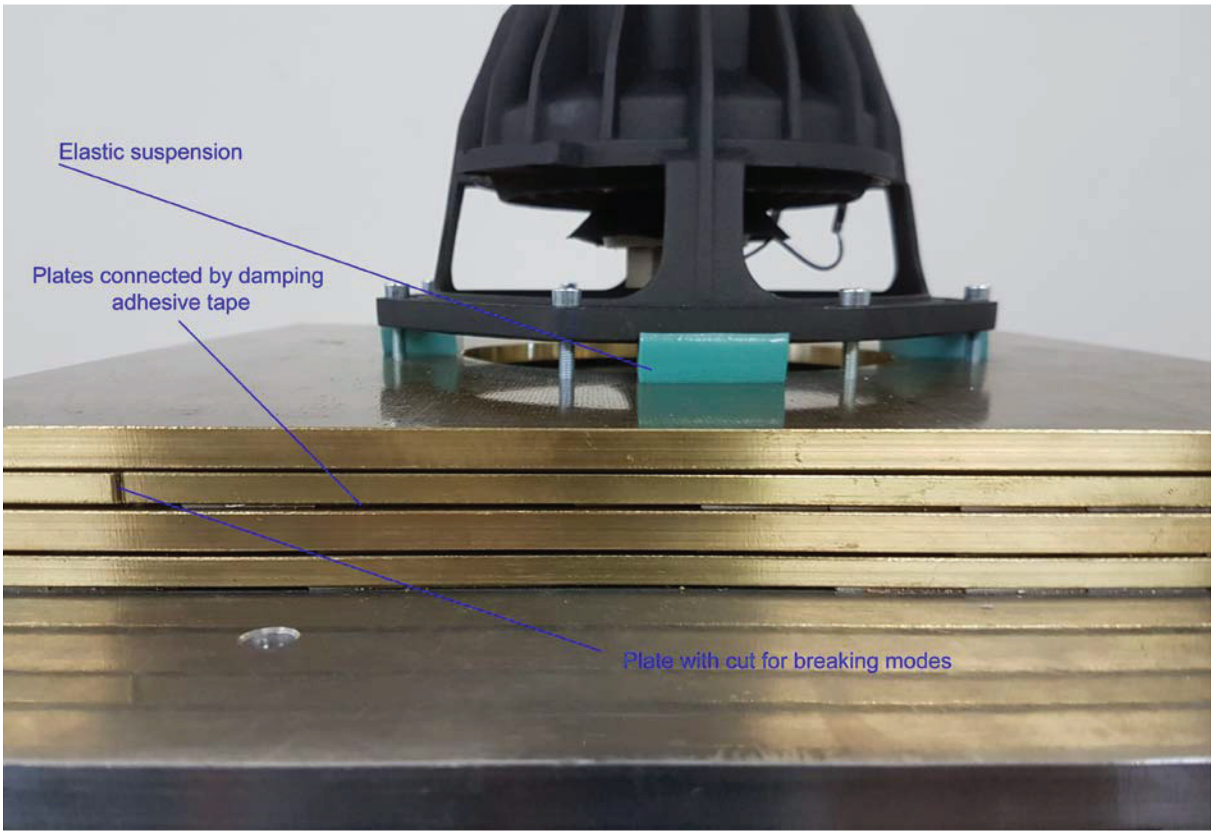

Fig. 2.3 - Example of multi layer mounting plate realization

3.REFERENCE SOURCES CHARACTERISATION

One of the most notable achievement of the project has been the characterisation of the reference sound sources that are used for substitution measurements both in laboratory and in the field. The stability, directivity, have been tested by many partners, with good agreement, and two carried out experiments to assess the dependence of the sound power emitted from the environmental parameters, static pressure, temperature and humidity (8, 9) . Narrow band measurement proved that the typical aerodynamic reference sound source can be used as a tonal source, with some precautions on averaging time.

An intercomparison of sound power measurement of reference sound sources following metrological rules common to key comparison typical of CIPM has been performed, and this is the first time that it has been done on this type of devices.

4. SPATIAL SAMPLING AND SCANNING SYSTEMS

It was clear from the beginning that a critical point of sound power measurement in essentially hemi-free fields was the correct measurement of the sound pressure or intensity over the measurement surface. Three different scanning systems have been developed, using from 1 to 12 microphone channels at a time (7). At this point, it should be noted that the new traceability line should favor comparison/substitution measurement: this fact implies that uncalibrated, low cost microphones can be used, they should only be linear in amplitude and have a good dynamic range, but may be not quite linear in frequency and must be stable in time. It is foreseeable that fixed arrays of many small, light MEMS microphones will be used for measuring sound pressure over the measurement surface, and being very small and light, the supporting structure can be light and will not alter significantly the sound field. This consideration applies only to measurement procedures in essentially free fields.

The influence of measuring surface type and distance from the source both for pressure and intensity measurements was studied and the conclusion has been that relevant ISO standards require a revision (11).

5. MAIN COMPONENTS OF MEASUREMENT UNCERTAINTY

One of the main driver of the project was the definition of the traceability chain in a direct way to fundamental units, time and length in this case. But it is the concept of the measurement procedure that needs a revision. Until now the traceability was to acoustic Pascal by means of calibrated transducers: the uncertainty calculations were mainly based on interlaboratory comparisons [1]. The situation is completely different when a primary standard is available: the measurement method of choice is a comparison (or substitution) between the reference standard (primary or transfer) and the device under test.

The need of calibrated transducers for sampling the pressure or intensity sound field is eliminated and the contribution to uncertainty is reduced to stability in time. But of course the different characteristics, both in spectral content and directivity, of the reference and test source are still a major component of uncertainty. A numerical study has been carried out to evaluate the uncertainty of comparison calibration in well defined conditions (source type, free or diffuse sound field), and the results are available in (2).

The numerical studies suggest that the number of microphone positions and in practice the accuracy of the sampling of the sound field has a great influence on the uncertainty.

Experimental measurements suggest that sampling is critical for the uncertainty of the sound power measurement: this is one of the reasons for which great emphasis was given to the development of scanning apparatus in the project. In fig. 5.1 the results of a comparison with a reference aerodynamic sound source for a directive broadband source in a hemi anechoic room over a 2 m radius hemisphere are shown, following the indication of three different ISO standards. The results are in some way exaggerated as one of the point arrays was specified for essentially omnidirectional sources, but even the schemes for directional sources show large deviations. In any case, the spatial sampling of the sound field may be the largest component of uncertainty for sound power measurement on real sources that are directive.

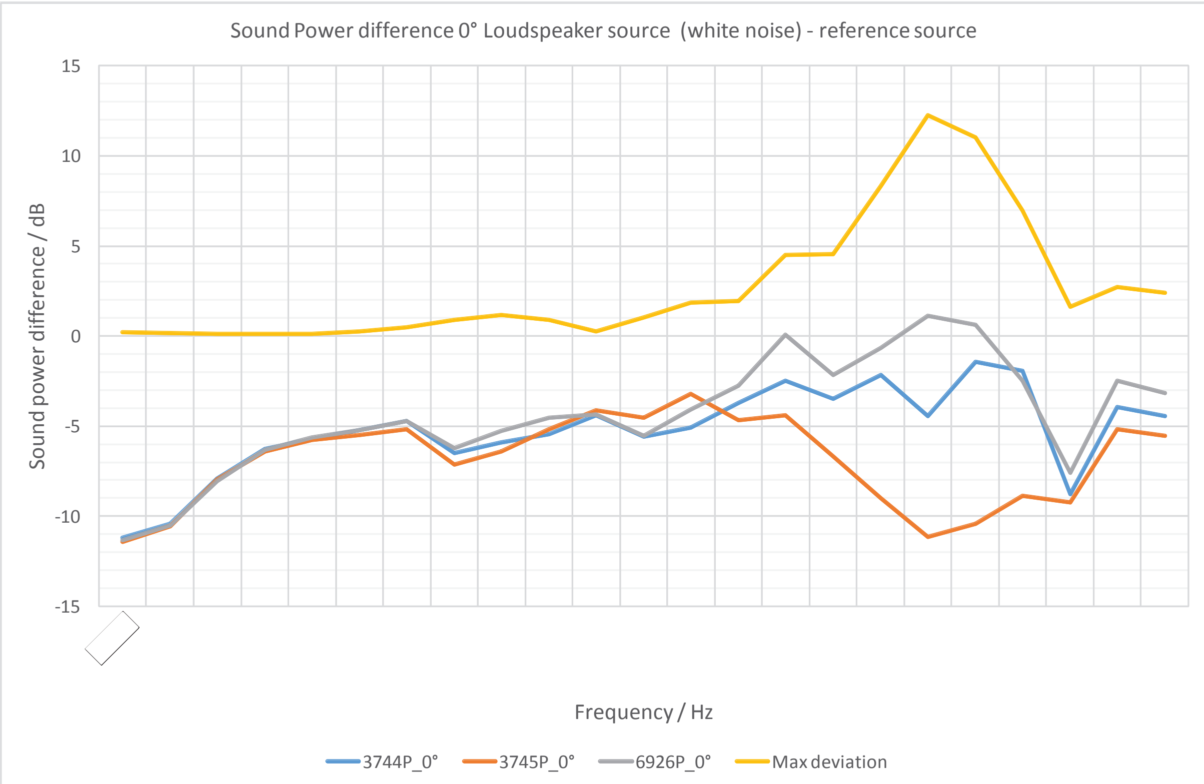

Fig. 5.1 - Difference of sound power between a reference sound source and a broadband directive source measured according to 3 ISO standards

It is clear that the uncertainty components are of various nature, but the traceability chain starts with the uncertainty of the primary standard. This is, of course, the starting point for the uncertainty evaluation. At present, only preliminary data are available. Two approaches have been used: direct, based on the uncertainty of the measurement of piston velocity and contributions of unwanted radiation and non uniform motions of the piston and an indirect verification based on comparison between calculated values and values measured on the basis of sound power over an hemisphere in a hemi free field. The analytical analysis has 4 main components, following eq. (1):

$$P_{PS} = \rho\, c\, \bar{v}^2\; S\, \sigma \qquad (1)$$

where:

P_{PS} : power of Primary Standard
ρ : density of air [kgm^{-3}]
c : speed of sound [ms^{-1}]
v : average speed of radiating element [ms^{-1}]
S : radiating surface area [m^2]
σ : radiation efficiency

The density of air and speed of sound uncertainty components account for less than 0.1 dB, but the other components are more complicate to evaluate because the primary standard definition assumes a perfect piston on a rigid infinite plane, but the piston is not perfect and the plane is neither infinite nor rigid. Therefore the radiation impedance deviates from the ideal case and this component is likely the largest one. Since it is very complicate to treat analytically the case, a possible approach is to evaluate the Rayleigh integral for all components vibrating (piston and surrounding), and calculate the difference with the power computed on the basis of the centre of piston velocity according to equation (2). This difference may be treated as a Type B component.

$$P(\omega, m_p, U, t) = \rho \cdot c \cdot \pi \cdot r^2 \cdot v_{eff}^2 \left[1 - \frac{J_1(2 \cdot k \cdot r)}{k \cdot r}\right] \qquad (2)$$

$J_1()$: Bessel function of the first kind
v_{eff} : velocity of piston [ms^{-1}]
m_p :mass of the piston and moving mechanical connection to the driver [kg]
U :driving voltage [V]
r :radius of the vibrating plate [m]
ω :$2.\pi$ frequency [rad s^{-1}]
k : wave number.

It is clear that having a rigid piston with vibration modes ideally outside the useful frequency range, and a surrounding plate rigid, heavy and well damped is essential in reducing the uncertainty. Guidelines for designing the piston are available in (3).

The primary standard realisations are still under development. But the impression is that the goal of 0.5 dB uncertainty from 100 Hz to 10 kHz is achievable with small further developments of the primary standard.

6. CONCLUSIONS AND FUTURE PROSPECTS

The intention of the project was very ambitious: to set up a new standard in the field of acoustics, that has not been very dynamic in recent times in terms of metrology, and to develop or critically revise new measurement techniques and services to customers. The progress is significant, and one of the strong points is the fact that the entire traceability chain, from primary standards to the measurement of customers devices has been analysed. In particular reference sound sources are now described by measurement data that allows to take the environmental influence into account, numerical models have shown the critical aspects of free and diffuse fields and their influence on the measurements, and many experimental verifications of the normalised measurement procedures have shown occasion for improvement.

The future prospects are mainly connected to input to standardisation working groups, to setup of new measurement services, including the calibration of arrays of sensors by means of a calculable acoustical free field source, the development of new sensors for a more efficient sampling of the acoustical pressure in sound power measurement by using arrays of MEMS microphones.

Furthermore, it seems to be very promising to extend the idea of traceability to other fields in applied acoustics, e.g. to building acoustics where the major quantities are airborne sound power or ratios of airborne sound power.

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