Microflown Technologies

The Microflown brings particle velocity to your world!

Very near field structural dynamics

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Summary: three sound fields

In acoustics, the two concepts of **'far field'** and **'near field'** are well known. However there is a third sound field, the **'very near field'**.
Two conditions limit the very near field. First of all, the measurement distance to the vibrating surface must be smaller than the characteristic size of the structure itself. Secondly the frequency must be lower than the speed of sound divided characteristic size of the structure.
Using the Microflown Scanning Probe in the very near field, a direct measure of the surface velocity is obtained.

The two conditions of the very near field

To be sure that one is measuring in the very near field, one has to obey two conditions:

1) The normal distance to the vibrating surface r_n must be smaller than the size of the source *L* divided by *2π:*

$$r_n < \frac{L}{2\pi}$$

2) The frequency is lower than the speed of sound *c* divided by the surface size *L:*

$$f < \frac{c}{L}$$

If a sound source has a size of 19cm, one should be measuring closer than 3cm to the source and the frequency should be lower than about 1800Hz.
If the sound source has a structural size of 6mm, the scanning probe has to be at 1mm distance and the highest frequency than ensures a very near field measurement is 65kHz.

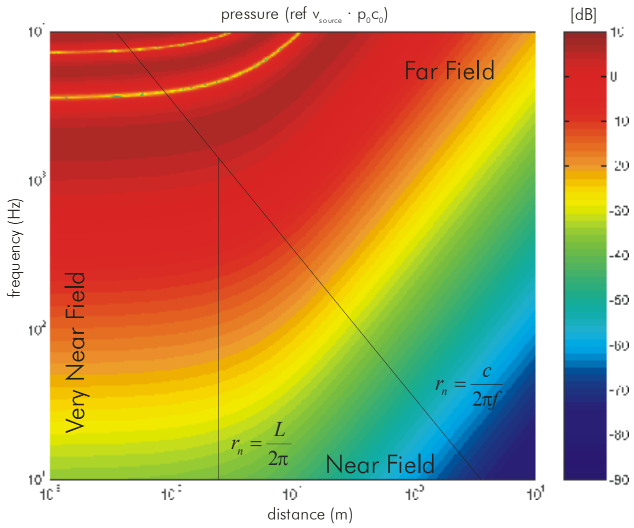
Particle velocity level and sound pressure level in the very near field

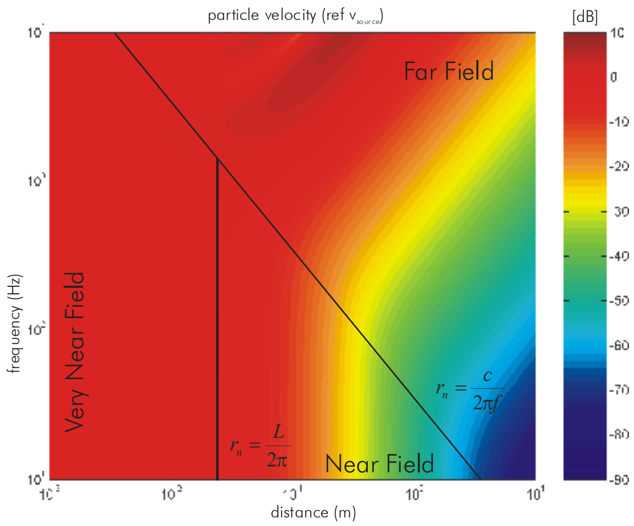
If the two conditions are satisfied, hence measuring in the very near field, the particle velocity level is linear dependent on the distance to the source and coincides almost with the surface velocity.
At the vibrating surface, the measured particle velocity equals the surface velocity. As the distance increases, the measured particle velocity underestimates the structural velocity. If the measurement distance is not exactly known, in the worst case, the measured particle velocity is only 0.75 times the structural velocity.

If the measurement distance to the source *is* known, the structural velocity can be determined exactly. It is very easy to calculate the actual surface velocity because the ratio between surface velocity and particle velocity is a linear relation with respect to the measurement distance.
If one is measuring at r_n=L/2π, the measured value is under estimated 2.5dB (which equals factor 0.75); if the measurement took place at r_n=L/4π, the measured value is under estimated 1.25dB (a factor 0.87) and so on.
The sound pressure is also linear dependent on the distance to the source in the very near field. However, the relation is not as easy as with particle velocity because the sound pressure level is frequency dependent and suppressed compared to the particle velocity level. Therefore, it is not trivial to calculate the surface velocity from the pressure signal.

Simulation of the sound field of a 19cm piston

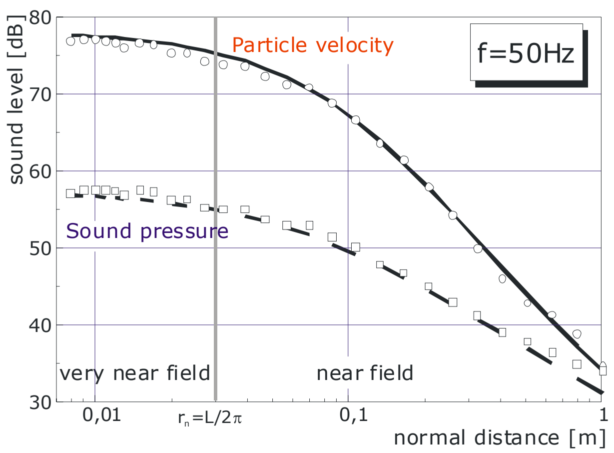
Below a simulation of a sound field in front of a 19cm piston is shown. Left the particle velocity field, right the sound pressure field. Zero dB in the left plot means that the measured particle velocity coincides with the surface velocity. As can be seen (left): in the very near field the particle velocity is almost constant and (right) the pressure is frequency dependent.

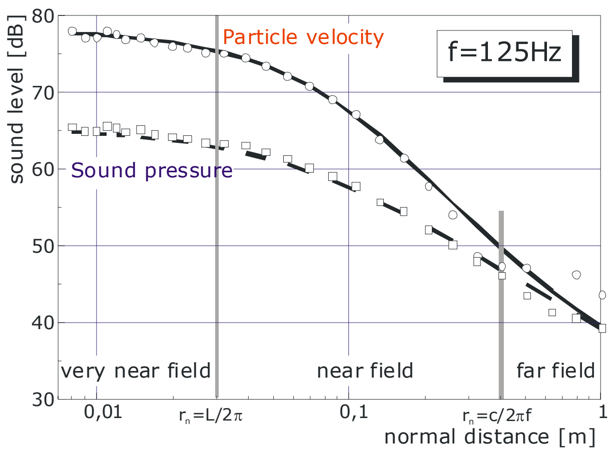




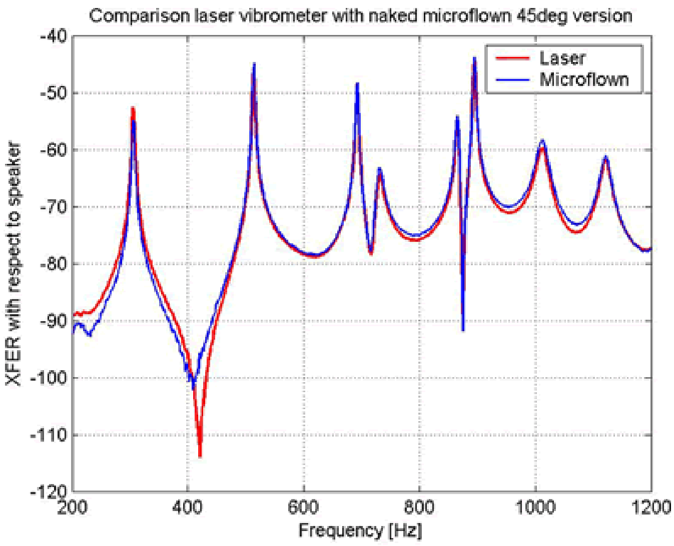
Examples of very near field measurements

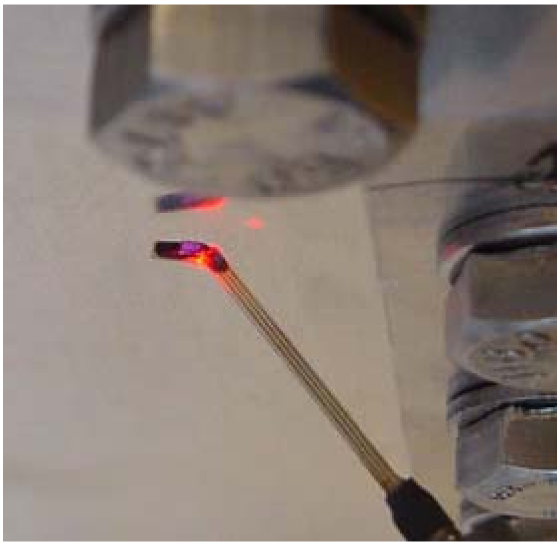
The sound field of a 19cm in diameter piston was measured at 50Hz. As can be seen, the particle velocity level and the sound pressure level is almost independent on the place (the decay is only 2,5dB and linear). Compared to the particle velocity level, the sound pressure level is suppressed and dependent on frequency. In contrast to the near field, the very near field region is not dependent on place.





As expected, if the velocity is measured very close to the surface, the measured particle velocity coincides with the surface velocity. A measurement below shows this. In a frequency span of 200Hz-1200Hz a comparison measurement is done with a Scanning Probe Microflown and a Laser. The Scanning probe was positioned 1mm from an aluminum plate that was vibrating, the laser was aimed at the same position and the result is plotted below: the surface velocity and the measured particle velocity nearby the plate measured by the Microflown coincide.



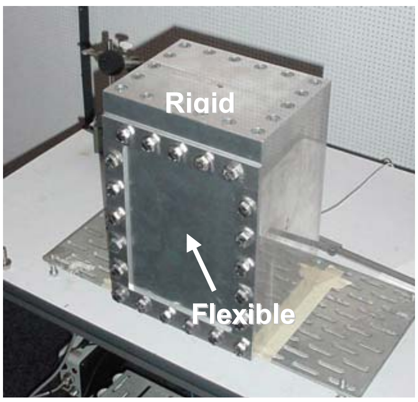


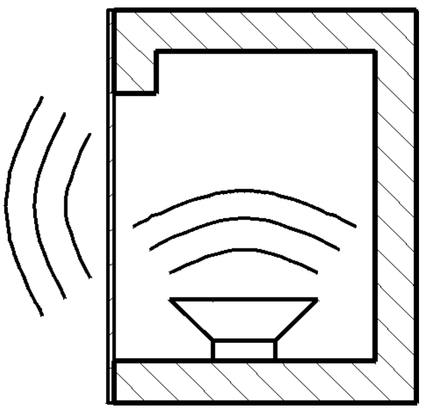
The lateral components of the particle velocity in the very near field

Apart from the normal particle velocity, the lateral components of the particle velocity in the (very) near field provide important information. It shows that the lateral velocity is zero at the maximum of the normal velocity and sound pressure. At a pressure maximum, the lateral derivatives are zero. It can be shown that if the derivative of the pressure is zero, the velocity in the lateral directions is zero.
Simulation and measurements of a vibrating plate in the 1-3 mode shows this, see below. The left simulation shows the pressure distribution and the middle one the particle velocity distribution. Three maximums are observed at the maximum amplitude of the flexible plate. In the right plot the lateral particle velocity distribution is shown. As can be seen in the right simulation, where the sound pressure and normal velocity is maximal, the lateral velocity is zero. This effect can be used to pinpoint the maximum of a sound source. The measurements that are shown below show the same.

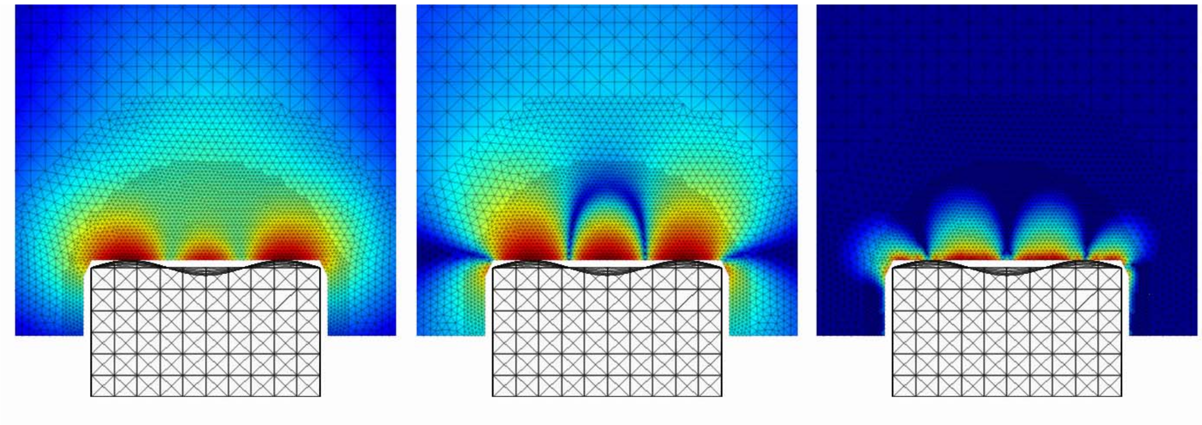
Application: find the modes of a vibrating plate

For a research project at the University of Twente a rigid box (20×30cm) is made with in the front a flexible 1mm aluminum plate. This plate is excited acoustically with a loudspeaker that is place in the box.

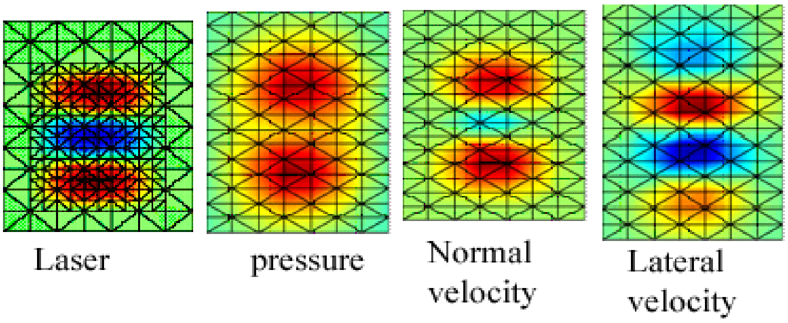




Problem was simulated, with a finite element program, see the figure below.



Left the simulated sound pressure, middle simulated normal particle velocity and right the simulated lateral particle velocity distribution of a flexible plate that is resonating in the 3-1 mode. As can be seen, the lateral velocity is zero at positions where the normal velocity is maximal and vice versa. Measurements of this box are shown below.



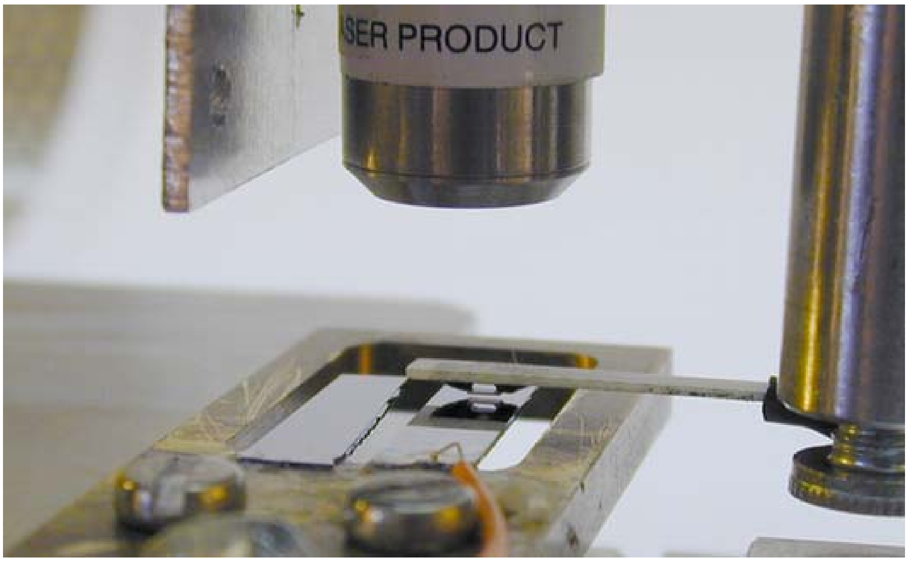
The figure shows the plate vibrations measured with a laser, the pressure and velocity distribution at 3cm from the plate. The plate is resonating in the third mode at 860Hz. As can be seen, even at 3cm from the plate the modes can be found with a Microflown that is measuring in the normal direction. The lateral velocity is zero at positions where the normal velocity is maximal and vice versa. With the lateral velocity distribution, the position of the maximums of the normal velocity can be found exactly.

Application: MEMS testing (find the modes in a small silicon beam)

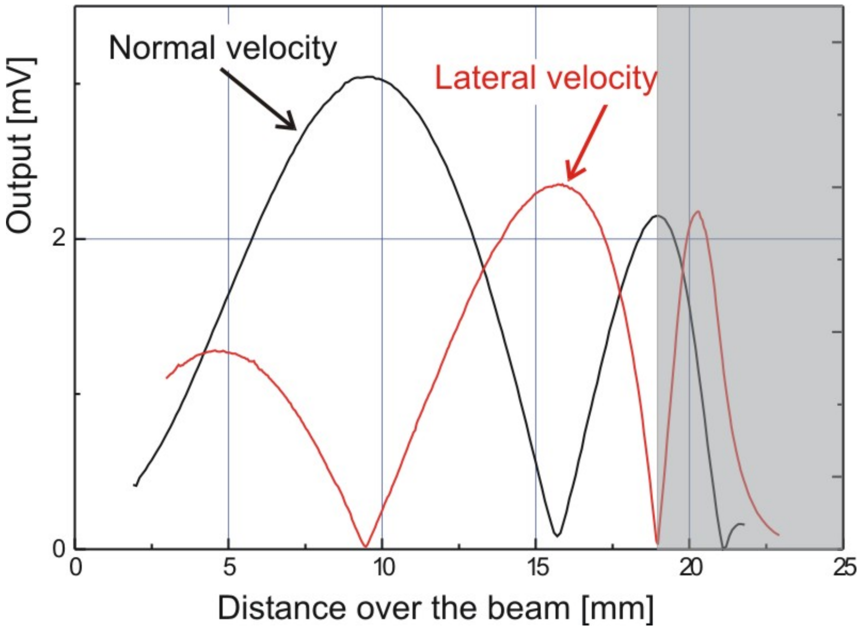
At the University of Twente a practical problem had to be solved: what is the mode of a small (5×17.5mm) silicon vibrating beam that is excited piezo electrically at a frequency of 10kHz? The problem was solved by use of a Microflown Scanning Probe that scanned the surface twice, one time in the normal direction and one time in the lateral direction. The figure below shows the silicon beam, the laser and the Microflown positioned in such way that it is sensitive in the lateral direction.

The Microflown is moved by a robot that made 50μm steps. The graph below shows the normal and lateral velocity as function of the position on the vibrating beam. As can be seen, there is a maximum at 9mm and at the tip of the beam. The gray part of the graph is showing the signals after the beam: this is caused by the sound field that is generated by the tip if the beam in combination with the figure of eight polar pattern of the Microflown.

The location of this maximum surface velocity can be exactly determined: the lateral velocity is minimal at these points. On the other hand, when the lateral velocity is maximal, the normal (surface) velocity is minimal.

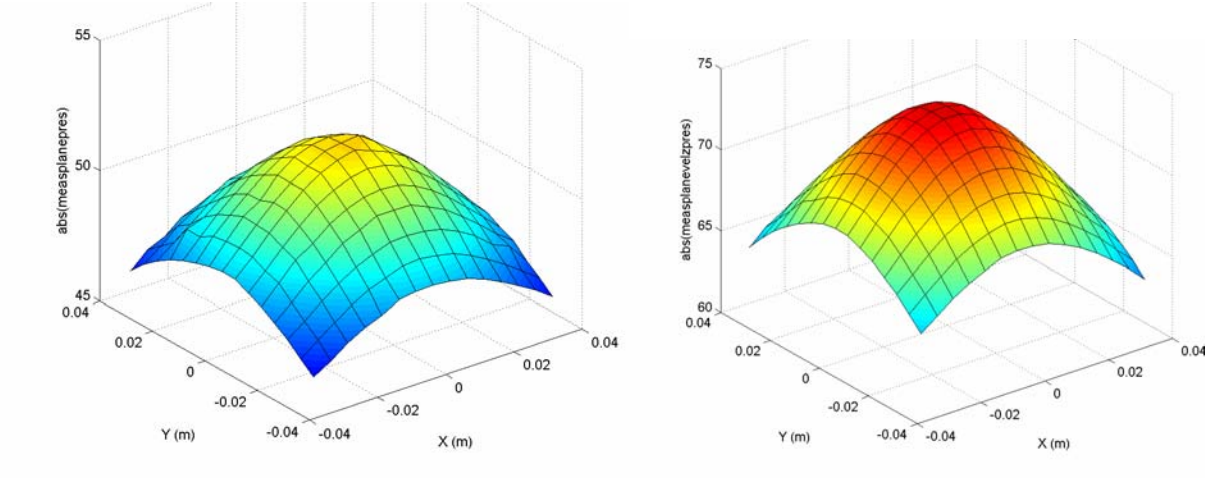


The surface velocity and the Microflown output coincide when the Microflown is placed so close to the object that it is in the very near field. This condition is fulfilled when the distance is closer than the size of the source divided by 2π. In this case the Microflown is positioned 1mm from the surface, the very near field condition was fulfilled and therefore measured velocity coincides with the surface velocity.

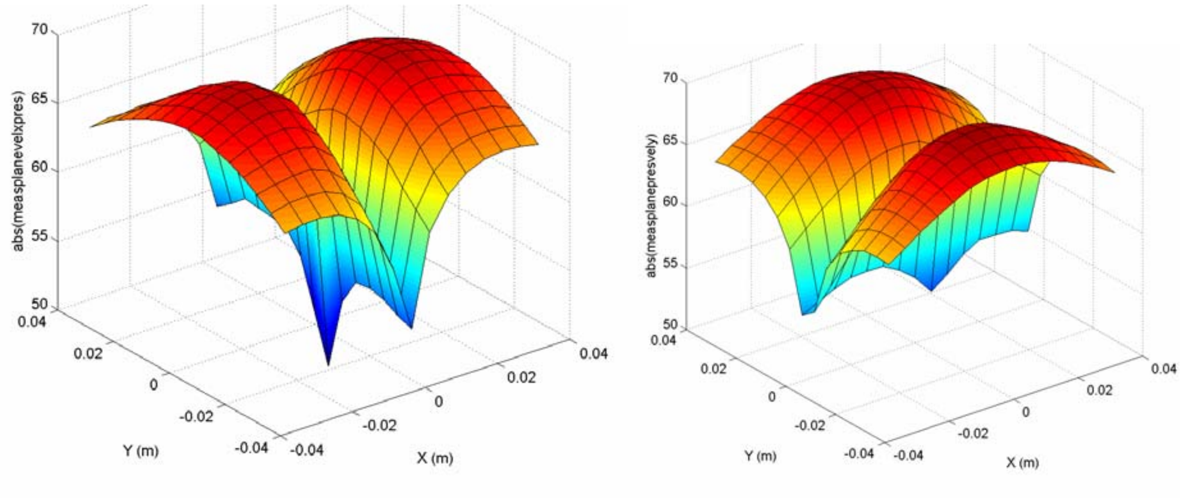


Application: air borne sound, measurement of the sound field components of a hole in a rigid plate

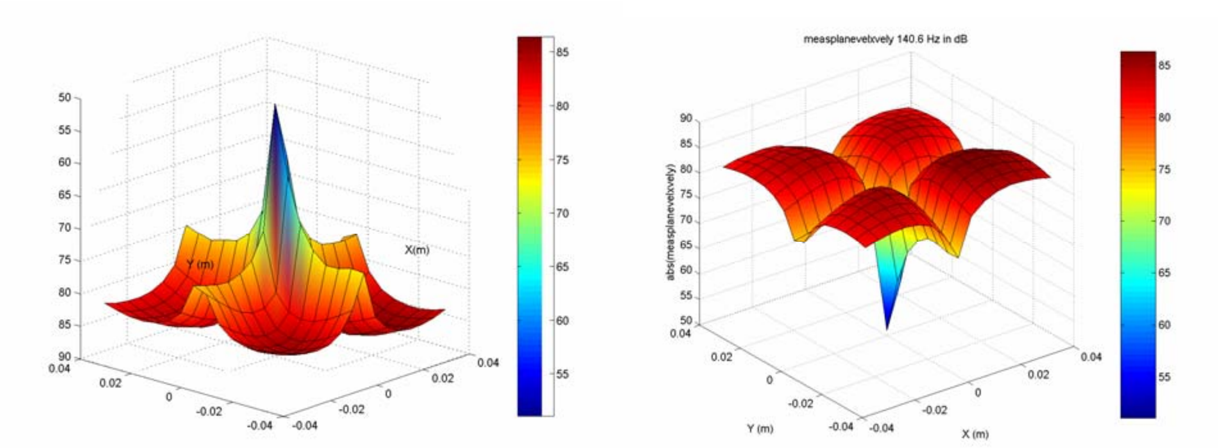
For a research project at the University of Twente a small (6mm) hole was made in a rigid, solid box. A loudspeaker was placed inside the box generating sound. At 3 cm in front of this box the pressure distribution, the normal velocity distribution and both lateral velocity distributions were measured. As can be seen, with the pressure distribution and the normal velocity distribution it is possible to find the location of the sound emitting hole but with the lateral velocity distribution, the position of the sound emitting hole is found much more precise: the x-lateral velocity shows a minimum at x=0 and the y-lateral velocity shows a minimum at y=0. Therefore the sound emitting hole is at position (x,y)=(0,0).



Measurement of the pressure distribution (left) and the normal particle velocity distribution (right) at 140Hz.



Measurement of the lateral velocities at 140Hz. Left the x-component, right the y-component.



Cross spectrum of the lateral velocities, displayed both normal as inverted. Where the cross spectrum is minimal, the sound source is located. Due to the measurement method, the method is accurate and low noise: due to the cross spectrum method, selfnoise is averaged to zero. A signal to noise improvement of 30dB is feasible.

Courtesy of Philips CFT