PRECISION PERFORMANCE: THE PURSUIT OF PERFECT MEASUREMENT

Researchers at Brüel & Kjær are using simulation to achieve new levels of precision and accuracy for their industrial and measurement-grade microphones and transducers.

by **ALEXANDRA FOLEY**

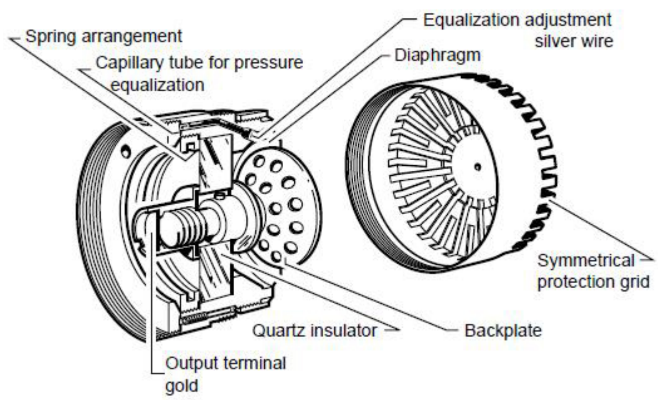

FIGURE 1. Left: Photo of a 4134 microphone including the protective grid mounted above the diaphragm. Right: Sectional view of a typical microphone cartridge showing its main components.

There will never be a perfect measurement taken or an infallible instrument created. While we may implicitly trust the measurements we take, no measurement will ever be flawless, as our instruments do not define what they measure. Instead, they react to surrounding phenomena and interpret this data against an imperfect representation of an absolute standard.

Therefore, all instruments have a degree of acceptable error—an allowable amount that measurements can differ without negating their usability. The challenge is to design instruments with an error range that is both known and consistent, even over extended periods of time.

Brüel & Kjær A/S has been a leader in the field of sound and vibration measurement and analysis for over 40 years. Their customers include Airbus, Boeing, Ferrari, Bosch, Honeywell, Caterpillar, Ford, Toyota, Volvo, Rolls-Royce, Lockheed Martin, and NASA, just to name a few.

Because industry sound and vibration challenges are diverse—from traffic and airport noise to car engine vibration, wind turbine noise, and production quality control, Brüel & Kjær must design microphones and accelerometers that meet a variety of different measurement standards. In order to meet these requirements, the company's R&D process includes simulation as a way to verify the precision and accuracy of their devices and test new and innovative designs.

➔DESIGNING AND MANUFACTURING ACCURATE MICROPHONES

Brüel & Kjær develops and produces condenser microphones covering frequencies from infrasound to ultrasound, and levels from below the hearing threshold to the highest sound pressure in normal atmospheric conditions. The range includes working standard and laboratory standard microphones, as well as dedicated microphones for special applications. Consistency and reliability is a key parameter in the development of all of Brüel & Kjær's microphones.

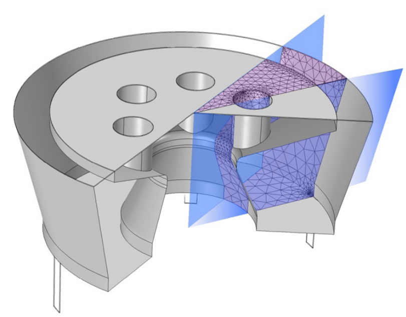

FIGURE 2. Geometry plot of the 4134 condenser microphone. The figure shows the mesh used in the reduced sector geometry, representing 1/12 of the total geometry.

"We use simulation to develop condenser microphones and to ensure that they meet relevant International Electrical Commission (ICE) and International Organization for Standardization (ISO) standards," says Erling Olsen, development engineer in Brüel & Kjær's Microphone Research and Development department. "Simulation is used as part of our R&D process, together with other tools, all so that we know that our microphones will perform reliably under a wide range of conditions. For example, we know precisely the influence of static pressure, temperature and humidity, and the effect of other factors for all of our microphones—parameters that would have been very difficult to measure were it not for our use of simulation."

The Brüel & Kjær Type 4134 condenser microphone shown in Figure 1 is an old microphone that has been subject to many theoretical and practical investigations over time. Therefore, the 4134 microphone has been used as a prototype for developing multiphysics models of Brüel & Kjær condenser microphones. To analyze the microphone's performance, Olsen's simulations include the movement of the diaphragm, the electromechanical interactions of the membrane deformations with electrical signal generation, the resonance frequency, and the viscous and thermal acoustic losses occurring in the microphone's internal cavities.

→MICROPHONE MODELING

When sound enters a microphone, sound pressure waves induce deformations in the diaphragm, which are measured as electrical signals. These electrical signals are then converted into sound decibels. "Modeling a microphone involves solving a moving mesh and tightly coupled mechanical, electrical, and acoustic problems—something that could not be done without multiphysics," says Olsen. "The models need to be very detailed because in most cases, large aspect ratios (due to the shape of the microphone cartridges) and small dimensions cause thermal and viscous losses to play an important role in the microphone's performance."

The model can also be used to predict the interactions that occur between the backplate and diaphragm. Among other things, this influences the directional characteristics of the microphone. "We used the simulation to analyze the bending pattern of the diaphragm," says Olsen. For simulations such as thermal stress and resonance frequency, model symmetry was used to reduce calculation time (see Figure 2). The reduced model was also used to analyze the sound pressure level in the microphone for sounds that are at a normal incidence to the microphone diaphragm (see Figure 3). However, when sound enters the microphone with non-normal incidence, the membrane is subjected to a nonsymmetrical boundary condition. This requires a simulation that considers the entire geometry in order to accurately capture the bending of the membrane (see Figure 4).

Simulation was also used to determine the influence of the air vent in the microphone for measuring low-frequency sounds. "We modeled the microphone with the vent either exposed to the external sound field, outside the field (unexposed), or without a vent," says Olsen. "While the latter would not be done in practice, it allowed us to determine the interaction between the vent configuration and the input resistance results for different low-frequency behaviors. This is one of the most important things about simulation: We can make changes to the parameters of a model that move away from already manufactured devices, allowing us to test other designs and explore the limits of a device (see Figure 5)."

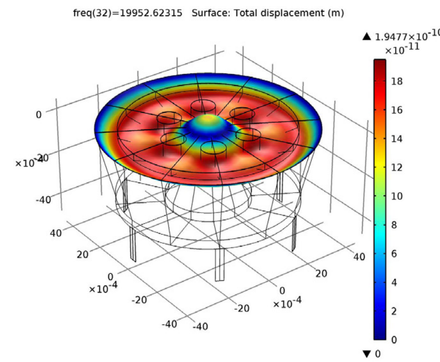

FIGURE 3. Visualization of the diaphragm deformation for sound at normal incidence, calculated using the sector geometry. The membrane deformation is evaluated at f = 20 kHz.

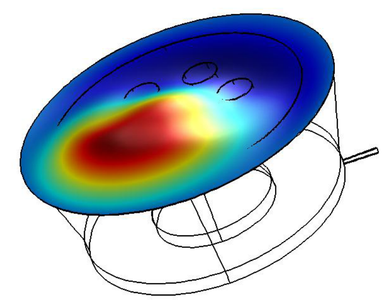

FIGURE 4. Simulation results showing the membrane deformation calculated for non-normal incidence at 25 kHz. Since the deformation is asymmetrical, this is calculated using the full 3D model.

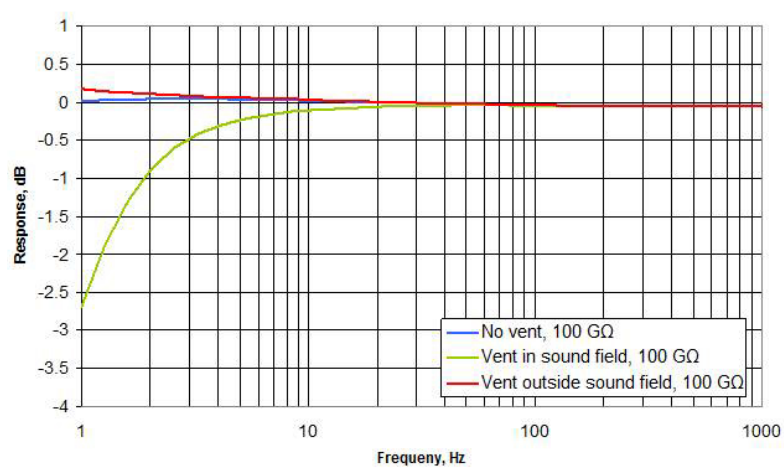

FIGURE 5. In the no-vent configuration, the sensitivity increase is due to the fact that the sound field becomes purely isothermal inside the microphone at very low frequencies. In the vent outside the sound field configuration, the curve initially follows the no-vent curve, but sensitivity increases further as the vent becomes a pressure release on the back of the diaphragm.

With simulation as part of the R&D process, Olsen and his colleagues are able not only to design and test some of Brüel & Kjær's core products, but devices can also be created based on a specific customer's requirements.

"With simulation, we can pin-point approaches for making specific improvements based on a customer's needs. Although microphone acoustics are very hard to measure through testing alone, after validating our simulations against a physical model for a certain configuration, we are able to use the simulation to analyze other configurations and environments on a case-by-case basis."

➔VIBRATION TRANSDUCER MODELING

Søren Andresen, a development engineer with Brüel & Kjær, also uses simulation to design and test vibration transducer designs.

"One of the complications with designing transducers for vibration analysis is the harsh environments that these devices need to be able to withstand," says Andresen. "Our goal was to design a device that has so much built-in resistance that it can withstand extremely harsh environments."

Most mechanical systems tend to have their resonance frequencies confined to within a relatively narrow range, typically between 10 and 1000 Hz. One of the most important aspects of transducer design is that the device does not resonate at the same frequency as the vibrations to be measured, as this would interfere with the measured results. Figure 6 shows the mechanical displacement of a suspended vibration transducer, as well as a plot of the resonance frequency for the device.

> "With simulation, we can pin-point approaches for making specific improvements based on a customer's needs."
>
> —**ERLING OLSEN, DEVELOPMENT ENGINEER AT BRÜEL & KJÆR**

"We want the transducer to have a flat response and no resonance frequency for the desired vibration range being measured," says Andresen. "We used COMSOL to experiment with different designs in order to determine the combination of materials and geometry that produces a flat profile (no resonance) for a certain design. This is the region in which the transducer will be used."

When designing the transducer, a low-pass filter, or mechanical filter, can be used to cut away the undesired signal caused by the transducer resonance, if any. These filters consist of a medium, typically rubber, bonded between two mounting discs, which is then fixed between the transducer and the mounting surface.

"As a rule of thumb, we set the upper frequency limit to one-third of the transducer's resonance frequency, so that we know that vibration components measured at the upper frequency limit will be in error by no more than 10 to 12%," says Andresen.

➔AS ACCURATE AND PRECISE AS POSSIBLE

While it may not be possible to design a perfect transducer or take an infallible measurement, simulation brings research and design teams closer than ever before by allowing them to quickly and efficiently test new design solutions for many different operating scenarios.

"In order to stay ahead of the competition, we need knowledge that is unique," says Andresen. "Simulation provides us with this, as we can make adjustments and take virtual measurements that we couldn't otherwise determine experimentally, allowing us to test out and optimize innovative new designs." ❖

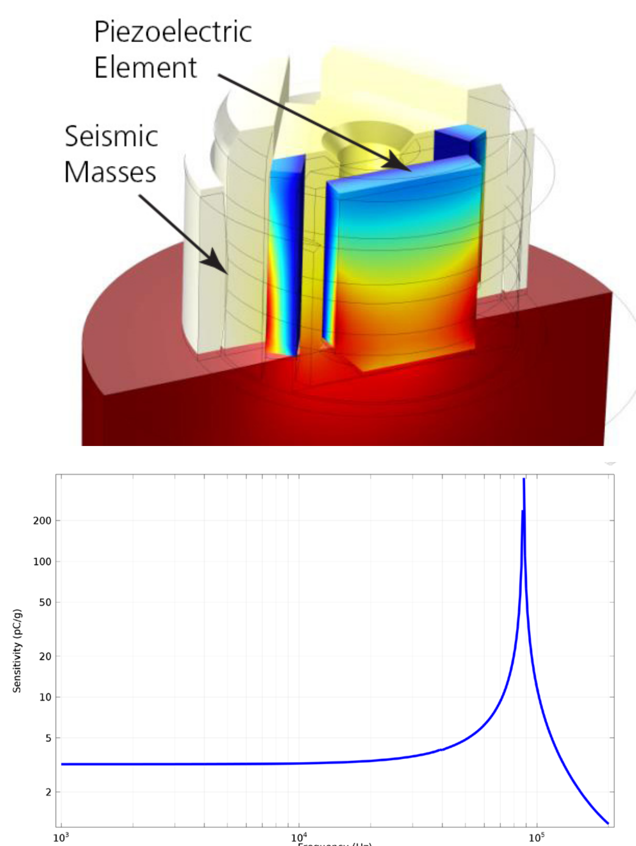

FIGURE 6. Simulation results of a suspended piezoelectric vibration transducer. Top: Mechanical deformation and electrical field in the piezoelectric sensing element and seismic masses. Bottom: Frequency-response plot showing the first resonance of the transducer at around 90 kHz. This device should only be used to measure objects at frequencies well below 90 kHz.