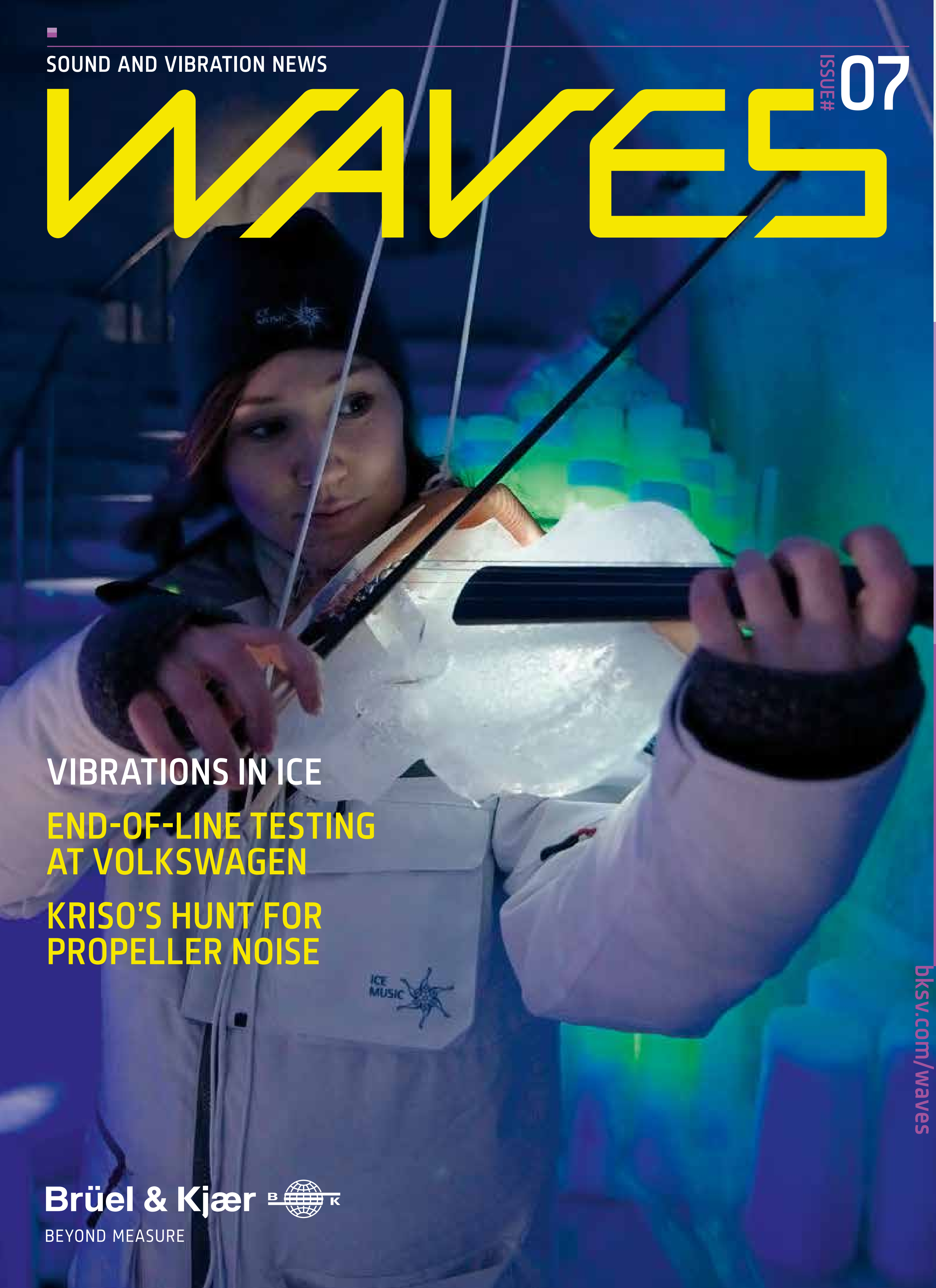
SOUND AND VIBRATION NEWS

WAVES

ISSUE# 07

APRIL 2017



VIBRATIONS IN ICE

END-OF-LINE TESTING AT VOLKSWAGEN

KRISO'S HUNT FOR PROPELLER NOISE

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Brüel & Kjær

BEYOND MEASURE

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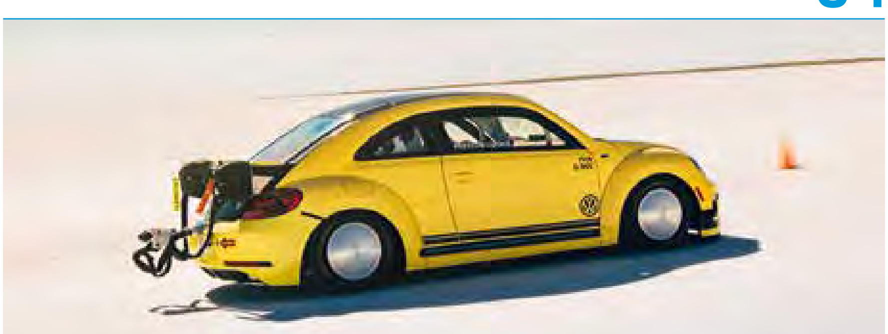

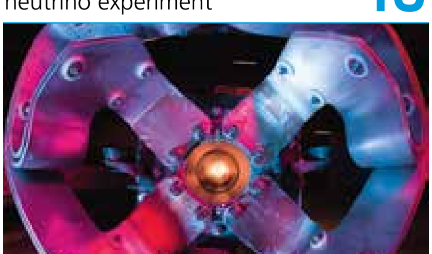

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FRONT COVER IMAGE
Elin Thorsell playing an ice violin
Photo © Karin Åberg

Brüel & Kjær
BEYOND MEASURE

LETTER FROM OUR PRESIDENT

BOOM TIME FOR SOUND AND VIBRATION TECHNOLOGY

The world is in a period of exponential population growth. According to the latest UN projections, the number of people on the planet will rise from 7.3 billion today to 9.7 billion in 2050. There are currently 30 megacities (cities of over 10 million people), and the UN expects this to double to 60 megacities by 2050. There are over one billion cars on the world's roads today, and according to the World Energy Council, this number is expected to double by 2050.

This population growth will lead to extreme pressure on our cities' infrastructures. As cities around the world grow and evolve to accommodate their growing populations, they will face incredible challenges in noise levels, safety and sustainability.

At the same time, consumers everywhere will begin to grapple the new reality of living in such densely populated environments. Their requirements for products and services will grow and change tremendously. To ensure they meet these new consumer demands, product manufacturers are testing their products as early in the development as possible, as well as through to production and to end-of-line testing.

In this issue of Waves, you can read about how Subaru uses sound simulation to design the sound of their cars directly towards the needs of their customers. You can also find out how Volkswagen is working with production testing of transmissions to ensure the highest possible quality.

Architecture and prestige buildings are also challenging the framework of acoustics. In this issue, you can meet Yasuhisa Toyota, who has been working his whole life to improve and refine the acoustics of concert halls. His most recent work is with Elbe Philharmonic Hall, Hamburg's new prestigious concert hall.

Sound and vibration in many ways is experiencing a golden age. Never before has acoustic technology been so important for creating future progress and ensuring better quality of life for all of us – especially as our global population grows. I hope you'll be inspired by our stories!

SØREN HOLST
PRESIDENT

END-OF-LINE

ALL GEARED UP AND READY TO GO

SEE MORE
Read about production testing solutions at

www.bksv.com/production-testing

TESTING

Customer expectations for the durability and comfort of cars, vans and trucks are ever increasing. Combine this with the highly competitive nature of the auto market, and manufacturers must find a balance point for producing quality products that are cost-effective, not only for themselves, but also to ensure that any added cost remains lower than the increased quality passed on to the customer. Customers want vehicles that work and are nice to be in, but they will compare prices versus features until they find the level of performance and quality they are willing to pay for.

In some vehicles, manufacturers may invest heavily in pursuit of a specific sound, and in others, manufacturers will be aiming for the quietest interior they can get. But as Dr Krohn (Head of Acoustics Quality Assurance for the Volkswagen factory in Kassel) pointed out: "You may want to hear the engine, but nobody wants to hear the transmission; it's annoying to the customer." That comment really sums up transmissions for the vast majority of drivers, but not just for sound, also for durability. The transmission is something that should just work and stay carefully in the background. Unless they are manually shifting gears, people don't even want to think about the transmission, and with the trend of vehicle interiors becoming increasingly less noisy, they especially do not want to hear it. ►

"YOU MAY WANT TO HEAR THE ENGINE, BUT NOBODY WANTS TO HEAR THE TRANSMISSION; IT'S ANNOYING TO THE CUSTOMER."

DR KROHN
HEAD OF ACOUSTICS QUALITY ASSURANCE
VOLKSWAGEN KASSEL

END-OF-LINE
TESTING

Transmission in a test stand

The Volkswagen plant in Kassel, Germany, is the Volkswagen Group's largest gear and transmission production facility. They make transmissions, literally from start to finish: from milling the gears to the final transmission assembly. They produce about 17,500 complete transmissions per day, and their goal is to produce transmissions that cost-effectively satisfy customer expectations for durability, ride comfort (including noise) and price.

TESTING TO INCREASE PRODUCTIVITY

Gears and transmissions are machine made to tolerance limits. But flaws (for example, nicks and surface ripples, or weaviness) are unavoidable and tolerance limit exceedance can happen due to tool wear, but with that kind of volume over the course of a single day, even a small percentage of substandard gears or, even worse, completed transmissions is a substantial number that must be reduced to an absolute minimum. This makes testing and finding the causes of defects and predicting tolerance exceedance necessary.

A first, knee-jerk reaction might be to assume that as complexity, quality requirements and customer expectations increase, the rigours of testing would increase and transmission quality rejections would also increase, but that is only half right. Yes, testing has become much more rigorous and fine-tuned, but the success rate for completed transmissions is better than it used to be, and, according to Dr Krohn, particularly in the last 5 years. So how do they manage to increase the testing strictures and have better end-of-line results?

ID ROOT CAUSES – ELIMINATE FAILURES

The answer, of course, lies in testing for the right reasons, establishing a control

DISCOM

For the past 20 years Discom has developed and distributed systems for acoustical quality analysis used in end-of-line testing in the automotive industry, and these systems are highly respected and used worldwide by companies in and around the automotive industry. Brüel & Kjær acquired Discom on July 26, 2016. This acquisition enables Brüel & Kjær to better support its customers by expanding its production quality testing capabilities to end-of-line analysis solutions and provides additional networks for Discom to better support customers and additional resources to facilitate adaptation to the ever-evolving automotive industry.

loop and identifying problems earlier and earlier in the process. Reworking a single gear pulled off the production line is not too costly, pulling a gear out of an assembled transmission is expensive, but pulling a transmission from a completed vehicle to fix that gear is prohibitively expensive and unacceptable – that vehicle actually reaching a customer, worse yet.

Testing is primarily focused on identifying durability issues and ensuring customer acceptance. Durability issues, such as nicks and surface weaviness in gears can lead to a failure in an assembled transmission (as well as added noise irritating the customer). And on top of the expected reliability, there is the ride quality and comfort that consumers have come to expect and associate with quality.

Of course, while testing for durability and customer acceptance, the outcome needs to be cost-effective. According to Dr Krohn, perfect gears and transmissions that function perfectly and produce insignificant noise, are producible, but definitely not cost-effective. At the same time, noisy vibration factories jammed into the drivetrain could be available for little more than the cost of materials. But would they even be worth that cost? Somewhere

in that spectrum are transmissions that are reliable, unobtrusive and affordable. The problem is that, as expectations rise, there needs to be a way to continuously move that convergence of durability, cost and acceptance further and further to the perfection side of the spectrum.

THE CONTROL LOOP AND ROTAS

Establishing a control loop with testing for each transmission family is the key element in keeping that convergence moving in the right direction. The basic elements of Volkswagen's control loop are cycles of testing, comparison and evaluation, refining test parameters and retesting throughout the developmental stages of the production line. The stages are a preliminary group, a pre-series and the final production line. Testing is the key element, and this is where Discom enters the fray.

Discom has had a close working relationship with Volkswagen for many years. Discom's Rotas Analysis System software is used both to test gears at the end of their production lines and also to test the completed transmissions at the end of their lines. ▶

"A SIGNIFICANT NUMBER OF FEATURES THAT ARE NOW PART OF THE STANDARD DISCOM SYSTEM ORIGINATED FROM DISCUSSIONS WITH AND REQUESTS FROM VW KASSEL PERSONS, INCLUDING DR KROHN."

HOLGER BEHME-JAHNS
GROUP LEADER SOFTWARE ENGINEERING
BRÜEL & KJÆR DISCOM

END-OF-LINE
TESTING

The gearset testing focuses on finding nicks, machining (spacing) issues and surface weaviness. The end-of-line transmission test simulates vehicle conditions and uses order-synchronous resampling, so the noise sources from different rotors inside the transmission can be separated.

The Rotas system consists of a latest-generation industrial computer that has been enhanced by a unique USB-based data acquisition front end specially developed by Discom. Two of the key elements of the Rotas software that are particularly beneficial to large production environments are a parameter database and a result database. Due to the order-synchronous resampling process, a root-cause analysis of the production defect is possible. The result database and associated tools in the Rotas system help to develop predictions on tool wear and related tolerance mismatch problems.

> “IT IS A FORMIDABLE CHALLENGE TO DESIGN AND MAINTAIN A NOISE ANALYSIS SYSTEM IN HIGH VOLUME PRODUCTION FOR ALL PARTICIPANTS. THE BEST CUSTOMER FEEDBACK I GOT RECENTLY WAS: IT IS A VERY USEFUL TOOL, AND IT IS CORRECT IN ITS FINDINGS. STILL, THERE IS A LOT MORE TO ADD.”
>
> THOMAS LEWIEN
> PRODUCTION TEST BUSINESS MANAGER
> BRÜEL & KJÆR, DISCOM

When creating a new production line, the first task is producing the ‘preliminary group’, which is around 20 pre-production transmissions. In this stage Dr Krohn’s team works with Discom to analyse data and find identifying characteristics. This is where the gears and produced transmissions will be tested on the production line with Rotas to form a baseline and begin to identify pertinent characteristics.

For example, a seven-gear transmission (six forward and one reverse) would typically have around 700 characteristics (two speed ramps per gear, which works out to 50 characteristics per test step or ramp) identified by Discom (examples of characteristics include spectral values, energy values and order tracks).

Once the preliminary baseline is established, the completed transmissions are put in vehicles and tested using a mobile test system to establish correlation with test stand data. The data and drive feedback are used to refine the test limits. This is an iterative process that leads to a much more refined set of limits for the next trip through the end-of-line test stand.

The next step in the process is the 'pre-series', which can consist of a couple of hundred transmissions. The pre-series is a more refined version of the preliminary group end-of-line test and mobile test, with continued cooperation with Discom. The major goal at this stage is to find the subset of those characteristics that are of specific relevance for the current transmission model and where the limits are most important. In the end, out of those 700 characteristics, the Volkswagen team will identify, perhaps, 200 or so that are relevant to the particular gearset and transmission. They will continue to adjust parameters and limits, looking for that best-fit for durability, customer acceptance and cost-effectiveness.

The dynamometer at the Volkswagen facility at Kassel

The production line may be the final step in the production line development process, but in practice, the production line is only one long stage in the test-loop refining process. All of the data for each gear and transmission test (passing and failing) is stored and available for retrieval for later reference and analysis, within seconds. This aids in developing predictions concerning tool wear (that leads to surface ripples and tolerance exceedance, etc.) and identifying root causes for faults that can be eliminated in the future.

THE FLAWS NEVER STOOD A CHANCE

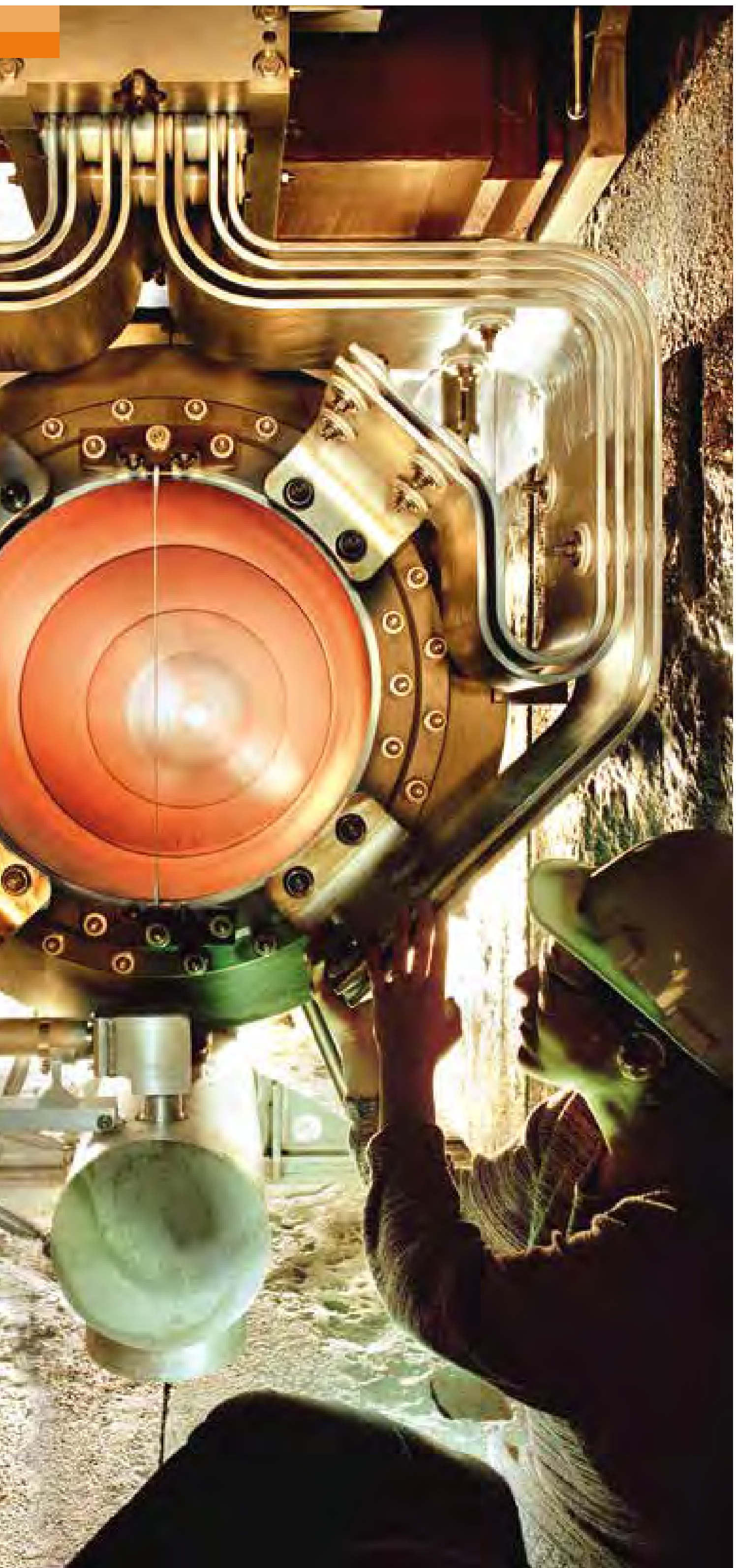
When machining and material issues can be found early in the process, they are much less expensive to deal with, gears can be melted down and remade. But the later issues arise in the production process the more expensive they become. For example, if a transmission is assembled and there is a tolerance mismatch with some of the gears that causes extra friction and noise, the entire transmission has to be taken apart by hand, the parts checked and then recycled through the system to get rid of the mismatch. And of course, the worst case scenario is a sub-standard transmission making it into a car. The testing procedures, systems and software developed and used by Volkswagen and Discom don't just weed out defective transmissions, they improve customer acceptance and cost-effectiveness by stopping the vast majority of problems early in the process before they can become increasingly expensive and aggravating to the end users, the customers…us. ■

SPOT THE DIFFERENCE

Can you spot the five differences in these two pictures?

See the solution on page 39

VIBRATION ANALYSIS HELPS NEUTRINO EXPERIMENT



Fermilab is America's leading particle physics laboratory and operates the world's most advanced particle accelerators. Scientists use particle accelerators to research some of the least understood particles in the universe: neutrinos. A vibration analysis project recently helped discover the cause of a small fracture in the powerful magnetic horn used to send neutrino beams to Minnesota.

Fermilab is managed by the Fermi Research Alliance for the US Department of Energy and it collaborates with scientists from around the world to investigate neutrinos, which are among the most abundant particles in the universe. Although neutrinos are all around us, they are very difficult to study.

WHY ARE NEUTRINOS IMPORTANT?

Neutrinos could provide the answers to some of the most fundamental questions about the nature of our universe: why we exist and why the universe is filled with matter rather than light and radiation. One of the strangest aspects of neutrinos is that they are able to oscillate – or change – from one type of neutrino to another.

As part of the Main Injector Neutrino Oscillation Search (MINOS) project, scientists are studying neutrino oscillation to see whether it can answer questions about the abundance of matter in the universe, or lead the way to new physics.

INTENSE BEAMS FOR GROUND-BREAKING EXPERIMENTS

Because neutrinos in Fermilab's experiment travel near the speed of light, physicists must place detectors far away to allow neutrinos time to oscillate. The MINOS project uses two detectors, one at Fermilab in Illinois and the other located 450 miles away in Minnesota. Fermilab's particle accelerator produces intense beams of high-energy neutrinos and sends the beams to Minnesota, where a 6,000-ton steel detector searches for neutrinos that have changed flavour during the split-second trip, enabling scientists to study neutrino oscillations.

Get more knowledge about neutrinos and Fermilab from this short animation (2:05)

> "WE EXPECT THAT AN IMPROVEMENT IN THE LIFESPAN OF THE NEXT GENERATION OF HORNS HAS BEEN INCREASED BY A FACTOR OF 2."
>
> KRIS E. ANDERSON

To manufacture neutrinos, sub-atomic particles called 'pions', which result from protons interacting with a target, are focused upon by two powerful magnetic horns and directed through a long decay pipe. During the time of flight in the decay pipe, the pions decay to a neutrino and a muon. The beam of neutrinos is not a continuous stream; it is a series of pulses. The beam cycle time is every 1.33 seconds and 4E13 protons per pulse are delivered in each 10μsec batch, resulting in an average incident beam power of 400 kW. For each beam pulse, the magnetic horns experience an electrical pulse with 200 kA peak current lasting 2.3 msec to focus the pions from target interaction and place them on a trajectory through the decay pipe and on to the detector in Minnesota.

POWER INCREASE MEANS DESIGN CHANGE

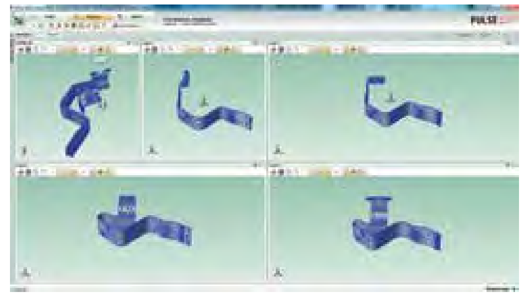
The first beam of neutrinos was sent to Minnesota in 2005 and, over the years, the beam power has increased from 400 kW incident beam power to 700 kW. This increases the heating and thermal stress in the focusing horns and reduces the fatigue-life safety factor unless design changes are implemented to the horns. In addition, the environment poses harsh conditions that accelerate corrosion and cause radiation damage that can decrease component lifetime. Design changes were implemented to improve cooling and enhance fatigue life. The original specification for horn lifetime was 10 million pulses with a fatigue safety factor exceeding two.

The lifespan of the new 700 kW horn was specified to exceed 50 million pulses, but after twenty-seven million pulses, a fracture occurred in the electrical bus stripline on the horn. The stripline is a complex structure with multiple unique boundary conditions and large variations in local modal damping.

DISCOVERING THE ROOT CAUSE

Kris E. Anderson, the lead project engineer at Fermilab, was in charge of finding the root cause of the problem. A vibration analysis project to characterize the dynamic response of the 700 kW horn stripline was set in motion. ▶

VIBRATION ANALYSIS HELPS **NEUTRINO EXPERIMENT**



Mode shape animation in PULSE Reflex™

The aim was to perform a full modal analysis – resulting in a set of modal parameters for the stripline assembly in the horn, measuring operating vibration data on the stripline conductors under typical operating conditions, and performing an analysis of operating vibration.

The measured data would then be used in analytical models to predict the useful life of the horn in terms of stress and strain, and extrapolate the results to provide an expected response of the full operating system.

MINIATURE TRIAXIAL ACCELEROMETERS

A spare 700 kW horn was used for the testing, geometry was created, and accelerometers set up. Using standard modal testing technology – including triaxial accelerometers, transducers and shakers – approximately 200 points were selected from an existing finite element analysis (FEA) wireframe model to create the experimental modal analysis (EMA) model.

These points were marked on the actual stripline conductor surface to guide the attachment of vibration transducers for live testing. A 10 lbf dynamic force shaker was used to excite the modes of the stripline.

During actual electrical pulse testing, three miniature triaxial accelerometers were mounted on the stripline to measure vibration, and the system was driven at 50, 100 and 200 kA. Time domain data was gathered and a frequency domain data reduction produced. The subsequent set of frequency spectra were closely spaced in time (100 spectra per second for 8 seconds), producing a surface plot of time versus frequency versus amplitude.

EXCESSIVE RESONANCE

At the fracture location, the horn displayed lightly damped modes at 120 Hz and particularly at 424 Hz. When driven by the electrical horn pulses every 1.33 seconds, these lightly damped modes led to increased local conductor displacements resulting from the electromagnetic conductor forces, and the modal ringdown in that region superimposed several hundred significant vibration cycles in between the 1.33 second cycle time. In essence, the 27 million cycles to point of failure approached the gigacycle fatigue regime.

INCREASING OPERATING LIFETIME

Further testing using a clamp restraint in the relevant area successfully removed the destructive resonance. Other design changes have been implemented to reduce the peak vibration displacements and shift modal frequencies higher, thus reducing displacement and subsequent conductor stress. The data has provided insight to address the problem in the current design and help enhance fatigue safety factor in future designs.

Plans include conducting modal testing and vibration measurements on future proposed stripline designs, to further understand the complex nature of the stripline response.

Kris Anderson comments: "We expect that an improvement in the lifespan of the next generation of horns has been increased by a factor of 2. By examining the modal data, future designs could have a significantly longer life." ■

A SPACE FOR CREATIVITY

The loudspeaker on the test stand is a 173 cm (5 ft 8 in) tall Confidence C4

Dynaudio, leading Danish producer of hand-crafted, high-end loudspeakers, recently opened the doors of its new, three-storey, 1600 m^2 R&D centre.

Situated in Skanderborg at Dynaudio's headquarters, this €4 m investment by GoerTek* provides 50 audio engineers with a fantastic playground for developing the future reproduction of sound and includes some of the most advanced measurement facilities in Europe.

At the core of the facility is the impressive 13 m × 13 m × 13 m measurement chamber, which includes two massive, robotic arms – one for elevating and rotating the loudspeaker under test, and the other, a 7 m wide, semicircle array of 31 Brüel & Kjær microphones for measuring the sound at numerous angles. The chamber serves to measure the direct sound from the loudspeaker, eliminating reflections from the walls by means of a time-gating technique. By turning the loudspeaker in a series of steps around the centre of the 31-microphone array, the full pattern of the speaker is quickly obtained. As Jan Abildgaard Pedersen, Dynaudio's CTO says, "Something that would previously have taken us three days can now be done in an hour".

A large part of Dynaudio's success is due to its production of speakers for Bugatti and Volkswagen. That is why the facility also houses a garage/workshop full of cars where engineers can fine tune, fiddle with and perfect the loudspeaker driver technology for Volkswagen.

With two listening rooms (30 and 60 m^2 respectively), project rooms and meeting rooms making up the rest of the facility, Dynaudio has created a space and atmosphere that will not only inspire innovation, but will also ultimately result in a shorter path from ideas to finished products. ■

* In 2014, the majority of shares in Dynaudio were acquired by Chinese Audio Company "GoerTek", which employs approximately 42,000

MAKING LIFE A BIT BETTER UNDER THE SEA

Noise pollution, in general, can have some particularly adverse effects on mental and physical health: increased stress levels, tinnitus, hearing loss and disrupted sleep make up only a partial list. Noise pollution is made up of noise intrusions and the gradual fluctuations in the soundscape's ambient noise.

Noise intrusions are characterized by their high-intensity, transient quality – typical examples are motorbikes, trucks, aircraft, road drills and sirens. Their noise stands out far above all other sounds, and due to their detrimental nature, national standards limit their maximum allowable noise emissions. Ambient noise, when too great for a sustained period is associated with health issues like stress, increased blood pressure and hearing loss.

But what about marine noise pollution? Regulation ranges from sparse to non-existent, despite studies that show noise pollution to be as, if not more, detrimental to marine life as it is to people. We share many of the same consequences – increased stress levels, hearing loss, disrupted sleep and communication interference – but much of marine life, mammals in particular, use sound for navigation and prey and predator detection, which isn't just a stressor, it's potentially fatal in the very short term.

Until fairly recently, the debate on how marine mammals are affected by anthropogenic noise mostly centred around what would be considered noise intrusions – naval sonar testing and air bursts used in the detection of fossil fuels, for example. But studies are beginning to focus more on the ambient noise environment, which includes commercial vessels. Many of the findings point to avoidance behaviour, problems communicating, finding mates, finding food and avoiding predators.

KRISO
KOREA RESEARCH INSTITUTE OF SHIPS & OCEAN ENGINEERING

KRISO'S HUNT FOR PROPELLER NOISE

Korea Research Institute of Ships & Ocean Engineering (KRISO) is a leader in ship and ocean engineering technology development. One of their focus areas is researching environmentally friendly shipping technology. Understanding propeller noise is an important aspect of that focus area.

Propeller noise, particularly turns (as spectral harmonics) and cavitation (as broadband noise), is one of the dominant sources of marine vehicle noise, and a prevalent source of marine noise pollution. The need to develop a low-noise propeller has become more and more important as the detrimental effects of marine noise pollution become more understood and more commonly observable. A propeller research team at KRISO is using their Large Cavitation Tunnel (LCT), to do just that. ►

LCT SPECIFICATIONS

Overall dimensions: 60 m × 22.5 m × 6.5 m (L×H×W)
Test section dimensions: 12.5 m × 1.8 m × 2.8 m (L×H×W)
Maximum flow velocity: 16.5 m/s

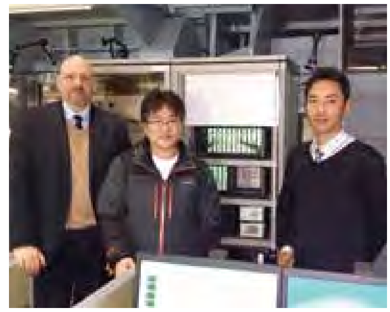
TEST AREAS

Interaction between hull, thruster, rudder and appendages, propeller cavitation inception speed test

GOALS

The design and testing of high-value-added merchant ship propellers. Testing of special ship propellers such as large- and small-scale high-speed vessels and Korean-type submarines ■

MAKING LIFE A BIT BETTER **UNDER THE SEA**



From left: Key Account Manager Patrick Wethly (Brüel & Kjær), Senior Researcher/PhD Mr. Hanshin Seol (KRISO) and Sales Engineer Hyun Ju Yoon (Brüel & Kjær Korea)

SCALING DOWN

Obviously, constructing full-scale ships for testing then redesign and construction anew, is prohibitively expensive. That means testing on scale models, which of course presents another set of problems, such as scaling effects and multi-path reflections in cavitation tunnels. So an effective scaled-down model propeller noise testing procedure must be investigated. This means that the propeller noise source mechanism must be understood so that its noise profile can be predicted and controlled in the full-scale ship design stage.

BEST FIT FOR THEIR FACILITIES

According to their research, single hydrophones can be used when propeller noise is greater than the background noise, but not if the noise level is comparable to, or lower than, the background noise. Using hydrophone arrays is a way to get around this problem. Most large cavitation tunnels use an array system that is installed inside an acoustic trough and isolated using acoustic windows, but accuracy is degraded by multi-path reflections in cavitation tunnels.

The team's goal was to find an array design optimization technique for cavitation tunnel noise measurements and, in the process, find the best fit for their LCT for minimizing the effect of multi-path reflections.

Their optimization technique begins with establishing design parameters for the various array setups under study, then proceeds to the objective function, which was to simultaneously examine the main-lobe beamwidth and maximum side-lobe level and finally apply global optimization using very fast simulated re-annealing (VFSR).

The KRISO team uses beamforming and a 45-channel hydrophone array, based on Brüel & Kjær Hydrophone Type 8103 + LAN-XI and PULSE™ for DAQ. In their selection process for the best-suited array, they looked at four hydrophone array setups on a 1.6 × 1.6 m frame and a minimum hydrophone spacing of 4 cm.

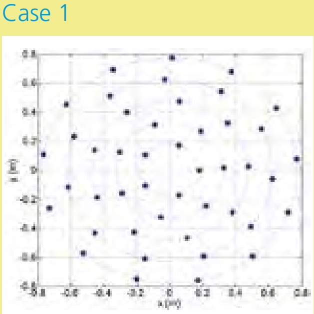
EVER ONWARD

They succeeded in finding the optimum design of a beamforming array and verifying their optimization technique. After applying the VFSR optimization method to minimize the object function and analyzing the data, circular array (case 2) and multi-spiral array (case 4) showed good performance in terms of minimum side lobe with 100 iterations. The process continues to provide results and has yielded continued research in the LCT where the team continues to explore the benefits and challenges of studying marine noise in a scaled environment. ■

For more information on this project, subsequent research and other KRISO projects, you can visit their website at www.kriso.re.kr/eng

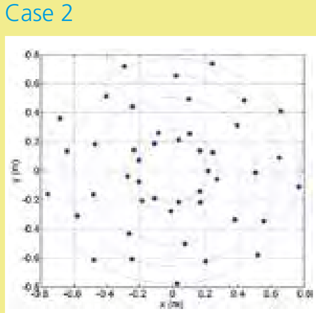
HYDROPHONE ARRAY SETUPS

Case 1



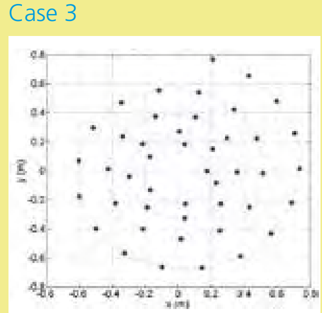
Circular array
Five concentric circles consisting of 5, 7, 9, 11 and 13 hydrophones.

Case 2



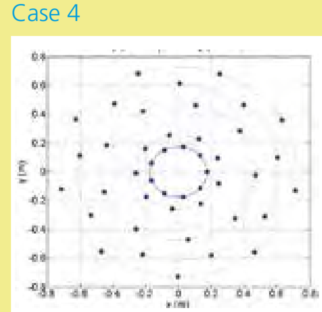
Circular array
Four consecutive rings with nine hydrophones spaced so that the area covered by each hydrophone is equal, plus an additional nine hydrophones placed at the centre of the array for high-frequency signals.

Case 3



Spiral array
A spiral of 45 hydrophones complying with the minimum spacing.

Case 4



Multi-spiral array
Set up as a multi-arm spiral as in case 2, including the nine central hydrophones.

WHAT IS CAVITATION?

Cavitation is a primary source of propeller noise. The noise is caused by popping bubbles, sort of. They aren't air bubbles, and they're not actually popping. They are imploding bubbles of steam.

Watch this video to learn more about cavitation (3:03)

Along with noise, when a steam bubble implodes, it creates a micro-jet that, over time, can result in considerable damage to materials in the immediate vicinity

WHERE DOES THE STEAM COME FROM?

To get steam, water has to boil, right? And if water boils at 100 °C, how does steam form in water that is well under 100 °C? The answer to that question is that water boils at 100 °C at sea level, where pressure is one atmosphere, which is about 101 kilopascals (kPa). If the pressure is increased, for example, to 200 kPa, the boiling point increases to around 120 °C. Likewise, if the pressure is reduced, the boiling point is reduced. So if the pressure drops to around 1.2 kPa, the boiling point will drop to about 10 °C.

FORMING BUBBLES OF STEAM IN COLD WATER

As propeller blades turn, pressure discrepancies occur. On the side of the blade that pushes against the water, pressure is increased. But on the other side of the blade the pressure drops, and the faster the blade turns, the lower the pressure drops. If the pressure drops enough, the water in that area boils.

AND THE NOISE?

The low-pressure zone is localized around the propeller, so when the bubbles leave that area they return to the normal pressure for whatever depth they are. This causes them to rapidly revert from gas to liquid, and because the gas takes up more space than the liquid, the bubbles implode. This creates a great deal of noise.

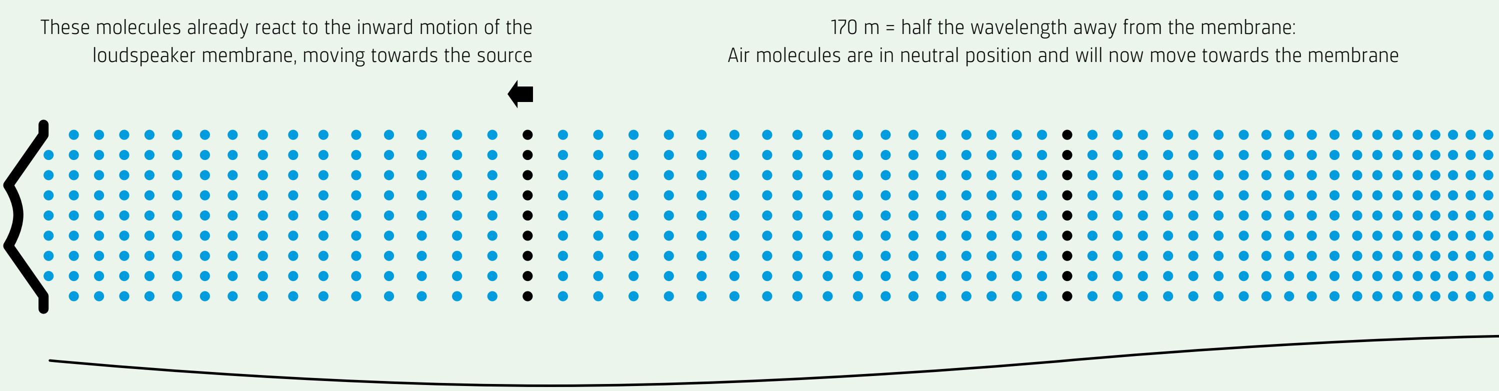
THE PHYSICS OF SOUND AND VIBRATION

WAVELENGTH, FREQUENCY AND SPEED OF

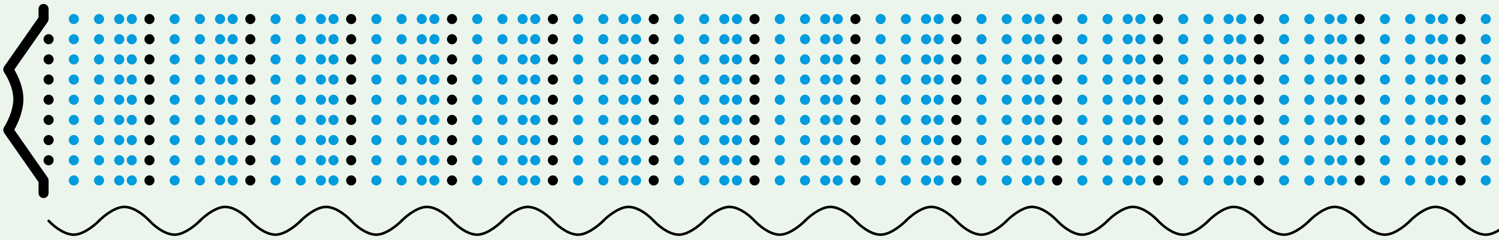
When you play music through a loudspeaker, the loudspeaker's membrane is set in motion, alternately moving in and out. On its way out, the membrane compresses the air right in front; when moving back into the loudspeaker cabinet, it leaves more space for the air in front, causing it to rarefy.

Both compression and rarefaction are a local disturbance, and the air will try to find equilibrium. When the movement of the membrane has increased the local pressure, air molecules right in front of the membrane will push against the molecules that are a little further away. Those molecules will in turn push against the molecules even further away and so on. Similarly, when the membrane moves back into the box it reduces local pressure and air molecules follow to fill the space. Consequently, the molecules further away must follow as well.

WAVELENGTH FOR 'SOUND' IN AIR AT 1 Hz: 340 m



WAVELENGTH FOR SOUND IN AIR AT 20 Hz: 340 m / 20 = 17 m



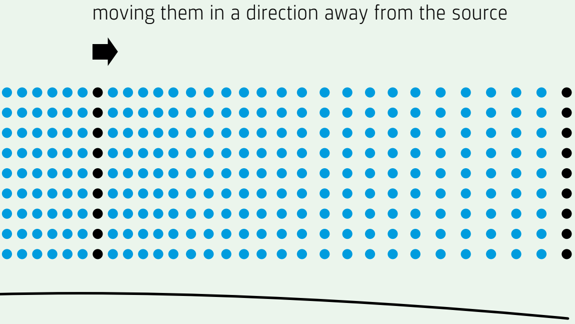
SOUND

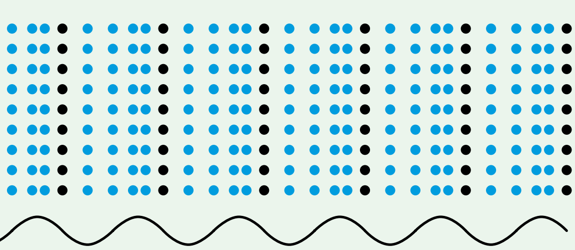
BY: **MATTHIAS SCHOLZ**
User Interface Designer
PhD Applied Acoustics
Brüel & Kjær

The molecules themselves only move back and forth a bit. What really is transmitted from one molecule to the next is the energy of the movement. The speed at which this energy propagates away from the source is the speed of sound. As a rule of thumb, the speed of sound in air is 340 m/s, but it increases and decreases with the air's temperature:

c_{air} = (331 + 0.6 * T) m/s where T is the air's temperature in °C.

The wavefront has reached these molecules moving them in a direction away from the source





This means one second after the loudspeaker membrane began to move, a listener 340 metres away from it will start to hear something.

If during this second, the speaker's membrane only does a single cycle of moving out, in, and back again, we say that it oscillates at a frequency of 1 Hz, which equals one cycle per second. Within that cycle, air pressure in front of the loudspeaker will have increased to a maximum before the membrane started to move back into the box, causing the pressure to decrease until it reaches a minimum, to then return back to neutral.

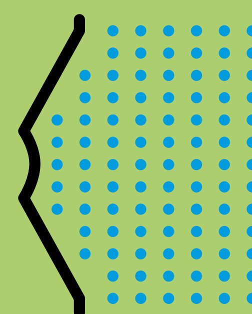
If we could stop time after one second and walk 340 metres away from the loudspeaker, we would observe the pressure distribution in front of the loudspeaker reflecting the pressure variation, thus forming one complete wavelength.

Most humans first start to hear sound at 20 Hz, that is when the speaker performs 20 cycles per second. Sound still travels at the same speed away from the source, and it still takes one second before a listener at a 340-metre distance starts to hear something.

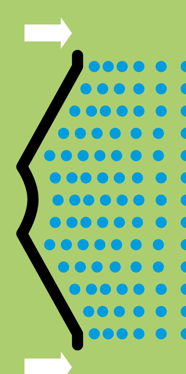
However, in that time, the speaker will already have performed 20 cycles and if we again stop time, we will have a pattern in the air where the pressure varies 20 times between maximum and minimum. The wavelength is defined as the length of this pattern for one cycle, and because we can fit 20 cycles into the distance of 340 metres, the wavelength for 20 Hz is 340 metres divided by 20, which is 17 metres. ►

MEMBRANE MOTION

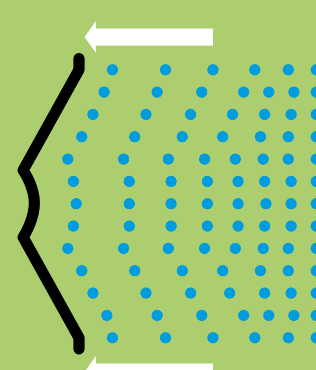
Membrane and air in neutral position



Membrane out and air compressed



Membrane in and air rarefied



WAVELENGTH, FREQUENCY AND SPEED OF SOUND

SPEED OF SOUND AT DIFFERENT TEMPERATURES

Freezing point 0 °C	331.6 m/s
Room temperature 20 °C	343.0 m/s
Desert 45 °C	358.0 m/s

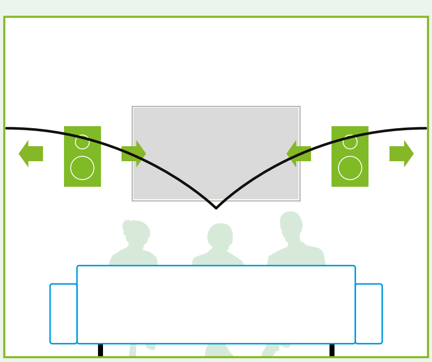
Equivalently, for 20 kHz, which is the highest frequency most humans can hear, the wavelength would be 340 metres divided by 20,000, and that is 1.7 cm.

WHY IS THE WAVELENGTH IMPORTANT?
The importance of the wavelength is that it helps us to relate the dimensions of objects to the frequencies in sound. This is relevant for almost all disciplines in acoustics. Let's just give two examples.

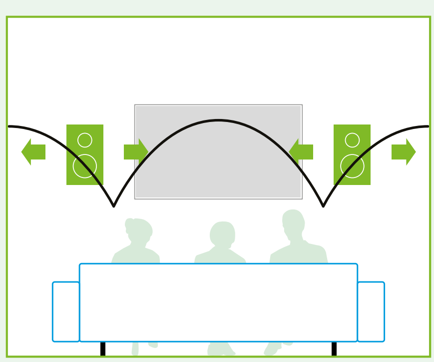
In room acoustics, sound propagates in confined spaces. Once it reaches a wall, ceiling or floor, it will be reflected back and interfere with other sound waves from the same or other sources. If the wavelength matches one or several dimensions of the room, these waves will create so-called 'standing wave patterns', by adding up in some areas (giving a booming impression) and cancel each other out in others (sound becomes weak). Therefore, knowledge of the wavelengths for relevant frequencies can be used advantageously to accentuate certain frequencies (for example, the placement of subwoofers at walls or even in corners) or to avoid the effect, if so desired, by altering the shape and dimensions of the room.

Just as important as the size of the room, is the size of objects in it. Objects significantly smaller than the wavelength will not reflect sound because if the wavelength is large, there will be practically no pressure difference across the object, i.e. the presence of the object won't matter. In contrast, if the wavelength of sound is comparably small, the object will act as a shield and reflector. This is why moving behind a column will strongly reduce high frequencies (short wavelengths) but leave low-frequency sound almost unchanged (long wavelengths), making sound appear dull. ■

STANDING WAVE PATTERN



Match for the lowest frequency, that is, longest wavelength: Very strong sound at the walls. Weak or no sound in the middle of the room



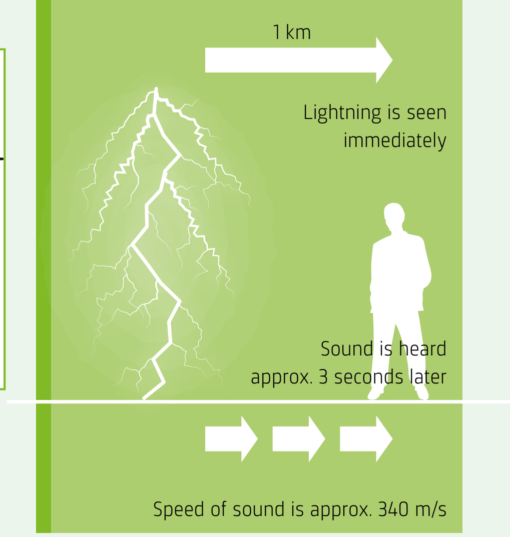
Match for the next higher frequency, where two wavelengths fit into the room: Strong sound at the walls and again in the middle of the room, alternating with areas of weak sound

KNOWING HOW TO REMEMBER THE SPEED OF SOUND IN AIR

Have you ever counted the number of seconds that passed from the moment you saw a lightning strike until you heard the thunder?

Many will know the rule of thumb that counting to three means that the lightning struck about 1 km away. With that in mind you can then roughly calculate the speed of sound: 1 km / 3 seconds ≈ 340 m/s.

This is because the speed of light is 300,000 km/s, so we see the flash immediately even if it is several kilometres away. However, the speed of sound is only approx. 340 m/s, so it will take the thunder a few seconds to travel just a single kilometre. ■



EXPERT PROFILE

THE SOUND OF MUSIC


Photo © Bertold Fabricius

Yasuhisa Toyota studied acoustic design at the Kyushu Institute of Design, Japan. Today, he is one of the world's leading acousticians as well as President of Nagata Acoustics America Inc.

He has been chief acoustician for over 50 projects worldwide, and cites the Suntory Hall, Tokyo and the Walt Disney Concert Hall in Los Angeles as two of his greatest achievements. Meet the man who decided as a boy in junior high school that his future career would somehow have to embrace his first love, music – and in particular classical music.

Taught in the fields of music and technology, there is no question why Yasuhisa Toyota does what he does – he is, quite simply, passionate about acoustic design. "Each project is different and unique," he says, "and each project provides me with different challenges. I've worked alongside many musicians and architects during my career and my inspiration clearly comes from them." Intrigued, we quizzed him further.

You obviously enjoy working closely with architects, but is design ever prioritized over acoustic quality?

The design process varies depending on the project, or indeed the architect. Some architects are very aware of the importance of acoustics; others are much more interested in the architectural design. Having been responsible for acoustics in a number of high-profile, successful concert halls around the world, I can reveal that the secret of my success is good and deep communication with my project colleagues, especially the architects. ►

THE SOUND
OF MUSIC

"I KNOW THAT I HAVE DONE MY JOB AS AN ACOUSTICIAN WELL WHEN AUDIENCES NO LONGER PERCEIVE THE LARGE DISTANCE TO THE MUSIC."

YASUHISA TOYOTA
PRESIDENT OF NAGATA ACOUSTICS AMERICA INC.

More than 1,000 curved window panels capture and reflect the colour of the sky, the sun's rays, the water and the city, turning the concert hall into a gigantic crystal

THE ELBPHILHARMONIE – FACTS AND FIGURES

- Total weight ca. 200,000 tons (equates to approximately 416,666 grand pianos, 722 Airbus A-380s or 2.5 Queen Mary cruise ships)
- Total gross floor area ca. 120,000 m² (equates to approximately 17 football pitches)
- The Elbphilarmonie's Grand Hall stands 50 metres above ground level and seats 2100 "vineyard style", where the orchestra sits in the middle of the auditorium, with the rows of seats rising up in steep tiers. This means that no audience member is further than 30 m from the conductor.

Source: elbphilharmonie.de/en

Building acoustics – art or science?
If by building acoustics, you mean room acoustics or room acoustical design, then I would say that that is closely related to art because there's always the music to consider, and music is definitely art.

Does your gut instinct or experience ever conflict with technology? If so, what wins?
Personally I think that instinct and technology complement each other, so there is no winner.

How has technology, for example, computer simulation, changed the way you work? Do you think it takes away some of the artistic nature of the job?
The change is incredible. Nothing would be possible in acoustical design without the computer technologies developed during the last twenty years. And, as long as we work with music in mind, I don't think the artistic nature of the job will ever disappear.

In your opinion, where can you experience the best acoustics in the world or most remarkable acoustic effect?
You can't single out the world's best acoustics. Acoustics cannot be judged independently or singled out from other factors, such as the musician(s), the program and so on – the acoustic experience is personal and varies depending on the whole package. For example, although technology has become an essential part of modern concert hall design, many would still refer to The Musikverein, built on

WHITE SKIN

To ensure perfect acoustics for the Grand Hall, a special material known as White Skin was developed by Yasuhisa Toyota and the architects. This consists of 10,000 sheets of gypsum fibre panels composed from a mixture of natural plaster and recycled paper. The panels, weighing between 30 and 125 kg, are milled according to intricate 3D calculations and produced exactly to the millimetre dimensions given, resulting in an acoustically optimal surface structure. The walls and ceiling merge into one another and appear like a single piece of skin covering 6500 m^2. With the help of an expansive reflector that is suspended from the middle of the vaulted ceiling, the panels project sound into every corner of the space – guaranteeing an optimal listening experience from each seat.

Source: elbphilharmonie.de/en

Vienna's Ringstrasse in 1870, as the best concert hall in the world. In my opinion, part of the reason that The Musikverein is so renowned is its superb resident orchestra, the Vienna Philharmonic. This is also true of other concert halls, for example, those in Amsterdam and Berlin.

More and more people are, for example, returning to buying vinyl records, as they believe that the quality achieved through technology takes away the soul of the performance. Could this be true of modern concert halls – that the sound, although acoustically perfect, can appear too clinical?
Yes, there are some people who are going back to buying vinyl records. But, I think this is mostly a reaction against highly advanced technology which, even though it's highly advanced, is still not perfect. For example, the CD was thought to be the ideal media when it first appeared, but then they developed the 'super' CD and so it goes on.

The situation for concert halls is different. I actually don't think that modern concert halls have acoustically exceeded the good historical concert halls and I don't think that the acoustic quality of the historical halls is diminished because of the modern halls. They are still up there with the best in the world. However, the good modern halls do have one advantage in that they are much more suitable for the large ensembles – for example, for performances of the works of Mahler, Bruckner, Wagner, Stravinsky and Shostakovich. The concert hall discussion is quite complicated and this is exactly why it's so interesting.

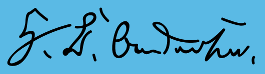
What's your latest project?
Elbphilharmonie in Hamburg, which was completed at the end of 2016 and inaugurated in January 2017. As part of that project, I measured and tested the sound quality and its distribution on an exact 1:10 model of the Grand Hall.

Finally, why is your work important?
Because my work impacts people's enjoyment of music.

WHO SAID **WHAT?**

"WHERE WORDS FAIL, MUSIC SPEAKS."

HANS CHRISTIAN ANDERSEN
(1805 – 1875)



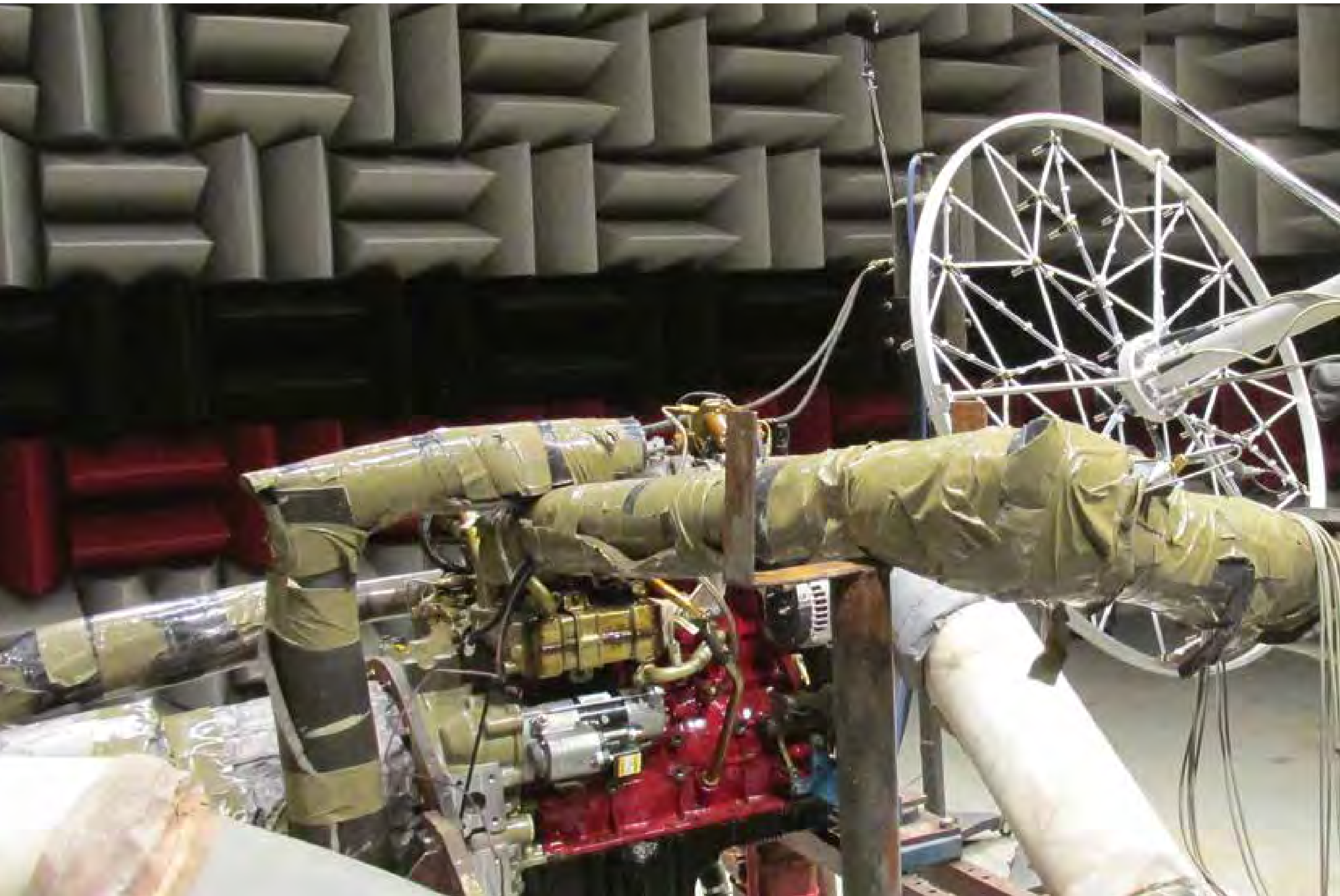
Danish author Hans Christian Andersen is best remembered for his fairy tales, known as 'eventyr' in Danish, which have been translated into more than 125 languages. A lesser known fact is that Andersen was also very interested in music and wrote lyrics for many songs.

The global language of music is also in play in this issue of Waves where you can read about a Japanese acoustician whose most recent project was in Germany (pp 21 – 23), and an American ice sculptor based in Sweden, who makes playable musical instruments out of ice (pp 40 – 42).

WORKING TOGETHER FOR THE GREATER QUIET

Partnerships are grand when they work. The teamwork they foster brings together different skill sets and resources with complementary areas of expertise, ensuring that the whole is greater than the sum of its parts. And back in the early 2000s, Cummins Inc. and Purdue University began a partnership that would greatly benefit both, beyond what they could achieve without the other.

Cummins is a global power leader that designs, manufactures and markets diesel and natural gas-powered engines for on- and off-highway use. Beyond keeping up with regulations and customer expectations that become more and more refined every year, Cummins wants to stay ahead of future requirements and expectations, as well. Frank Eberhardt is an NVH Technical Specialist at Cummins Inc. who specializes in diesel engine noise and vibration measurement, including noise source identification using near-field acoustic holography (NAH) and beamforming tools. His mandate within

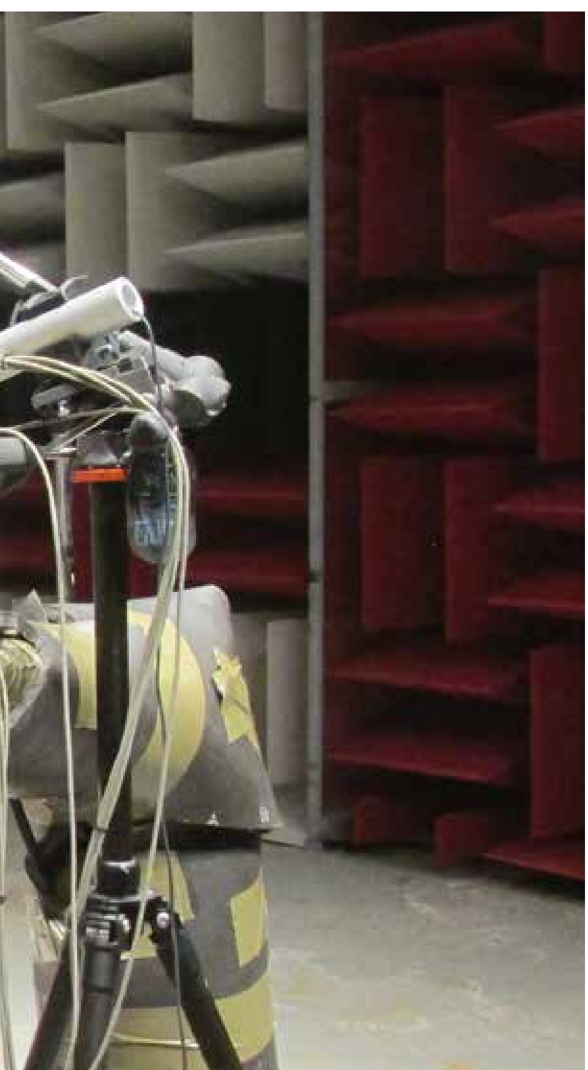


Cummins Inc. (Columbus, Indiana, USA) manufactures diesel and alternative fuel engines from 2.8 to 95 liters

the research and development department is to develop tools and processes that will result in quieter engines. And toward that end, Cummins is interested in exploring the latest aspects of source visualization technology.

Purdue is a highly respected research university with a prestigious history of partnering with companies for the furtherance of education for their graduate programs and to allow experts to push the boundaries of their various fields. One of those experts, Dr J. Stuart Bolton, is a professor of mechanical engineering at Purdue University with 30 years of experience with holography and has research focus areas in acoustics and sound field visualization. He first became acquainted with Brüel & Kjær's holography system in 1985, when Jørgen Hald and Bernard Ginn brought the first Spatial Transformation of Sound Fields (STSF) system to Purdue for a demonstration.

Frank Eberhardt, NVH Technical Specialist at Cummins Inc.



CUMMINS' QUEST

In their quest for ever-quieter engines, Cummins faces a host of challenges that need to be taken into account and overcome. For example, not only is the front of a diesel engine already a minefield of potential noise sources, there are new contributions resulting from increased demands placed on components to meet emissions regulations. According to Frank Eberhardt, an increasingly prevalent noise contributor is "the ever increasing demand for reduced emissions, which puts more demands on the engine and fuel system where cylinder pressures and fuel systems pressures are always rising to accommodate these requirements. Higher system pressures do not bode well for engine NVH." This requires newer and better noise identification methods and technology.

And because of the way that noise sources may interact with each other, some sources won't be noticeable until they are past the design phase and already assembled as part of the engine. ►

WORKING TOGETHER
FOR THE GREATER QUIET

Purdue University, in West Lafayette, Indiana, is well-known for the quality of its engineering programs, and is approaching its 150th anniversary in 2019

PURDUE
UNIVERSITY

For example, higher fuel system pressures could induce gear rattle or an increase in peak cylinder pressures could manifest as combustion noise at specific component locations. So a problem also arises if the experimental, design and analysis teams aren't using the same tools. If a problem is found that has its root cause from another development stage, that problem must be 'translated' to data that can be used to find the source of the problem.

PURDUE'S PASSION

Dr Bolton, is working with his graduate students, Tongyang Shi and Yangfan Liu, to push the boundaries of existing technology and techniques for spatial localization of various noise sources (both combustion and mechanical). Using NAH, he began by assessing current spatial localization of various noise sources (combustion and mechanical). But a well-known limitation of NAH is its upper frequency limit in relation to the size of the array and spacing of its transducers. The transducer spacing must not be greater than one half of the maximum wavelength of the sound emitted from the noise source. This would, for instance, limit the maximum valid frequency for an array with a spacing of 10 cm between transducers to approximately 1700 Hz. However, wideband acoustic holography (WBH) can deal with frequencies that are up to three times greater.

WORKING TOGETHER

Having decided on WBH as the methodology, they focused on finding the right set of tools, versatile enough to integrate custom software and algorithms and provide a common framework that could

be used in each stage of production. Providing a common set of tools, or framework, would be a great way to align the experimental, design and analysis worlds so that they speak the same language and function better as a team. PULSE™ LabShop was selected because the adaptability designed into LabShop allows users to develop algorithms and software that are tailored for their specific needs. This allowed Dr Bolton and Mr Eberhardt to make applications specifically for diesel engines and keep them within the PULSE LabShop framework and toolset. So not only do they have a tool designed specifically for their area of interest, but that tool stays inside the PULSE framework, which means that the analysis, experimental and design teams can all use a common set of tools.

WIDEBAND ACOUSTIC HOLOGRAPHY

The next step for Dr Bolton and his team was to reproduce the data generated using the Brüel & Kjær WBH method developed by Jørgen Hald. And as recommended by Jørgen, recreate the sound field and eliminate spurious sources. These spurious sources, or ghost sources, can occur under certain conditions. This is an important aspect of WBH; it is an iterative process, so it eliminates ghost-source problems that can affect other equivalent source identification methods.

A secondary goal of Dr Bolton and Mr Eberhardt is to develop an alternate strategy of representing the virtual grid they must set up. Rather than using a virtual grid of monopoles (a grid of sources that each radiate sound in all directions equally well), they place a higher order, or multipole, source (able to create more complex wave patterns) in an equivalent location to the target sound (the offending noise) to be identified and thereby create a more detailed and accurate reproduction of the target sound.

Professor Bolton (right) meeting with his students Tongyang Shi (left) and Yangfan Liu (centre) at the Ray W. Herrick Laboratories, a Graduate Research Facility of Purdue's School of Mechanical Engineering

In addition, they are working on using radiation modes (orthogonal modes distributed over the surface) rather than point sources; they will be able to multiply surface velocity by the radiation modes to obtain sound power. Then, to unequivocally reduce sound power, it is necessary to reduce the coupling between the surface velocity and the offending mode or modes.

GREATER RESOLUTION

The project is still in progress but they are getting positive results. By using tools that can be shared throughout the engine design process, they aim to create more accurate and detailed representations of the sound profile. They are on track to increase the efficiency of the design process and reduce the number of steps required to solve future noise-related problems. ■

> "WORKING WITH BRÜEL & KJÆR IN THE AREA OF ACOUSTIC HOLOGRAPHY IS PARTICULARLY EASY AND REWARDING BECAUSE OF THEIR LONG HISTORY OF TECHNICAL LEADERSHIP IN THIS AREA."
>
> DR J. STUART BOLTON
> PROFESSOR OF MECHANICAL ENGINEERING
> RAY W. HERRICK LABORATORIES, PURDUE UNIVERSITY

SOUNDS LIKE FUN

PLEASE DO ~~NOT~~ TOUCH THE EXHIBITS

All of the exhibits are meant to be interacted with (or for the most part, to be played with). This interaction (play) piques interest and prompts questions. So the experiments have to be designed with two aspects in mind, one to demonstrate a concept and the other to make it interactive and relatable (able to be played with).

Photo courtesy of Experimentarium, Adam Mørk

John explains how the Laserharp works (1:09)

Experimentarium is a Danish non-profit foundation whose sole purpose is to encourage people, particularly children, to develop an interest in the sciences and investigate how the world around them works.

John Østergaard Madsen uses his background in innovation, product development and electrical engineering to create exhibitions for Experimentarium. His responsibility is to ensure that experiments and exhibitions both illustrate a concept and entice interaction. So being a sound and vibration magazine, we asked him a couple of questions about sound and vibration.

How do sound and vibration influence your designs?

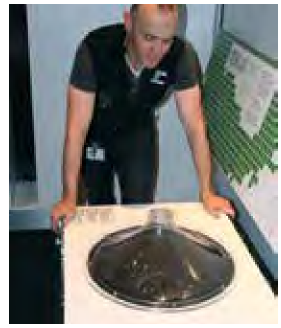
In my work as an exhibition developer at Experimentarium, I help to convey a part of the scientific nature of our world. Vibration and sound (audible vibrations) occur naturally in many of our exhibits, but can also be tested directly in others. As an engineer, I see vibrations as an absolutely fundamental feature of the universe – from small scale, where we have fast vibrations of elementary particles (expressed, for example, in temperature and electromagnetic radiation), to the vibration of large, coherent structures in materials and air that we hear and feel as human beings, to slow, large-scale vibrations where, for example, galaxies interact with each other. As a musician and music lover, sound is my primary source of artistic experience.

Why is it important that children and young people learn about sound and vibration?

I think that it is important that they learn about sound and vibration because mankind has always tried to understand the world we find ourselves in with different methods and philosophies. Sound is a way of sharing knowledge, a medium for the dissemination of stories and music and a source of, at worst, stress-inducing annoyance. The observation of vibrations can tell a lot about systems, materials and the fabric of which the universe is created. Vibration is a natural and inevitable part of our everyday lives and the universe. ▶

John Østergaard Madsen playing Laserharpen (the Laser harp)

SOUNDS LIKE FUN


Pellets bounce to the rhythm of the speaker membrane, varying in pattern as the frequency is changed

Vibrating, music-playing, 3-metre-high tree trunks in the 'Tunnel of Senses'

To learn about and investigate vibration is one of the ways to gain a greater understanding of the world around us, and interactive science setups describing these phenomena for children and young people can greatly support and inspire an increased interest and curiosity for the natural sciences.

Which exhibit best lets people see the relationship between sound and vibration?

We have a few, but the exhibit that shows this best is probably in our 'House of Inventions'. The 'Feel the Sound' exhibit visibly demonstrates the relationship between sound and vibration. We want to show that sound is generated due to membrane movements, but since our eyes cannot clearly see the membrane vibrations at frequencies where our ears hear them, we must show the vibrations in a different way. A simple method is by placing small, lightweight balls on a horizontal loudspeaker membrane so that guests can play a selection of low-frequency tones and see how the balls bounce around as the frequency changes.

What was your first project?

My first project at Experimentarium was 'Laserharpen' [the Laser Harp]. As an engineer and musician, it was a great gift and joy to have the opportunity to take on such a task. The only starting criteria I had was that the laser beams should be shaped like a 3/4 cage where notes are played when a beam is interrupted and that the laser beams should be easy to see and safe to use. And now it is here, in the new Experimentarium. It is a pleasure to see Laserharpen used with so much joy and enthusiasm by our guests.

One challenge here was to ensure that the sound would primarily be heard inside the laser cage without disturbing nearby exhibits. A directional loudspeaker centred above the cage was part of the solution, but was missing a little fullness and body in the lowest frequencies, which was compensated by an additional loudspeaker placed in the immediate vicinity of Laserharpen.

Which of your projects is most influenced by your interest in sound and vibration?

That would be the vibrating, music-playing, 3-metre-high tree trunks in our 'Tunnel of Senses'. The project manager asked if we could get a tree trunk to vibrate and play music. It's not what tree trunks usually do best, and the first impression was that it could not be done. But after a bit of thinking, ideation, drawings and consultation with colleagues, we produced a functioning prototype. By placing a ButtKicker® [low-frequency audio transducer] on top of the log and placing the log in spring suspensions at both ends, we were able to get it to vibrate. So a tree trunk can play music if you make a channel in the middle of it, place a small speaker inside the top of the tree trunk that plays into the channel and drill small holes into the channel. Without a basic understanding of sound and vibration generation, the idea for this construction would certainly not have been developed. But now they are there in the centre of the Tunnel of Senses: 3-metre-high tree trunks that vibrate and play music. ■

A NEW WHITE PAPER FROM THE STACKS

ACTIVE VIBRATION-BASED SHM SYSTEM: DEMONSTRATION ON AN OPERATING VESTAS V27 WIND TURBINE

SEE MORE
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Can you detect a 15 cm crack in a wind turbine blade without stopping the wind turbine? A three-year-long research project, partly financed by the Danish government, proved that this is indeed possible.

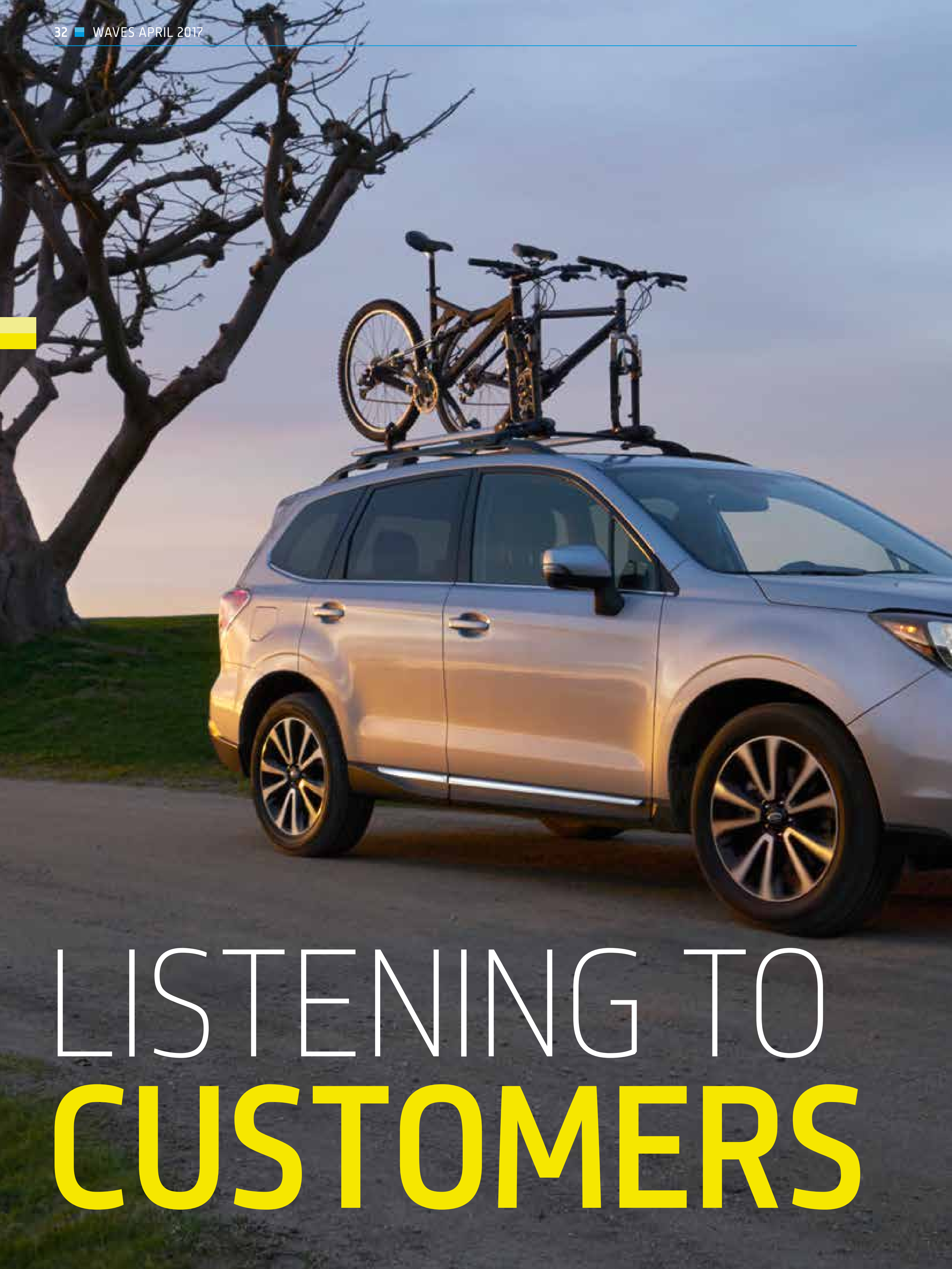
Modern wind turbine blades are designed to last for 20 to 25 years under severe weather conditions, and during this period, damage is unavoidable. Almost inevitably, a small blade defect will develop into a bigger failure, which if no countermeasures are taken, will become critical, causing serious consequences.

Repairing a small defect is significantly cheaper than repairing a bigger one or replacing an entire blade. Therefore, wind turbine operators pay close attention to monitoring their fleets' blades. Today, this is done by periodical visual inspections conducted every one to two years. For such an inspection, the wind turbine has to be stopped, then a service technician, often trained climbers, checks every inch of the blade's surface and documents any defects found. This is a tedious and risky job that can only be done in good weather conditions. Since such inspections are quite expensive, many in the industry realize that a better approach is needed.

One solution could be an automatic, remote, structural health monitoring system that can instantaneously identify damage without stopping the wind turbine, thus avoiding expensive downtime. Brüel & Kjær, in cooperation with leading Danish wind turbine specialists, has developed a prototype of such a system – an active, vibration-based, structural health monitoring system that uses an actuator and accelerometers to collect vibration data, while a damage detection algorithm indicates if blade damage is present. The solution was used to monitor a real Vestas V27 wind turbine for four months, resulting in the detection of a 15 cm crack on a blade's trailing edge.

NOT JUST FOR WIND TURBINES

It is believed that the same principle can be used for monitoring pipelines, tanks, chimneys, aircraft fuselages, and other thin-shell structures.



LISTENING TO CUSTOMERS

Subaru has always had a people-first approach to car making. As one of the hottest car brands – 2016 was its ninth consecutive year of sales increases in the US – it plans to continue its success by listening to customers' needs and preferences, and it has gained valuable results from sound simulation tests.

Subaru is clearly growing significant market share and customer loyalty in the US. Sales of the Outback model increased by 22.7% through the first three months of 2016, compared to the same period in 2015, and December 2016 represented the best month ever for Subaru of America, topping off the best year in the company's history in terms of both sales and market share.

Subaru has been investigating the way its customers expect their cars to sound and has made some very interesting and useful discoveries about how sound volume, character, and response expectations are quite different for customers driving its traditional sedans, wagons and SUVs compared to customers of its sporty models – even in some cases where the same people own both cars.

SOUND PREFERENCES

Car customers are increasingly concerned about acoustics and this is a major factor when developing new products. The relationship between sound quality metrics and human perception is not fixed, and customer expectations can certainly change over time.

In general, as overall quality improves, vehicle manufacturers are putting a lot of effort into specific attributes of their products to better align vehicles to meet customer expectations. But how can manufacturers ensure they are delivering what customers want from their vehicles in terms of NVH performance and character?

STRONG PARTNERSHIP

Ryan Plum, Manager in the Body & Vehicle Evaluation Department at Subaru, says: "The US is our biggest market and we have indeed experienced a lot of growth here. We want to keep that momentum and keep in touch with our customers' needs and preferences going forward."

"We have a long history of trusting Brüel & Kjær's measuring equipment in our testing," says Ryan Plum, "and we have worked with them over the years as technical partners in our pass-by noise testing and sound source testing. With its engineering experience and outstanding state-of-the-art 4WD NVH chassis dynamometer, Brüel & Kjær quickly became a trusted partner for us. And the close proximity of the Application Research Centre (ARC) to our Research and Development office in Ann Arbor made it a natural fit." ►

LISTENING TO
CUSTOMERS

"The ARC represents a huge value for us," continues Katsuyoshi Tanaka, General Manager of the Engineering Department at Subaru Research and Development. "Having access to a world-class facility when we need it – along with the operational expertise and hardware availability – is important for a small company like Subaru. The large inventory of testing hardware and the knowledge to use and apply it in innovative ways gives us a strong partner to rely on when we need it."

SOURCE PATH CONTRIBUTION

To understand sound and vibration strengths and weaknesses, Subaru has been conducting numerous in-depth studies of both its competitors and its own vehicles – with both subjective and objective measurements.

Identifying the sources of vibroacoustic emissions that drivers both hear and feel is essential to creating comfortable vehicles. One way to understand how vibrations develop from the source into passenger impact is to analyse the transfer path or the source path contribution (SPC). This can provide insights into the origins of sound, tracing them back to the root cause, such as a specific engine mount.

In 2016, a road noise SPC project was conducted with Brüel & Kjær's Global Engineering Services on a Subaru prototype vehicle, under several different operating conditions. The goal was to build a test-based SPC model to predict the noise contributions from different sources and to identify the dominant sources and paths affecting these contributions. The analysis identified structure-borne/airborne and front versus rear contributions and the results were analysed to determine the dominant sources and paths that contribute to the receiver's experience.

"We've been able to find and attack unwanted NVH characteristics from a very detailed and specific methodology. The SPC testing has been effective in both issue discovery and modelling of the subject car, moving into different techniques and strategies to attenuate any issues," explains Ryan Plum.

NORTH AMERICAN JURY STUDY

To ensure that the prototype met North American customers' expectations, another project was developed to create a sound quality target. A subjective jury evaluation using the Brüel & Kjær NVH Simulator was carried out. The goal was to build a jury test with 5 vehicles with different sound characteristics (3 measured

> "WE HAVE A LONG HISTORY OF TRUSTING BRÜEL & KJÆR'S MEASURING EQUIPMENT IN OUR TESTING."
>
> RYAN PLUM
> MANAGER, BODY & VEHICLE EVALUATION, SUBARU

vehicles and 2 digitally modified vehicles) to determine customer preferences for engine sound characteristics.

The NVH Simulator accurately recreates the noise and vibration of a vehicle in an interactive environment. Users can experience and evaluate the sounds and vibrations of a real or virtual vehicle while 'driving' through a virtual scenario. The simulator responds to the driver's input, reproducing the correct sound and vibration for the vehicle parameters, in conjunction with a representative visual scenario. Just as in a real vehicle, the stimuli are affected by changes in the road surface, vehicle speed, engine speed and throttle position.

"In a neutral, relaxing and even fun environment, the results from our customer clinics using the NVH Simulator have helped us learn the likes and dislikes of customers in a way that is easy for everyone to understand – from the experienced NVH engineers in the company to executives," explains Ryan Plum.

PERFORMANCE AND COMFORT

Brüel & Kjær's simulator module (the VSound™ System) was also used to help identify users' preferences while driving the actual vehicle. "Using the sound simulator, we've run clinics to check the blind preferences of drivers in both our performance segments and the more standard segments – so it's not just about performance, but also comfort," explains Ryan Plum.

"We've been able to fine-tune our current sounds to try different things and also create completely new 'virtual vehicles' to explore how far we can push things in terms of aggressive or sporty sounds that customers want in their daily driven vehicle. In some cases, we've also received really strong feedback about what our customers do not want."

"It's really a powerful tool – and the fact that it is integrated with the upstream engineering and discovery work is fantastic," says Katsuyoshi Tanaka. "A stop by the ARC to try out the simulator has become a required stop for any visiting NVH engineer when they come to Michigan!"

CONTINUING TO LISTEN AND LEARN

Subaru is using the results from the various studies to decide which sound and design technologies to use, and which are not cost-effective considering customers' needs within different segments. "We continue to use these studies to help us

determine the ideal engine characteristics for a segment. It can save us a lot of time and money and also help to avoid a complete 'miss' when designing or tuning a vehicle's sound package," says Ryan Plum.

"We are eager to expand our relationship with Brüel & Kjær. With each new project, we gain increased confidence in their abilities and the value it represents to Subaru. We have a few projects in the pipeline – including new directions of collaboration and also a continuation of the work we have already done," concludes Ryan Plum.

TECHNICAL REVIEW

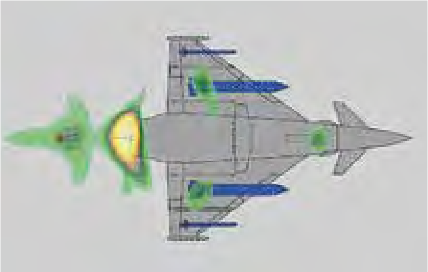
The Brüel & Kjær 'Technical Review' offers a deeper understanding of the many specialized disciplines within sound and vibration. It is where you will find the latest in-depth theory, measurement techniques, and details about specific instrumentation and technology.

KNOWLEDGE CENTRE

The Brüel & Kjær Knowledge Centre is our online library containing a wide range of detailed technical information.

Here you will find:

- Case studies
- Application notes
- Conference papers
- Primers and handbooks
- Technical reviews



Sound intensity map of the Eurofighter Typhoon fighter jet

For example, read on for the highlights from two white papers examining how noise models are validated for military aircraft, and how commercial aircraft manufacturers are using a new method to measure the noise impedance in the acoustic panels that line engine ducts. For the full details, visit our Knowledge Centre and read the latest issue of the Technical Review that has both of the complete white papers.

FLIGHT TEST VALIDATION OF NOISE MODELS FOR HIGH PERFORMANCE MILITARY AIRCRAFT USING BEAMFORMING

Airbus Defence and Space is in the process of developing software to optimize the airport take-off and landing-approach paths of their military aircraft for minimum noise impact on nearby communities. Calculation of the noise impact requires computer models of the noise sources on the aircraft, the propagation paths (including possible reflections) and the metric(s) used to quantify the perceived noise on the ground. The main noise sources on the aircraft are typically: jet, engine intake and aerodynamic sources around the landing gear and the airframe. Initially, Airbus used simple analytical models to quantify source strengths and directivities, but in order to get accurate predictions from the models, a test-based calibration must be performed.

In June 2015, Airbus Defence and Space asked Brüel & Kjær to propose a series of fly-over beamforming measurements for calibration of source levels and directivities for their Eurofighter Typhoon fighter jet. The Airbus project leader was Christian Waizmann, and Dr. Ernst Grigat was the technical project coordinator. They had seen our conference papers based on our cooperation with Japan Aerospace Exploration Agency (JAXA) on fly-over beamforming, which describe the use of a microphone array on the ground to localize and quantify noise sources on a passing business jet. A new challenge in connection with the Airbus measurements was the determination of not only source strengths but also their directivities.

A series of measurements was performed with Brüel & Kjær's standard 135-element, 29-metre-diameter microphone array in November 2015 at Neuburg Airfield in Germany. A total of 20 flyover measurements were performed over two days. Synchronization between the array data and the on-board data of the aircraft was obtained using GPS time signal in both systems. The figure shows an example sound intensity contour map on the underside of the Typhoon for a flyover at an altitude of 47 m with a speed of 100 m/s. Averaging was performed while the aircraft approached at 10 m and 20 m ahead of the vertical axis of the array.

The landing gear was up, but two external fuel tanks were fitted under the wings (shown in blue). Based on maps for each position of the aircraft (relative to the array) and on a set of operational conditions, the sound power of the individual sources and their directivities could be estimated and used to update the computer model of noise radiation. Using the calibrated model, more effective minimization of community noise exposure can be performed. ▶

TECHNICAL
REVIEW

Portable Impedance Meter Type 9737 is a user-friendly kit for quick, non-destructive acoustic material testing

Impedance testing of a GKN Aerospace zero splice acoustic panel

NEW METHOD FOR IN SITU MEASUREMENT OF ACOUSTIC ABSORPTION

Commercial aircraft manufacturers are always looking for ways to minimize airplane noise in the surrounding community. Acoustic panels line aero engine ducts to reduce radiated noise levels, and quality control of these panels is under ever increasing scrutiny. Approximate liner DC flow resistance measurements (frequency = 0 Hz) on unbonded acoustic materials have been replaced by measurements of the in situ acoustic impedance spectra of the fully bonded product after all manufacturing processes are complete. To meet this need, Brüel & Kjær has brought to the market a state-of-the-art flanged portable impedance tube, with routines for measurement of panel impedance, non-linearity, and quality control pass/fail tolerances.

The portable tube measures impedance, a parameter not normally assessed in interior acoustics, where the absorption parameter rules. However, impedance gives the designer the information needed to assess and refine the acoustic losses in a panel build-up.

Control of acoustic absorption is key to producing acceptable cabin acoustics in cars, trucks, trains, and aeroplanes as well as for room acoustics. Wall-mounted absorbers are one means to reduce the percentage of reflected sound. The acoustic absorption of large samples is typically measured in dedicated reverberation room facilities, while small-scale samples may be cut and inserted into impedance tubes. However, the final installed state is not always the same as that measured in a laboratory. The installed absorber build-up may differ due to variability in the absorber materials. It may also be affected by local constraints (for example, through induced changes to material densities, or by changes to the effective cavity depths). The measurement of the in situ acoustic performance of these absorbers has therefore recently gained greater focus as designers try to maximize the potential absorption per unit area in the installed environment.

Available methods for in situ measurement include the Adrienne in situ reflection method, and the Microflown p-u probe method. However, these procedures measure only the absorption coefficient spectrum of a given build-up, whereas the Brüel & Kjær tube measures both absorption and impedance, allowing an assessment of the frequency-dependent resistive and reactive components of a given installation. Crucially, this additional information allows a build-up to be either redesigned or refined to provide improved absorption per unit area.

Brüel & Kjær has recently performed a study comparing flanged impedance tube measurements with those taken in a reverberation room and from the traditional impedance tube method with a sample holder. The portable flanged impedance tube was shown to be quicker, simpler, and more repeatable than both the reverberation room and sample holder impedance tube tests. The portable tube allows fast non-destructive in situ material measurements as the meter just needs to be placed on the surface of the absorber. It is an excellent tool for benchmarking and may be used to measure the impact of the installation (for example, effects of facing sheets, curvature, material compression, bagging, etc.), while the impedance information may be used for re-tuning of the build-up for improved performance.

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Dr Per Brüel (1915-2015) wrote the first Technical Review

68 YEARS OF TECHNICAL REVIEWS

Since 1949 Brüel & Kjær has published 177 Technical Reviews. The first one was written by Dr Per Brüel and titled: 'New Instruments in Acoustic Research', describing the features and uses of the high-speed level recorder and the beat-frequency oscillator.

BRÜEL & KJÆR

Number 1
Jan. 1949

Technical Review

Teletechnical, acoustical and medical research

New Instruments in Acoustic Research

by

Per V. Brüel, D. Sc.*)

Summary.

A new electrodynamic high-speed level recorder with writing speeds up to 1000 db/sec and a new beat-frequency oscillator with regulating compressor are described. It is shown how it is possible with these two instruments to make recordings of frequency responses of microphones, amplifiers, loud-speakers, etc., building-acoustic recordings of sound insulation of walls, and automatic recordings of reverberation curves in halls.

Since long it has been Brüel & Kjær's desire to develop a level recorder faster than any high-speed level recorders known before, as, for example, the well-known Neumann recorder. In co-operation with the Acoustics Laboratory at the Chalmers University of Technology at Gothenburg we therefore examined various principles for recorders, and presently it was decided to make an electrodynamic recorder.

The principle of the apparatus is shown in fig. 1. The writing arm and the movable switch on the input potentiometer are both connected to a coil which is movable in a magnetic field. The coil is without current when the input voltage on the amplifier is 10 mV.

Any deviation of the input voltage on the amplifier will produce a current in either one or the other direction in the coil. In this manner the coil is set in motion and with the potentiometer arm searches out a new position, in which the current in the coil ceases again.

Six different interchangeable potentiometers can be used on this recorder. Four of them are logarithmic and have the ranges: 10, 25, 50 and 75 db. All these potentiometers have logarithmic resistance distribution. A fifth potentiometer gives linear scale from 10 to 110 mV and has hyperbolic resistance distribution. The sixth is a phon potentiometer for recording of noise from 35 to 110 phons. Fig. 3 shows the inside and outside of the potentiometer.

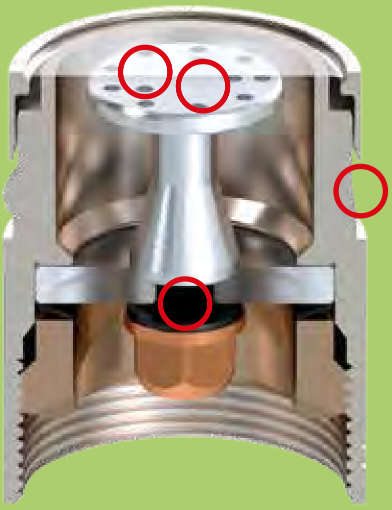
Fig. 1 and 2 show the construction of the recorder. The magnetic circuit consists of two cylindrical permanent magnets producing a radial field. The coil is mounted upon two light brass tubes which run on two hard

*) Since January 1948 at Brüel & Kjær A/S, Nærum, Denmark. Before that time associate professor at the Acoustics Laboratory, Chalmers University of Technology, Gothenburg, Sweden.

SPOT THE DIFFERENCE

Our microphone on page 9 had been modified in five places.

Did you get it right?



VIBRATIONS

From building giant ice sculptures in the Rocky Mountains in Colorado to creating Ice Music in Swedish Lapland, Tim Linhart is pushing the boundaries of what can be done with ice.

Photo © Karin Åberg

IN ICE

See the glowing igloo concert hall and hear the ice instruments (4:11)

To create a musical instrument from ice, it's crucial to understand its strengths and weaknesses. For ice sculptor, Tim Linhart, it all began in Colorado, 20 years ago: "A friend who built guitars asked if it was possible to build an instrument out of ice. So I built a giant bass, put strings on it from a piano, tightened the strings, plucked them, and heard music. However, I thought if I just tightened the wires some more, it would be louder. Instead, the frozen bass exploded!" This was just the start of Tim Linhart's long career creating many different ice instruments.

COLDPLAY

Ice absorbs vibrations, but not as much as wood, so the sound from an ice instrument is sharper and brighter than a traditional one. According to Tim, ice lets you hear more detail: "Because the ice is always changing, the crystals grow in different directions and there's a lot of tension. When you send vibrations through the ice the molecules become more evenly spaced and flexible and good for creating music."

And, just as a traditional wooden violin gets a richer sound with age, so does an ice instrument: "The more vibration, the mellower the sound," says Tim. "The guitars in particular get a sweeter sound over time, as the ice gets thinner."

To make an ice guitar, Tim builds the front and back plates out of ice and freezes them overnight. Then he carves the finer details and gradually builds up the space between the plates with ice. From there, a traditional neck, bridge and strings complete the instrument.

SWEDEN CALLING

Thirteen years ago, Tim was invited to Sweden to work with the Ice Hotel. Here, he built an ice pipe organ with 56 pipes, along with an ice orchestra. "I thought that this was going to be a great cold location for a concert," says Tim.

"Of course, I'd not counted on 450 people showing up for the first concert! All the warm bodies meant the temperature went up from -4°C to about 12°C. The tuning of the instruments went nuts and it was a bit of a musical disaster! As the temperature rises, the stringed instruments go down in pitch and the pipe organ goes up."

ICE AUDITORIUM

Following this, Tim began designing his own auditorium to provide good acoustics and keep temperature fluctuations to a minimum.

The result was the ice concert hall, constructed with two spherical igloos for the audience and a stage placed in the middle, slightly recessed to keep the temperature low. Tim created a vent at the top of each dome, allowing the warmth from people out and helping to maintain the optimal temperature of -5°C.

The walls of the concert hall are sprayed with water for a smooth ice finish, creating a reflective material that bounces the notes around and enabling the instruments to spread a powerful, crisp and rich sound throughout the room.

CHALLENGING ENVIRONMENT

"The acoustics are complex," says Tim. "There's an amazing sweet spot in the middle of the igloo, which is wonderful for all the sound. But there are also places where you can't hear the bass drum, for example."

Photo © Karin Åberg

Tim Linhart is the founder of Ice Music in Swedish Lapland. He has been an ice sculptor for 35 years, and working with ice instruments for the past 20 years

Because ice is less resonant than wood or metal, amplification is required for the string instruments: "I make a small hole in the side of the guitars for a transducer. In violins, I use two transducers, so vibrations from both plates are picked up. I place the transducers as far away from the strings and the bridge as possible, because we want to hear the ice." ►

VIBRATIONS
IN ICE

> "A FRIEND WHO BUILT GUITARS ASKED IF IT WAS POSSIBLE TO BUILD AN INSTRUMENT OUT OF ICE. SO I BUILT A GIANT BASS, PUT STRINGS ON IT FROM A PIANO, TIGHTENED THE STRINGS, AND HEARD MUSIC."
>
> TIM LINHART

It takes 35 hours to complete a mandolin

Mattias Sandlund playing an ice cello

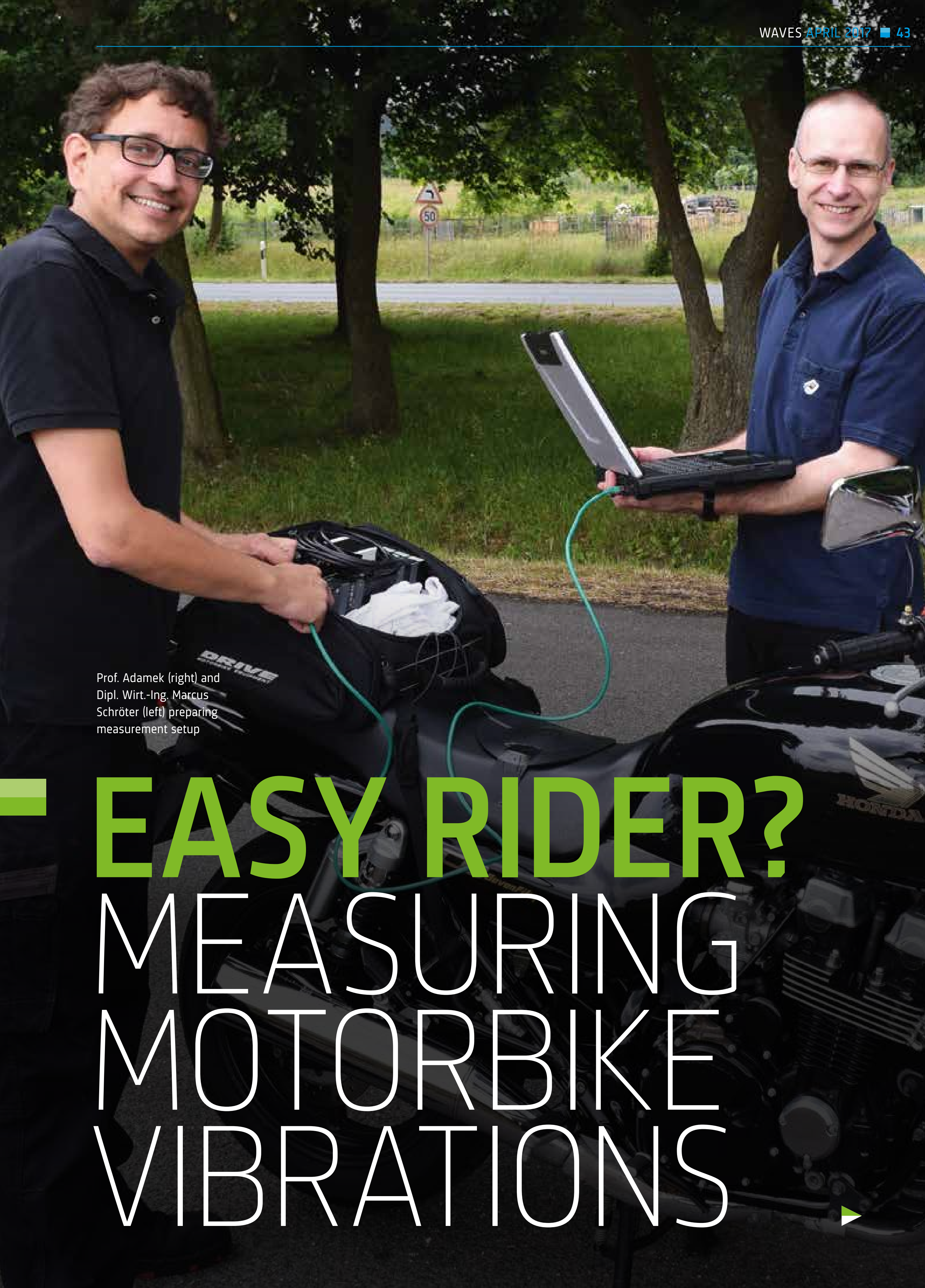
Tim works closely with a sound engineer to manage the cold and moisture interfering with the different channels. "The whole environment is challenging because of the close proximity of electricity and water," explains Tim. "Every now and then a buzz occurs and the sound engineer helps identify it. He goes round with a hair dryer – even sometimes fixing channels mid-concert!"

The LED lighting used inside the instruments – to brilliant atmospheric effect – can also result in interference in the sound system. "If a mic and LED light are too close within an instrument, it can cause a problem," explains Tim. "We moved the LED lights out of the violins to avoid the issue."

NEW DESIGNS

With the pitch problems in mind, Tim has invented new instruments, such as the 'Graviton' – a massive 37-string instrument with 2.2 tons of steel plates, some weighing up to 75 kg. The plates are hung on the end of the strings instead of tuning pegs. The weight creates tension in the ice and helps to hold consistent tuning. Another invention is the 'Rolandophone', which is a giant percussion instrument with 44 pipes that looks a bit like a pan flute.

To give everyone the best seat in the house, Tim is planning a new design for the next ice concert hall. He wants to add geometric billowed ribs on the roof of the new auditorium to enhance the acoustic experience. "If all goes to plan, the new concert hall will have a large dome in the centre for the orchestra, a dance floor, and three surrounding domes with space for 350 people," concludes Tim. ■



Prof. Adamek (right) and Dipl. Wirt.-Ing. Marcus Schröter (left) preparing measurement setup

EASY RIDER?

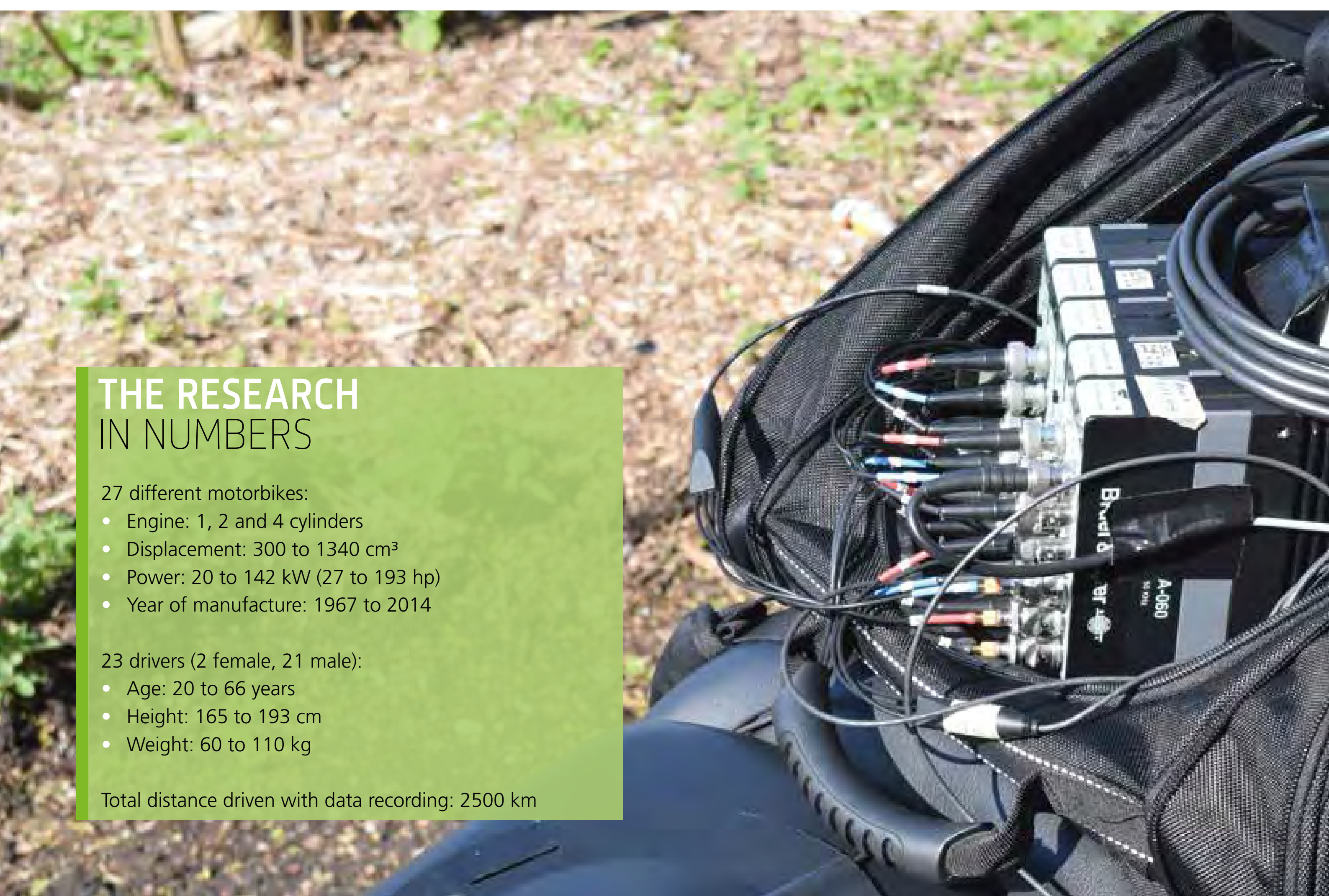
MEASURING MOTORBIKE VIBRATIONS

EASY RIDER? MEASURING MOTORBIKE VIBRATIONS

If you ride a motorbike for any length of time, you might notice that vibration from the engine causes hand numbness – or white-finger syndrome – and other unpleasant physical sensations. Vibration levels can have a negative impact on health and on a rider's reactions, contributing to accidents.

Excessive vibration in a motorbike's handlebars can make riding uncomfortable and even unsafe. Most riders notice these sorts of vibrations at some time and report experiencing hand cramp or numbness, which is not good news when you need your hands to control nearly every aspect of a motorbike on the road!

Motorbike riders are exposed to both whole-body and hand-arm vibrations. The magnitude of vibration exposure depends on several factors, for example, driving speed, the engine's RPM, the type of tyres and tyre pressure, and the road conditions. It also depends on the way you sit on the motorbike and grip the handlebars. Vibration transmitted through handlebars and footrests seem to cause the most problems.



THE RESEARCH IN NUMBERS

27 different motorbikes:

- Engine: 1, 2 and 4 cylinders
- Displacement: 300 to 1340 cm^3
- Power: 20 to 142 kW (27 to 193 hp)
- Year of manufacture: 1967 to 2014

23 drivers (2 female, 21 male):

- Age: 20 to 66 years
- Height: 165 to 193 cm
- Weight: 60 to 110 kg

Total distance driven with data recording: 2500 km

> “BIKERS ARE EXPOSED TO EXCESSIVE VIBRATIONS AND MANY REPORT EFFECTS ON THEIR BODY. HOWEVER, MOST DO NOT PERCEIVE THESE VIBRATIONS AS TROUBLING.”
>
> PROFESSOR ADAMEK

An EU Directive provides limits for vibrations experienced by people who ride motorbikes as part of their profession. These values can also be used as guidance for non-work-related riding. The Directive states that exceeding these limits over an extended period can negatively affect health, resulting in, for example, vascular or muscular disorders. In addition, overall performance can be influenced, increasing the risk of accidents.

MEASURING OVER 2500 KM ON 27 BIKES

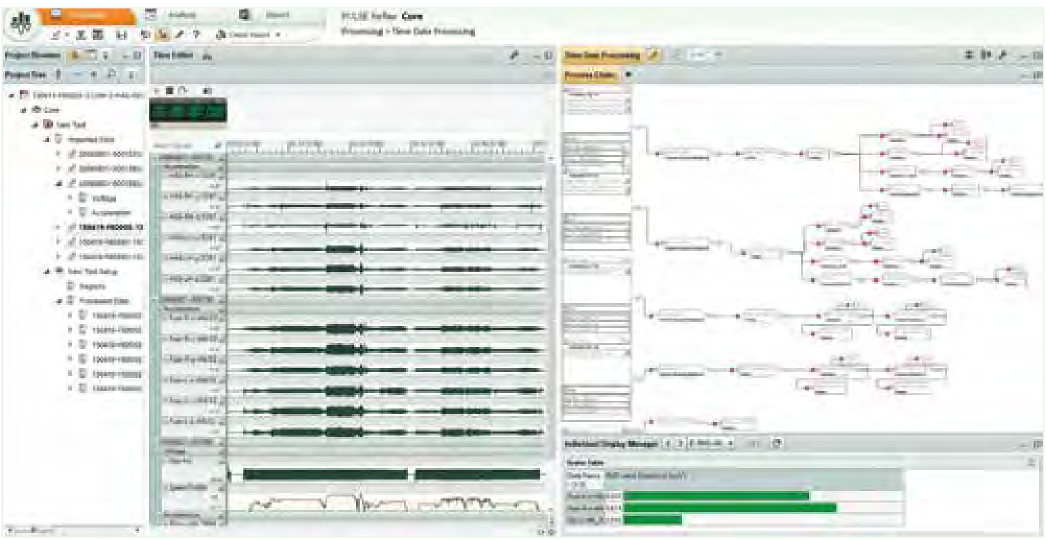
Professor Adamek from the University of Applied Sciences Osnabrück, Campus Lingen in Germany took on the challenge to determine the vibration exposure to motorbike riders and recently published an impressive research project. Vibration was measured over a total of 2500 km, driven on 27 bikes, with 23 different drivers.

The research looked at people who ride motorbikes for their profession (using police motorbikes and the St. John’s accident assistance motorbikes) and for private use. The goal was to quantify the exposure to vibration while riding, and to develop the order of magnitude of this exposure depending on motorbike types for different riders.

In the past, a number of studies have looked at vibration and motorbikes but none of these have considered three sources of vibration together: the handlebars, footrests, and the seat. ▶

EASY RIDER? MEASURING MOTORBIKE VIBRATIONS

Analysis with PULSE Reflex Core: Time data with acceleration-signals and speed profile on the left and process chain with part of the result table on the right



SUBJECTIVE ASSESSMENT – WHAT DO YOU FEEL?

To start with, 217 people (6% female and 94% male) answered a questionnaire about their experiences of motorbike vibrations.

Overall, people reported that vibrations were particularly noticeable when driving on the motorway.

The results indicate:

- 83% of riders experienced some physical effects related to motorbike vibration
- 12% of riders experienced circulation problems
- Approximately 2/3 of riders reported that vibration was not at all (or only slightly) problematic, despite reporting physical effects

COLLECTING DATA WHILE RIDING

All the measurements for the riding assessment part of the study were gathered using a stand-alone recorder (Brüel & Kjær LAN-XI NOTAR) and Brüel & Kjær triaxial accelerometers mounted on both handles, both footrests, and one on the seat. In addition, the velocity was recorded using GPS technology.

The footrests varied significantly in design from each other. Measurements were done on pedals or platforms, which were different shapes, depending on the motorbike model. Different types of accelerometers were used, depending on whether the footrest had a rubber surface, and the mounting was done with or without an adapter. In one case, a magnet adapter was used. Data was recorded using the LAN-XI with a mobile power supply installed on the driver's seat in a seat-bag. Finally, data analysis was carried out using Brüel & Kjær's PULSE Reflex™.

TESTING DIFFERENT CONDITIONS

Each motorbike drove approximately 40 km with data recording in progress. In total, 2500 km was driven on 27 bikes including test runs and endurance tests to gather all the measurements. Vibration data was measured over a 5 to 10 minute period for each of the following different conditions:

- At a constant speed of 50 km/h
- At a constant speed of 90 km/h
- At a constant speed of 130 km/h
- Driving on a winding country road with varying speed, acceleration, and braking

The road surface was considered 'good' on the constant speed driving routes and 'good to medium' on the country road.

EVALUATIONS

Vibration at the handlebars was filtered (frequency range 6.3 to 1250 Hz) and then the vibrations of the three measured translational directions (x, y and z) were combined to form a total value. The total value was then given frequency-dependent evaluation factors, which map the sensitivity of the hand-arm system to different frequencies. The frequency-evaluated total vibration value was then used for assessment.

To ensure the reproducibility of the measurements, the accelerometers were mounted with cable straps and a tool to tighten the straps with always the same force

For whole-body vibrations (at the footrests and in the seat), the filtering was in the frequency range from 0.8 to 80 Hz. The oscillation direction (x, y or z) with the highest value was then evaluated. For motorbike oscillations, it is always the z-direction (perpendicular to the road surface) that has the highest oscillation value, so only this was used in the evaluations.

INDIVIDUAL RIDER INFLUENCES

For a given motorbike model, the individual rider can significantly influence the actual vibration exposure through their driving pattern. To determine the influence, measurements were carried out with three different drivers (Driver 1: 183 cm, 95 kg; Driver 2: 177 cm, 67 kg; Driver 3: 183 cm, 70 kg) on the same day, on the same bike (BMW F800GS, 2012) and on the same test route. All sensors remained mounted between the test drives, to exclude mounting related variations.

It was found that differences between riders could be attributed to different driving styles (choice of gear, intensity of acceleration and deceleration), the choice of 'line' (resulting in contact with different road surface) and seat posture (different grip and self-stabilisation). The study indicates that each driver literally has it 'in his or her hands' to influence the magnitude of vibration exposure (for a given motorbike).

The measurements also indicate that vibration depends on the age of the bike (older ones lead to stronger vibrations than newer ones) and the number of cylinders (for example, vibrations of single cylinder bikes exceed those of four cylinders). In contrast, the driver's weight and driver's experience seem to have little or no significance.

EXCEEDING RECOMMENDED LIMITS

In this study, the exposure limits of the EU Directive were reached and, in some cases, clearly exceeded* (with regard to an exposure time of 8 hours per day, see sidebox table).

All measurements indicate a significant variation depending on the bike model. In general, values increase with increased speed. In the case of hand-arm vibrations, the 8-hour action value of 2.5 m/s² was (depending on driving mode) exceeded by all makes of bike, but also the limit value of 5 m/s² was exceeded by a number of bikes.

For whole-body vibrations, the magnitude of vibrations increases with increased velocity and the vibration at the footrests exceed those on the seat. The action value of 0.5 m/s² was exceeded by all vehicles (depending on the driving mode). When driving under varied modes (cross country, cornering, braking, and accelerating) even the limit value of 0.8 m/s² was exceeded in z-directions for almost all measurements.

For the investigated vehicles in the police service, both the hand-arm and whole-body vibration values were exceeded, but the limit values were not. However, the St. John's service riders did not exceed the values.

CONCLUSIONS

Professor Adamek concludes that bikers are exposed to excessive vibrations and many report effects on their body. However, most do not perceive these vibrations as troubling. Measurements of human vibrations for motorbike riders clearly exceed the recommended limits, and whole-body vibrations exceeded the limits more than hand-arm vibrations*. For a given bike model, the individual driver can significantly influence the actual vibration exposure through their driving style and seat posture. ■

* To inform various groups of riders about the vibration exposure risk, the results from this study are available in a public database that can be accessed from the project homepage: www.hs-osnabrueck.de/de/motorrad-humanschwingungen/

EU DIRECTIVE ON VIBRATION (2002)

The Directive aims to ensure the health and safety of people exposed to vibration. It distinguishes between hand-arm vibration and whole-body vibration and defines the following exposure limit values (standardised to an 8-hour reference period):

Hand-arm vibration

- Exposure limit value = 5 m/s²
- Exposure action value = 2.5 m/s²

Whole-body vibration

- Exposure limit value = 1.15 m/s² (x,y); 0.8 m/s² (z-direction)
- Exposure action value = 0.5 m/s²

BRÜEL & KJÆR NEWS

CVLD is Back

Constant voltage line drive (CVLD) and constant current line drive (CCLD) have been around for a while and they have a lot in common, but due to production cost, CCLD had been the favourite. Thanks to improvements in technology, production cost for CVLD is no longer the deterrent it once was. CVLD is now an attractive option to CCLD, especially in the defence industry due to CVLD's superior immunity to EMI, EMP and Magnetic field interference. CVLD also benefits from lower ground-loop sensitivity (44 dB lower than CCLD preamplifiers) and a greatly increased maximum cable length when compared to the typical CCLD cable length of 30 metres – CVLD cable lengths can exceed 1000 metres.

RoHS2

Brüel & Kjær cares about the environment – sound, vibration and RoHS (Restriction of Use of Certain Hazardous Substance in Electronic and Electronic Equipment). And to ensure that we continue to protect human health and the environment, we are making sure that we meet Directive 2011/65/EU in order to reduce the potential exposure of hazardous substances during the use phase of our products.

Sonoscout 2.0 has been released

Version 2.0 of the Sonoscout™ app was released on the 19th of January, and the initial customer response has been very positive. This release significantly updates the look and feel of the app and adds new features. This app automatically updates on your iPad® based on the common iOS settings in either iTunes® or on the iPad® itself. When the updated app is opened for the first time, the start screen will show a highlighted list of new functionality, which includes ASAM-ODS .ATFX file export and the in-app LAN-XI battery meter.

Wi-Fi upgrade for the ASUS router in the Type 3660-A LAN-XI frame

We have greatly improved the connectivity for the Type 3660-A LAN-XI frame's ASUS router. The firmware for this upgrade is available for all customers who have purchased A-frames that use ASUS routers. The software update will not have any impact on calibration. All A-frames (using ASUS routers), purchased after December 2016, already use the new firmware.

NEW SOFTWARE PLATFORM FOR OPERATIONAL MODAL ANALYSIS AND STRUCTURAL HEALTH MONITORING

Based on cutting-edge technology and innovative new techniques, the new platform doesn't just replace our existing market-leading solution for Operational Modal Analysis (OMA) with a significantly enhanced one – it also adds unique tools for Structural Health Monitoring (SHM).

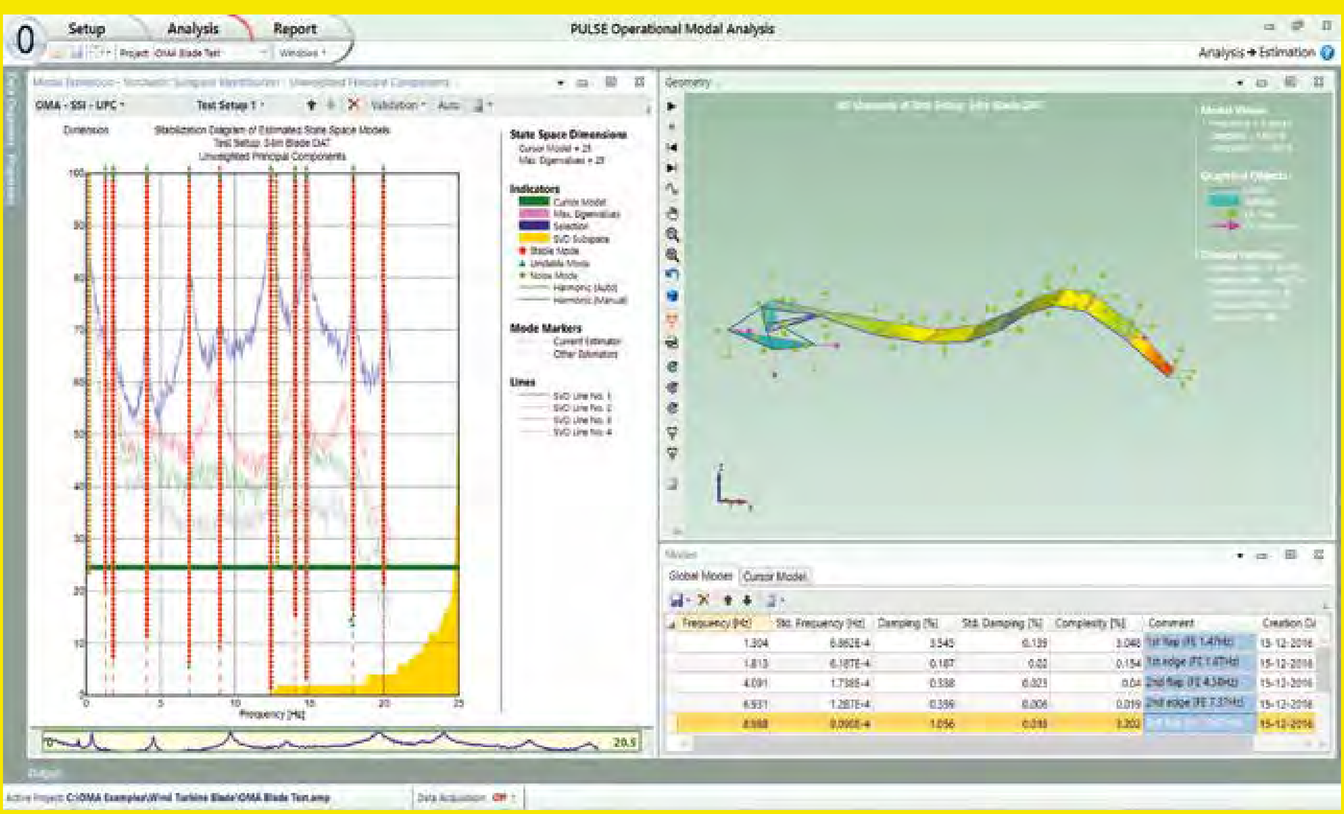
New major OMA features include:

- Geometry creation tool
- Removal of harmonics in the time domain
- Uncertainty calculations of modal parameters
- Integrated reporting using Word and PowerPoint®

Special SHM features include:

- Automatic measurement file upload and processing
- Automatic mode tracking as a function of the analysis sessions
- Robust damage detection indicators based on changes in the physical domain using state space models
- Notification services such as visual, auditive, email and web services

The software is designed for seamless integration with PULSE for measurement and Test-FEA integration, but can also be used as a stand-alone package. ■



CUSTOMER NEWS

SEE MORE
Read the full case study at:
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REDUCING THE IMPACT OF MINING NOISE IN THE COMMUNITY

Vale SA is a Brazilian-based global mining company that transforms natural resources into wealth with social responsibility and respect for the environment. It operates in approximately 30 countries worldwide.

The organization carries out industrial operations in the Complexes of Vargem Grande, Itabiritos and Paraopeba, which are located in five different municipalities in the state of Minas Gerais, Brazil.

Vale's Environmental Control Center is responsible for the environmental management of its mines. It sought a noise monitoring system to measure, record, communicate and reduce the noise impact of its operations on neighbouring communities.

Vale selected Brüel & Kjær's Sentinel noise monitoring system to help balance its operations with impact on the community. The system automatically correlates weather parameters, including air temperature, wind speed and direction. With recorded audio, it also identifies which noisy events are caused by its mining activities, and which are caused by another source of environmental noise.

Vale also opted to use Predictor-LimA noise mapping software in its Sentinel system. Predicting noise levels enabled Vale to map and use software noise simulation to decide on strategies for production and circulating traffic at the mine.

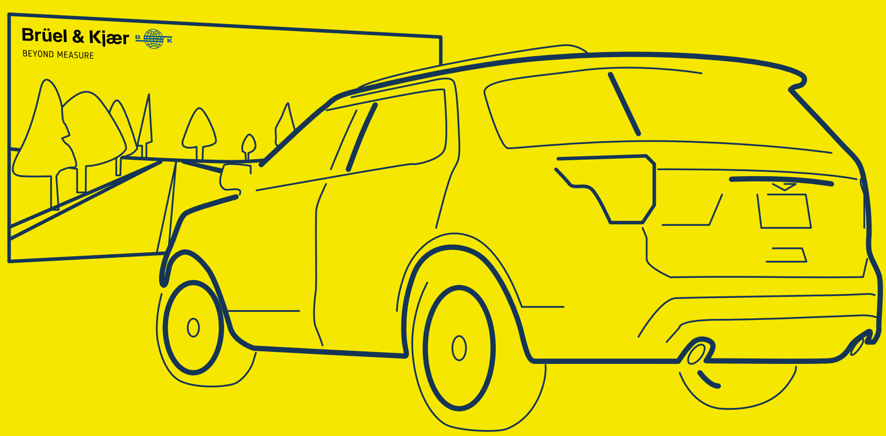
Sentinel and Predictor-LimA have made it possible to reduce noise impact events. These processes have resulted in fewer community grievances and, in particular, reduced staff time spent dealing with community complaints.

Engage with Strathclyde 2017 – bringing together academic and industrial experts

Many of our researchers are renowned global experts in their respective fields, aiding the scientific community and teaching at renowned centres of excellence. One of them, Dr Dmitri Tcherniak, has been invited to attend the upcoming Engage with Strathclyde 2017 held in Glasgow at the University of Strathclyde on the 2 – 5 May 2017, where he will be a keynote presenter at the Advances in Monitoring and Assessing Structural Integrity event, showcasing how the cost of maintenance and management of sustainable energy assets can be reduced. Dr Tcherniak will talk about the recent advances in vibration-based structural health monitoring for wind turbines.

More details

ADDING VALUE FOR AUTOMOTIVE CUSTOMERS



Automotive customers are increasingly demanding the provision of an integrated solution, combining hardware, software and services. Ford Motor Company has been working with Brüel & Kjær's NVH simulator products for a number of years.

Ford utilizes Desktop Simulators (DTS) to help refine their NVH targets and troubleshoot sound quality issues. The DTS allows Ford to evaluate standard NVH test or computer-aided engineering data in a true driving environment, converting the data in real-time, into an accurate representation of the sound in response to the drivers' inputs to the controls.

The limitation of the DTS is that it only handles the sound of the vehicle, not the vibration. There are many NVH phenomena where the total perception of the issue is a combination of the sound and vibration experienced by the driver or passenger, for example, vibrations felt through the steering column and seat.

Ford evaluated a prototype of a Full-Vehicle Simulator (FVS) at Brüel & Kjær's Engineering Services facility at Millbrook and realised this was the next step in producing a more immersive experience for NVH evaluation. Ford took delivery of their FVS in December and has begun exploring the capabilities of the new system with the goal of integrating it into their product development processes.

"We realised that the FVS added the missing dimension of vibration and took us to the next level in improving NVH assessment and better decision making. It requires a significant investment in resources but the benefits to our NVH development make it worthwhile", says Mark Stickler, Ford's Manager for Powertrain NVH

FIVE QUESTIONS FOR THOMAS

Dr. Thomas Lewien founded Discom, provider of automotive production test systems, in 1995. His background in acoustics, NVH and signal processing, has resulted in 35 years of experience in developing electronics and software. His hobbies include photography, motorbiking, sailing and taking things apart to find out how they work.

MOTTO:

TRY A DIFFERENT ANGLE*

How do you see your role with Brüel & Kjær?

My role is to help integrate Discom into Brüel & Kjær and to make Brüel & Kjær successful in production testing.

What is the best advice you've been given?

To keep trying. At the age of six, I set out to build a small plane. I crashed with it on the slope of my uncle's garden – it did not fly at all. His advice was to try again with a different design. Reminding myself to look at things from a different angle still helps me in my daily work.

If you could have two super powers, what would they be and why?

Flying would be one of them, and I'm sure that anyone who has ever flown a glider would agree. Healing people would also be a marvellous gift.

What drives you in your work?

The unique opportunity of following a product through its entire life cycle: from ideas to development, from production to customer applications. Then refining it, re-designing it and creating the best possible solution.

What irritates you most about your own personality?

I should probably have a little more patience with others.

* An (in)famous developer rule says: 90% of the time the problem is not in the 10% you are looking at.

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