# CASE STUDY

## Isuzu – Improving the Sound Quality of Diesel Engines

Automotive
Japan
PULSE Beamforming, Acoustic Holography

*In order to improve the perceived sound quality of diesel engines, Isuzu cooperated with Brüel & Kjær to develop mapping of Sound Quality metrics, where noise sources can be identified based on their sound character using perception-based metrics such as loudness, sharpness and roughness. Together, they also developed a new impulsiveness algorithm to clearly identify the source of impulsive noise in diesel engines. The result of the Isuzu/Brüel & Kjær project is now the world's first commercially available sound quality metrics mapping software for beamforming and Statistically Optimal Near-field Acoustic Holography (SONAH) systems.*

*Photos courtesy of Isuzu*


Brüel & Kjær

## The Company

Isuzu Motors Limited is a Japanese commercial vehicle and diesel engine manufacturing company, with headquarters in Tokyo. Since the first truck rolled off the assembly line more than 80 years ago, Isuzu has been pioneering technological innovations. Isuzu's corporate vision is to be a leader in transportation, commercial vehicles and diesel engines, supporting its customers and respecting the environment.

Isuzu Motors Limited now focuses on trucks and buses with production in Japan, Thailand and various other countries. The trucks range from small pickups to very heavy trucks.

***Fig. 1***
*Isuzu's R&D facilities*

Today, engines are still the heart of Isuzu, and over 20 million of them have been delivered to customers worldwide. They range from 2.5-litre (4-cylinder) to 16-litre (6-cylinder) and are noted for their reliability and durability. In fact, Isuzu is the supplier of diesel engines to Opel and General Motors. As well as trucks, Isuzu engines are also used in the marine market and for industrial machinery such as excavators and cranes. Isuzu's main focus is on developing diesel powertrains and improving powertrain quality.

Isuzu's R&D facilities are located at its Fujisawa plant in Kanagawa Prefecture, south of Tokyo. First commissioned in 1961, this huge site also handles the assembly of commercial vehicles, and manufactures various components.

Isuzu's relationship with Brüel & Kjær goes back more than 30 years and all their microphones and the majority of their accelerometers are from Brüel & Kjær. In addition, Isuzu has many PULSE Data Acquisition and Analysis systems and some wheel arrays. A large portion of FFT and CPB analysis at Isuzu is done using PULSE.

## Why Map Sound Quality Metrics?


In recent years, environmental issues have placed emphasis on vehicle emission and vehicle noise including improved engine noise performance. It is becoming increasingly important not just to reduce the radiated sound pressure, but also to improve the sound quality of vehicles for the comfort of both passengers and local residents. Isuzu regards sound quality as a key selling point and differentiator.

Diesel engines make a characteristic noise known as diesel clatter, diesel nailing, or diesel knock. This is caused largely by the sudden combustion of fuel that has already evaporated when combustion starts. Although unavoidable, this sound is not desirable and it is notoriously difficult to identify precisely where the sound is coming from.

Traditional microphone array techniques, such as beamforming and near-field acoustic holography (NAH) localise noise sources based on physical quantities such as sound pressure and sound intensity. However, other sources may have higher values of sound quality metrics, so the objective data in the contour plot may not accurately reflect one's subjective perception. For example, improving the perceived sound quality of diesel engines may require the identification of noise sources emitting impulsive or rough sounds rather than having higher sound pressure level. For this reason, Isuzu got together with Brüel & Kjær to develop mapping of Sound Quality metrics, where noise sources can be identified based on their sound character using perception-based metrics such as loudness, sharpness and roughness. Together, they also developed a new impulsiveness algorithm to clearly identify the source of impulsive noise in diesel engines.

"The goal behind mapping Sound Quality metrics is to identify annoying or bad quality sound," says Mr. Haruki Saito, Manager and Specialist, Noise & Analysis Experiment Group. He continues, "In the past we could measure overall sound pressure level, but the measurement was objective and did not provide subjective analysis of the sound as perceived by humans."

## Simulation

In order to validate the Sound Quality mapping, a simulation using ideal point sources with different sound characteristics was performed. It was carried out using both beamforming and acoustic holography techniques. In the simulation, individual sources had a dominant sound character, for example, sound pressure level, loudness, sharpness, roughness, and impulsiveness, and they were separated spatially on a source plane.

For the simulation of beamforming, a 66-channel wheel array with a diameter of 1 m was used, and monopoles were distributed on the source plane 1 m away from the microphone array. For the simulation of acoustic holography an 8 × 8 rectangular array having a microphone spacing of 5 cm was used, and the distance to source was 7.5 cm.

In the simulation of both array techniques, the Sound Quality mapping was able to identify sound sources based on their individual characteristics rather than using traditional measures such as sound pressure, and the results corresponded well with those based on the designed characteristic of individual sources.

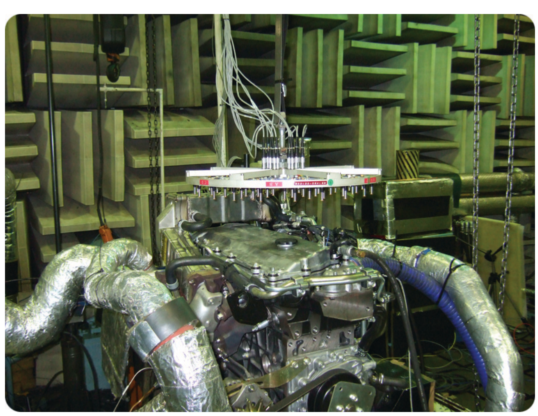
## Integrating the Algorithm

Following simulation and validation, Brüel & Kjær and Isuzu together developed an impulsiveness algorithm to reliably predict the perceived impulsiveness of diesel engine noise. It was confirmed to be useful by comparing the predicted impulsiveness with the results of a listening experiment where perceived impulsiveness of diesel engine noises was evaluated. The impulsiveness algorithm was then integrated with Sound Quality mapping in order to identify impulsive noises in a more efficient manner.

## Engine Noise Testing

Finally, the mapping of Sound Quality metrics was applied to practical measurements of two diesel engines (A and B) designed for commercial vehicles – the first, a 5.2 l, in-line 4-cylinder engine and the second, a 9.8 l in-line 6-cylinder engine.

***Fig. 2***
*Using an 84-channel Sector Wheel Array, beamforming and SONAH measurements were carried out in a hemi-anechoic chamber on both engine A (left) and engine B (right*



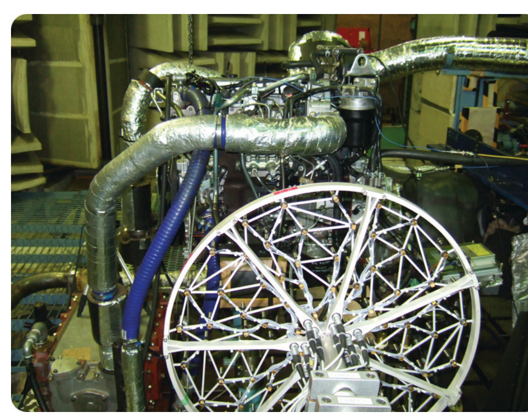
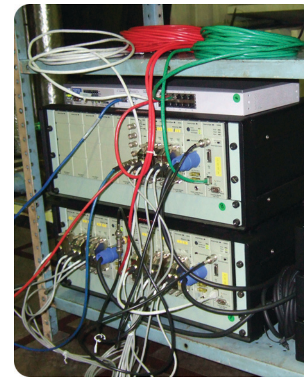


*Fig. 3*
*PULSE in Isuzu's sound quality mapping facility*

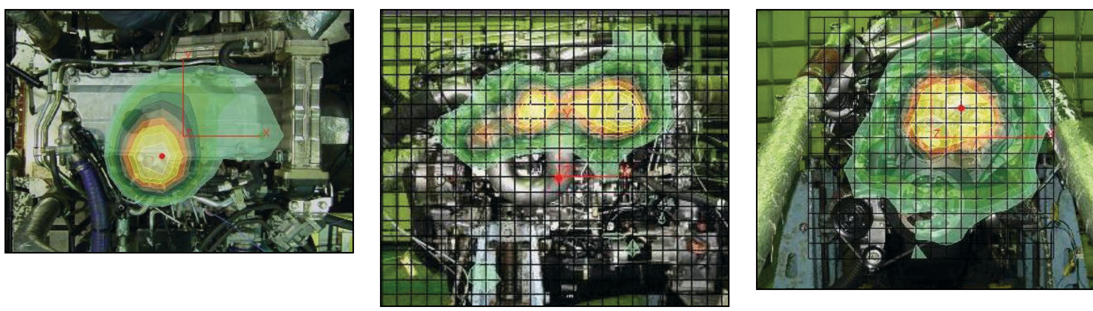


To cover a broad frequency range, both beamforming and SONAH methods were used – beamforming to identify noise sources at high frequencies and SONAH at low frequencies. An 84-channel sector wheel array of 0.5 m diameter was used to perform all measurements. Mr. Saito says, "It takes about a day to set up the system, make the measurements on three surfaces and process the data using Brüel & Kjær's PULSE platform software". Measurements included Run-up/run-down from idle to maximum RPM as well as steady state.

The resulting location of problematic noise sources in the Sound Quality maps disagreed largely with that of traditional sound pressure maps. In the case of the beamforming and SONAH tests on engines A and B, modifications were made on the head cover and the valve gap, and the effect of the modification was validated by performing measurements using a single microphone positioned at a distance of 1 m.

Mr. Saito says, "By identifying the problems we can make design changes and ultimately improve the sound quality. But we have to decide which metrics are important for various engine conditions, for example, one of the methods is to record the sound quality metric followed by jury evaluation". He continues, "At the moment, we focus mainly on airborne noise. The dominant diesel engine noise is from 800 Hz to 4 kHz. Injector and turbo charger noise can reach 10 kHz and this is currently measured using PULSE and one microphone. We're very interested to see if the frequency range of sound quality metrics mapping can be increased so that these noise sources can be fully evaluated".

*Fig. 4*
*Mapping various metrics using beamforming. From left to right – Stationary Loudness, Roughness, and combined metrics*



Isuzu no longer considers sound quality metrics mapping to be an experimental technology and is the first company in the world to actively use this solution to perform real measurements. Mr. Saito believes that, "Sound Quality metrics mapping software will be very beneficial to Isuzu and will become an increasingly valuable tool. The initial tests were made to examine the sound quality of the powertrain on a test bench. However, having seen the results, the department responsible for testing on whole vehicles with engines installed is very interested in using the same technology". He concludes, "I am very satisfied with sound quality metrics mapping and it has huge potential to enable Isuzu to develop our diesel engines that will continue to lead the world".

## Now Available as Standard

As a result of the cooperation between Brüel & Kjær and Isuzu, mapping of Sound Quality metrics has been implemented in PULSE Beamforming Type 8608 and PULSE Acoustic Holography Type 8607 and is the world's first commercially available sound quality metrics mapping software for beamforming and SONAH systems – a first class example of how Brüel & Kjær and one of its key customers worked together to develop cutting edge technology for the automotive industry.

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