REDUCING NOISE AND VIBRATIONS

Acoustics play a critical role in product development across various engineering domains, significantly impacting both functionality and user experience. Often, products are designed without adequate consideration of their acoustic properties, focusing primarily on compliance with regulatory noise standards. This oversight can lead to suboptimal user experiences and necessitates post-market adjustments based on customer feedback or as a response to evident product performance issues. Sorama emphasises the importance of incorporating acoustic considerations early in the design process to enhance product sound quality and reduce vibrations.

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AUTHORS' NOTE

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Insight into vibrations

Loud products contribute to a noisy, and therefore unhealthy work and living environment. Air conditioners, air circulation systems, vacuum cleaners and coffee machines are well-known examples of products that can be perceived as a noise nuisance. Gaining insight into the vibrations that are present in a product and using that information in a holistic approach enables the development of high-quality products with more acceptable noise levels.

Noise reduction

Incorporating noise reduction in product development is essential. As consumer expectations and regulatory demands evolve, the emphasis on noise reduction will continue to grow, making it a critical consideration in the design and development of new products.

When a product emits unwanted noise, this can point towards underlying issues, such as broken components or friction between different parts. Identifying the root cause of specific sound problems enables quick troubleshooting and can prevent further breakdown of the product. Solving sound issues in product development is a complex process that involves multiple disciplines, including acoustics, engineering, materials science, aesthetics and user experience. This is one of the reasons why it is so often done after the product has been launched and a sound problem has occurred.

Vibrations in machines

Apart from gaining insight into vibrations of products that can be perceived as a noise nuisance, Sorama's technology also provides understanding of vibrations that could prevent the product from functioning as it should or introduce wear to the product.

As an example, take an industrial machine for which vibration regulations are not met. Vibrations in the machine could lead to serious consequences, such as parts or the whole machine breaking down. Sound imaging technology provides insight into the origin of the vibrations of the machine. Furthermore, the measurements can show how vibrations travel from their origin to other parts of the machine. Given these insights, the manufacturer could create design changes on the pinpointed problematic components of the machine, which could prevent future breakdowns.

Acoustic Design Cycle

It is Sorama's goal to simplify sound issues in product development. The Acoustic Design Cycle (Figure 1) is an iterative cycle that relies on gaining insight into unwanted sound and translating this to proper solutions, instead of the traditional trial-and-error method. This design cycle depicts how acoustics should be addressed in the design process. It is similar to general design thinking, as it is an iterative process that is user-centred and holistic. This approach, where results are achieved through conscious competence instead of coincidence, will result in a shorter time to market and simultaneously increase customer satisfaction.

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Sorama Acoustic Design Cycle.

Sound imaging technology

Using high-resolution acoustic cameras, detailed sound data from the product are captured. The acoustic cameras from Sorama consist of a microphone array with tens to hundreds of microphones, depending on the research, aimed at near-field (< 0.03 m) and far-field (> 0.5 m) measurements. Subject to the purpose of the measurement, different acoustic cameras can be used. For acoustic product design, the Sorama CAM64 (16 by 16 centimeter array with 8 x 8 microphones) and CAM1K (64 by 64 centimeter array with 32 x 32 microphones) are used. In general, the CAM64 can be used to perform measurements on smaller products, while the CAM1K can cover bigger surfaces.

The gathered data is transferred to the Sorama portal, which visualises the sound through, for example, frequency spectra, far-field beamforming, and near-field acoustic holography analysis (see the text box). Hence, it can be identified how the sound behaves and where it originates. These measurements can be done without any prior knowledge of acoustic cameras. To go even more in depth or receive assistance during the measurements, Sorama offers consultancy services to its customers.

Acoustic Design Cycle in action

To show the role of acoustics in product design, the case of a well-known premium brand coffee machine (Figure 2) is presented. Throughout the entire process, sound imaging was used to make data-driven decisions. Due to the size of the coffee machine, the measurements were done with the Sorama CAM1K. This camera covered the entire coffee machine when performing near-field measurements.

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The well-known premium brand coffee machine that was used for the measurements presented in this article.

Far-field and near-field

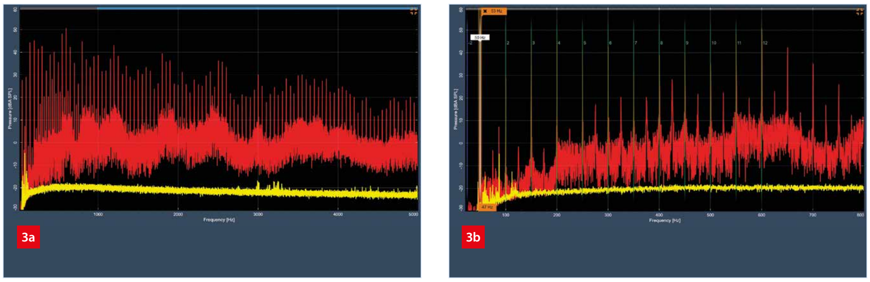
Far-field beamforming is sound localisation at a far distance from the object under test. This measurement technique visualises the location from which sound is radiating most dominantly over a selected frequency range. The sound localisation is done with a heatmap, consisting of colours in the range from blue to red. A red colour indicates a high sound pressure level, while a blue colour describes a lower sound pressure level. This can be compared with a thermal camera that produces a heatmap from which the location of the highest temperature on an object can be identified.

Near-field acoustic holography gives highly detailed information about the behaviour of pressure waves very close to the object under test. Similarly to far-field beamforming, a heatmap of colours in the range from blue to red is used, but the definition of the colours is different. For near-field acoustic holography, a red colour means a maximum pressure, while a blue colour describes a minimum pressure. Sorama's cameras provide this information in three different projection modes: Pressure (Pa), Velocity (m/s) and Intensity (W/m^2). Depending on the purpose of the measurement and the acoustic properties of the object under test, the most suitable projection mode can be selected for acoustic analysis.

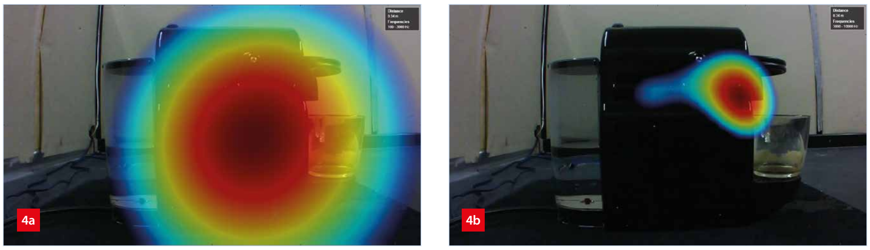
Using near-field acoustic holography, at a single frequency the distinction can be made between propagating waves (waves that exist in the far field and the near field) and evanescent waves (waves that only exist in the near field). The evanescent waves contain a lot of details describing the source. Measurements in the near field help to exploit this high level of detail. For example, they provide insight into how pressure waves move over the surface of an object (using the Pressure projection mode) or where certain vibrational modes can be found in the housing of a device (using the Velocity projection mode).

Research & Analysis

During the research and analysis phase, the importance of sound design for the value of the products is established; what norms are put on the product by stakeholders? Sorama's software tools were used to analyse sound images and data to diagnose the cause(s) of noise or poor sound quality. Specific areas or components contributing to unwanted noise or suboptimal acoustic performance were pinpointed.

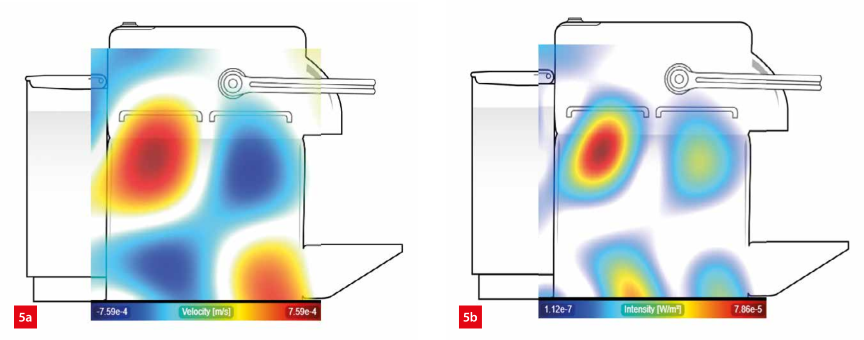


The frequency spectrum of the background noise (yellow) and the coffee machine noise (red) for two frequency ranges ('zoomed out' and 'zoomed in', respectively). The vertical scale represents the pressure from –30 to + 60 in dB(A) SPL.
(a) 10 Hz - 5 kHz.
(b) 10 Hz - 800 Hz; the location of the harmonics is indicated with green vertical lines.



The time-averaged far-field beamforming image, showing colour-coded sound intensity in dB(Z) SPL for the lower and higher frequencies, respectively.
(a) 100 Hz - 3 kHz.
(b) 3 kHz - 10 kHz.

Far-field measurement
To discover where the sound was coming from, far-field measurements were performed, yielding the sound pressure level (SPL) in decibels; either dB(A) or dB(Z) – here, A refers to frequency weighting to account for the human ear sensitivity, while Z stands for zero weighting. In the frequency spectrum, many peaks were observed, most of which were identified as harmonics of the fundamental frequency of 50 Hz (Figure 3). When inspecting the far-field beamforming sound images, the lower frequencies seemed to come from the middle of the coffee machine (Figure 4a), while the higher frequencies were radiating from the top right (Figure 4b). After identifying which part of the coffee machine was radiating the noise most dominantly, near-field measurements were performed to fully understand the data in high detail.



The near-field acoustic holography image of the side of the coffee machine, showing the measurement results at a frequency of 800 Hz.
(a) Particle velocity (m/s).
(b) Intensity (W/m^2).

Near-field measurement
After doing a few sets of measurements, at a frequency of 800 Hz (which describes one of the highest peaks in the frequency spectrum), a standing wave was found that made the casing vibrate. A standing wave is a wave that oscillates in time but does not change its position. In this case, the standing wave describes a structural vibration in the casing of the coffee machine. It can be identified by detecting maxima that are in phase (both coloured red or both coloured blue) or out of phase (red and blue coloured) with one another in the casing of the coffee machine. Locations that are not coloured red or blue do not vibrate at all.

The physics behind this can be described by nodes and antinodes. Nodes are locations that have zero amplitude and therefore do not move, while antinodes are locations that move with the maximum amplitude. The locations of the antinodes are described by red and blue colours. When the red and blue colours are seen next to each other, the antinodes are moving out of phase with one another. For example, the location with the red colour is moving towards the viewer, while the location with the blue colour is moving away.

Figure 5 presents the near-field measurements, showing acoustic holography images of the side of the coffee machine. These results are displayed as either particle velocity (Figure 5a), demonstrating four antinodes, or intensity (Figure 5b), which gives insight into the location of the centres of these antinodes and shows how this dominant vibration behaves. Here, the intensity is the time-averaged product of the sound pressure and the particle velocity (in the normal direction), and hence provides a measure for the amplitude of the vibrations in the normal direction.

Specification & Modelling
All of the findings in the previous phase were converged in order to define clear goals and draw the boundaries to which had to be adhered. In the project with the coffee machine, it was decided to mitigate the standing wave as much as possible, while keeping the internal systems of the coffee machine intact. This implied a restriction to adaptations in the casing of the machine.

Design & Creation
To address the structural vibration in the casing following a rapid prototyping approach, metal strips were applied to the locations of the antinodes that were out of phase with one another. This adaptation is depicted in Figure 6. By increasing the casing's stiffness, its acoustic properties were changed. The measurements gathered could now be incorporated in the product design and aesthetics.

Validation & Testing
As can be seen in the frequency spectrum in Figure 7, the original measurement of the coffee machine had a sound

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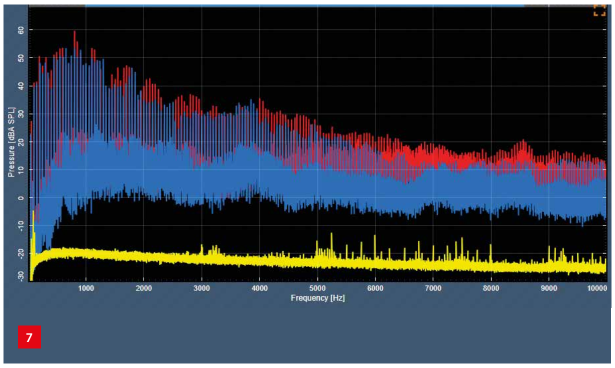
The metal strip adaptation attached to the side of the coffee machine.

pressure level of 71.6 dB(A). After applying the metal strip adaptation, the sound pressure level decreased to 67.9 dB(A), which is a prominent reduction. The total reduction after increasing the stiffness of the casing was equal to 3.7 dB(A). In order to verify the effectiveness of the solution, the near-field sound images were compared for the before-and after-adaptation scenarios (see Figures 8 and 9). This comparison shows that the colour intensity of the sound image has been reduced. This means that the vibration amplitude has decreased and verifies that the solution, applying stiffness to the casing in a certain position, mitigates the standing wave that is present in the casing.



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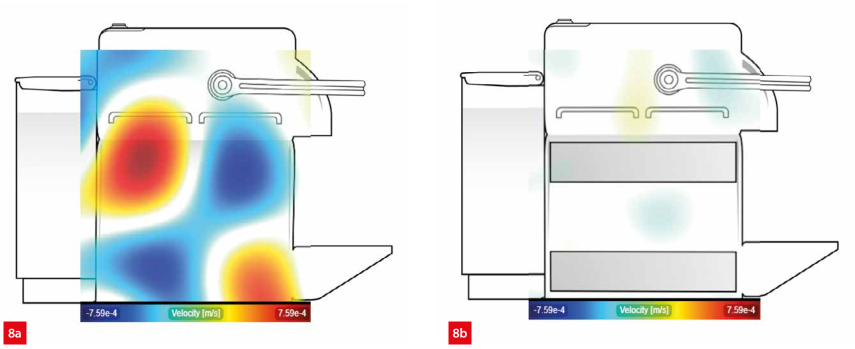
The frequency spectrum of the background noise (yellow), the coffee machine before the metal strip adaptation (red) and the coffee machine after the metal strip adaptation (blue). The overall sound pressure levels of these measurements are 32.0, 71.6 and 67.9 dB(A), respectively.

Evaluation & Communication

After testing and validation, all the data and findings were consolidated into very concise and to-the-point communication materials. These results allowed communication with other departments, such as the design team, to create a casing that incorporated the 'metal strip adaptation' in order to deliver a next iteration of the model that was much quieter.



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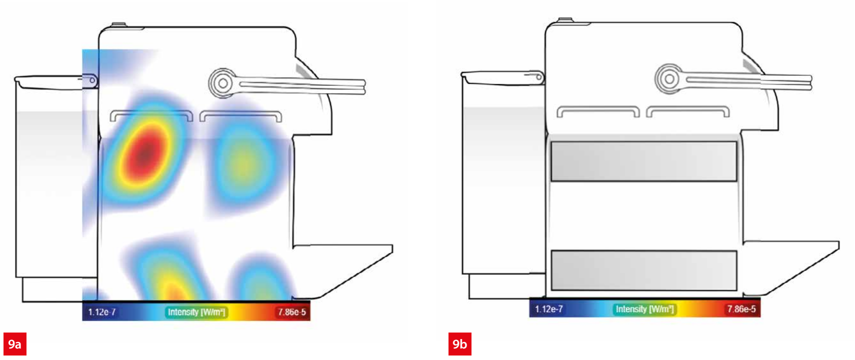
The near-field acoustic holography image, displaying the particle velocity (m/s), of the side of the coffee machine, demonstrating the effect of the metal strip adaptation.
(a) Without adaptation.
(b) With adaptation.



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The near-field acoustic holography image, displaying the intensity (W/m^2), of the side of the coffee machine, demonstrating the effect of the metal strip adaptation.
(a) Without adaptation.
(b) With adaptation.

Conclusion

Acoustics are an integral aspect of product design that significantly influences both the functionality and user experience of various products. As demonstrated in this case study, addressing acoustic properties early in the design process is essential to prevent noise-related issues and enhance product quality.

A reduction of 3.7 dB(A) is a prominent change, even though it might seem like a small number. Since the decibel scale is a logarithmic scale, a reduction of 3.7 dB(A) means that the measured sound pressure level is 1.5 times smaller. Furthermore, a sound pressure level reduction could mean that the noise radiated from the product now complies with norms and standards that describe noise limits of products, while before the reduction this was not the case.

Utilising sound imaging technology provides engineers with a more complete overview of the acoustic behaviour of their product and enables optimisation of this aspect. Sorama aims to make this technology as accessible as possible, with user-friendly and easy-to-use products and interfaces, based on the idea that engineers do not have to be acoustic experts to perform acoustic measurements and analyses.