Assessment of windscreen wiper actuator noise using a novel three dimensional scan based sound visualization technique

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Summary

Noise vibration and harshness engineers use sound visualization techniques as key tools in their effort to localize and reduce noise. A variety of sound visualization methods have been developed throughout history to gain information about noise sources by identifying noise strength, location, radiation and distribution.
In this paper the application of a novel three-dimensional scan-based sound visualization technique, Scan & Paint 3D, is discussed. This technique is based on a single USP which consists of one pressure microphone and three orthogonally placed particle velocity sensors. The USP is moved manually across a sound field, whilst filming the event with an infrared stereo camera to track the position and angle of the USP in a three-dimensional field.
This application concerns the investigation of two actuators for windscreen wipers used in the automotive industry. One actuator is working correctly whereas the other actuator has an unknown defect. The Scan & Paint 3D system is used to visualize particle velocity distribution and sound intensity vectors in order to detect and rank the noise sources of the actuators and localize the defect. Measurements are performed within a few minutes. The results obtained show high noise emission levels around the motor of the defective actuator. Accurate results combined with short time requirements and high flexibility, make this method an efficient sound source visualization technique for stationary sound sources.

Introduction

Nowadays, modern cars use a variety of actuators. As well as many other applications, actuators are used in cars for windscreen wipers, chair adjustment, electric windows and HVAC's. Actuators are often roughly enclosed and mounted inside a car hard to reach places. This makes it difficult to visually analyze the source of a defect. The use of a noise source visualization technique can help improve the understanding of noise issues in such products. Either in-situ or on a test bench.
In this paper the noise emission levels of a pair of windscreen wiper actuators are investigated. One actuator is thought to be defective. The aim of the measurement is to identify the possible defect within the malfunctioning actuator. This is done by measuring the sound field produced by the two actuators to identify and rank dominant noise sources.
The Scan & Paint 3D system is used to carry out the measurements (Figure 1). The system is comprised of a single USP (also known as a 'Microflown', Figure 2), a signal conditioner, a data acquisitioning device, a stereo IR camera, a remote control and a standard laptop. The Scan & Paint 3D system is able to visualize 3D sound vectors of sound intensity and particle velocity with a resolution down to 3 mm. Due to its ability to measure particle velocity and as a result of the near field effect, the system has low susceptibility to background noise and can be used in real operating environments. The small sensor size makes it possible to perform measurements in areas that are otherwise difficult to reach. The measurements presented are performed without the use of an acoustically treated environment.

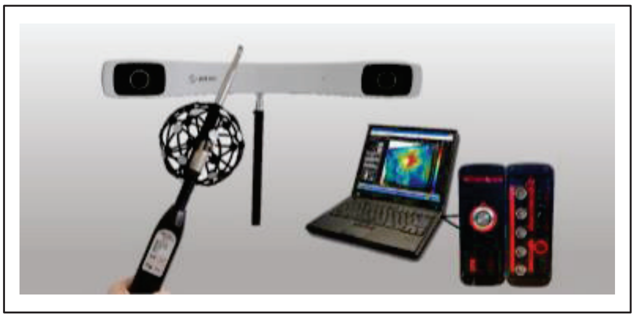

Figure 1: Microflown Scan & Paint 3D system.

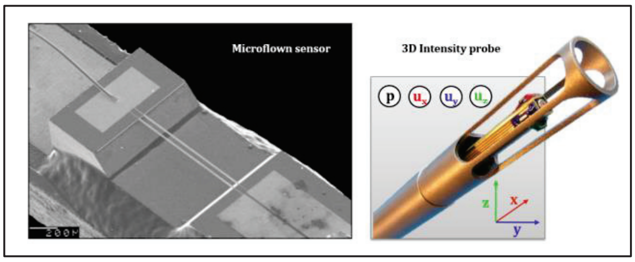

Figure 2: Microflown particle velocity sensor close-up (left) and 3D Sound Intensity Probe (right).

Theory

A brief introduction to positioning and tracking of the probe is given first. Followed by a description of the probe used with Scan & Paint 3D in comparison with traditional sound intensity probes. Finally, the sound mapping procedure is defined.

Tracking

The USP is manually moved across the three-dimensional space around the actuators. The tracking is done with a stereo camera omitting infrared light (IR). The IR light is reflected by retro-reflective markers attached to a sphere in an asymmetric pattern. Inside this sphere the probe is mounted in a fixed position. The software recognizes the asymmetric pattern and is able to track the position angle and rotation of the probe. The precision of the tracking system is < 0.5 mm Root Mean Square Error (RMSE) and < 1 deg RMSE.

Note the scanning traces of measurements around the defective and normal actuators differ since scanning is done manually. The results are given in Figure 3.

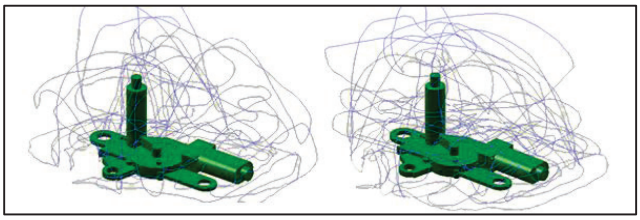

Figure 3: Scanning traces of measurement around functional (left) and defective (right) actuator.

Three-dimensional sound intensity using a p-u probe

Since the Microflown measures particle velocity – a vector quantity – more of the available acoustic information is measured, compared to a traditional pressure microphone, which measures scalar values only. Using a *p-u* probe, sound intensity is calculated by taking the time averaged cross-spectrum of pressure and particle velocity (1) without any approximation. Traditional sound intensity probes, however, such as the *p-p* intensity probe, estimate the quantity of particle velocity by taking the gradient between the two sound pressure signals. For a *p-p* intensity probe the limitation of the frequency range is therefore related to the spacing between the microphones. Different spacers are required to measure within different frequency ranges. The *p-u* intensity probe is a non-distributed sensor and is capable of measuring sound intensity over the frequency range of 20 Hz to 10 kHz without requiring spacers [2].

The error in intensity calculations for a *p-p* intensity probe depends on the pressure-intensity-index. A high ratio indicates a large error potential, and mostly occurs in environments with many reflective surfaces or high background noise levels. The *p-u* probe however is unaffected by high pressure over intensity levels. Intensity measurements with the *p-u* probe become less accurate in reactive sound fields. [3] States that in practical situations the error would increase significantly if the imaginary part of the intensity (reactive intensity) exceeds the real part (active intensity) by more than 5 dB. This corresponds to a phase of ± 72 degrees between sound pressure and particle velocity. To check the reliability of the sound intensity results, Scan & Paint 3D offers the option to plot reactive sound intensity levels.

Sound intensity mapping

Using acoustic sound intensity mapping, it is common to study acoustic sound fields in terms of the active, or propagating, part of the complex intensity [4]. The imaginary part, also known as the reactive intensity, representing the non-propagating acoustic energy, is rejected.

$$I = \{I_x, I_y, I_z\} = < pu >_t = \frac{1}{2} Re\{pu\} \qquad [\text{dB}] \quad (1)$$

To calculate and plot sound intensity vectors Scan & Paint 3D uses a spatial discretization filter. A three-dimensional grid is generated around the object under investigation. The size of the inner grid cells are configurable and determine the resolution of the results. For this application a grid cell size of 10 mm is used. For each grid cell active sound intensity levels (SIL) are calculated for the three axes using u_x, u_y, u_z. The modulus (2) of the three orthogonally active sound intensity vectors is calculated by the software to visualize the sound energy distributions (Figure 4). This quantity provides directional information about the flow of acoustic energy.

$$|I| = \frac{1}{2}\sqrt{(Re\{pu_x\}^2 + Re\{pu_y\}^2 + Re\{pu_z\}^2)} \qquad [\text{dB}] \quad (2)$$

Results

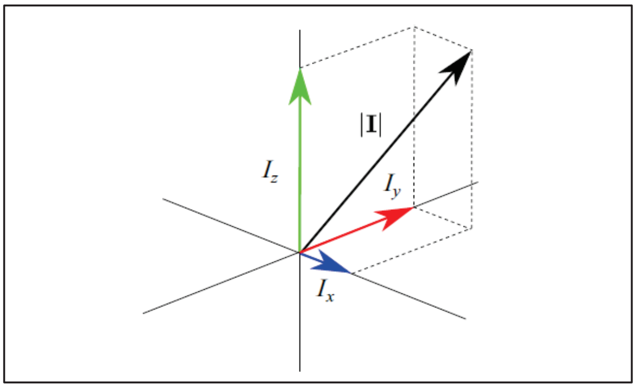

Figure 4: Schematic representation of the three-dimensional modulus of sound intensity vectors.

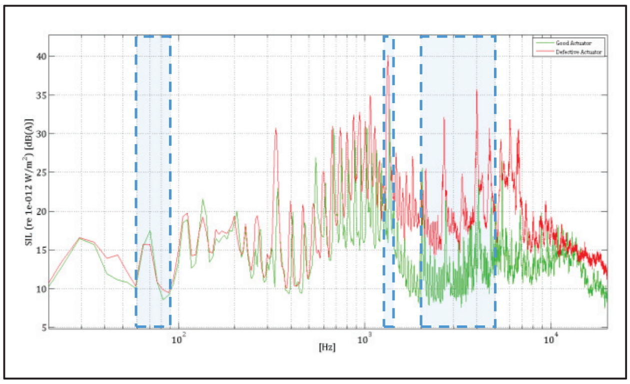

Figure 5: Averaged sound intensity spectrum of full measurement for normal (green) and defective (red) actuator.

Figure 5 shows the average sound intensity spectrum recorded for the functional actuator (green) and defective actuator (red). The sound intensity level (SIL) is averaged over the full measurement. The spectrum shows the noise radiated from the defective actuator is higher than the noise radiated from the functional actuator at 330 Hz and above 660 Hz. The highest SIL was measured for the defective actuator within the 1300-1360 Hz frequency range.

For accurate sound source localization, a band-pass filter is used to visualize results in specific frequency ranges. The ranges highlighted in Figure 5 indicate the pass-band frequency ranges that are used for sound source localization and ranking of noise emission levels throughout this paper. The results are presented for the following pass-bands:

- 60 – 90 Hz
- 1300 – 1360 Hz
- 2000 – 5000 Hz

The dynamic range in Figure 5 is of a different order than those in Figure 7 and Figure 8, because in the latter figures a plane is created for better visualization of sound intensity distribution and particle velocity. Measurement points outside the plane are disregarded, which affects the averaging, thus resulting in higher peak levels compared to the average SIL of the full measurement displayed in Figure 5. In addition, the dynamic ranges used for the color maps are set manually to obtain more distinghuishable results.

A 3D mapping of sound intensity vectors is displayed in Figure 6 for the frequency range 2000 Hz – 5000 Hz. The defective actuator (right) clearly produces higher noise emission levels. For more detailed visualization of the sound field, a plane is created in Figure 7 and Figure 8. Figure 7 displays the sound intensity distribution along the Y-axis for all three frequency ranges as stated previously. The functional actuator is presented in the left column, the defective actuator in the right. The first row shows the distribution of noise from the operating motor (the position of the motor is indicated by the dashed circle) for the frequency range 60 – 90 Hz. The results are almost equal for both the functional and defective actuators. This is in line with the averaged sound intensity spectrum in Figure 5, where both SIL's are alike.

The second and third row in Figure 7 display the sound intensity distribution for the frequency ranges of 1300 – 1600 Hz and 2000 – 5000 Hz respectively. The color maps clearly identify the dominant noise emission areas around the motor enclosure. The dominant noise emission area is most apparent at the frequency range between 2000 – 5000 Hz. Peak SIL measures around 60 dB.

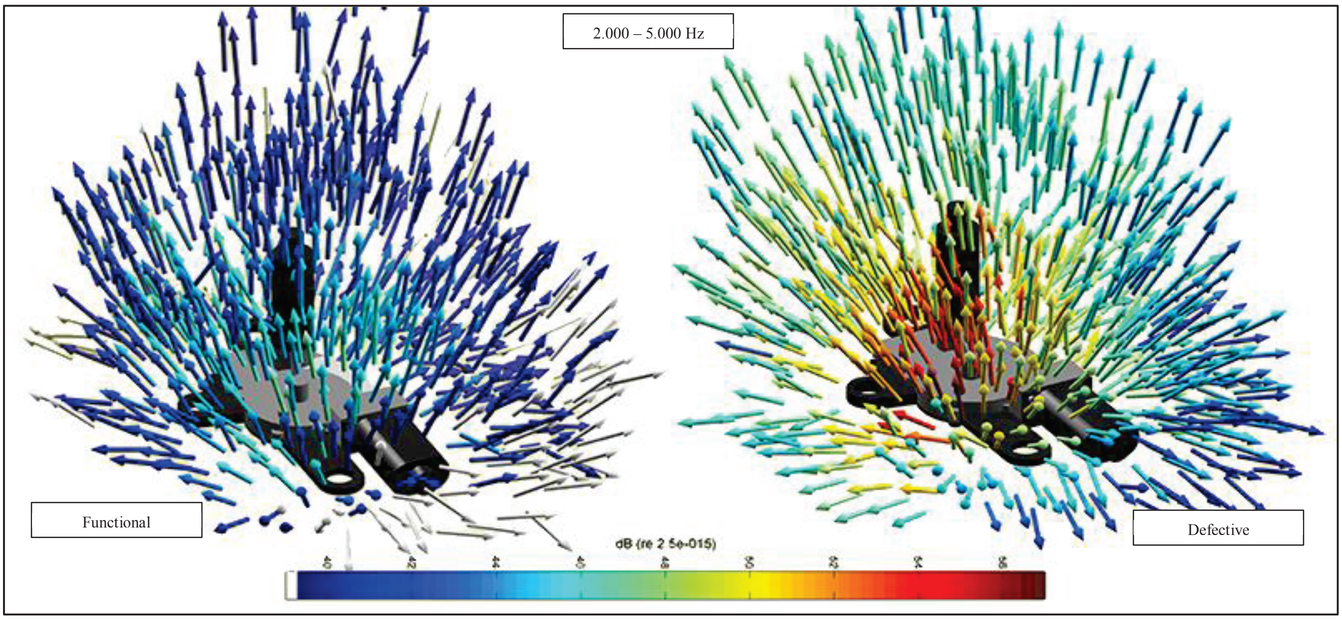

Figure 6: Sound intensity distribution 2000 – 5000 Hz, 39 – 56 dB for normal (left) and defective (right) actuator.

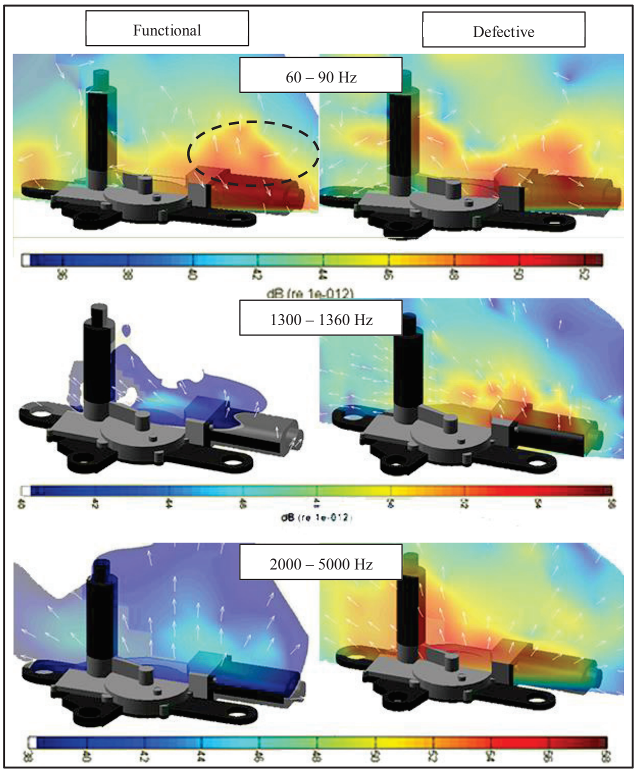

Figure 7: Sound intensity distribution along the Y-axis for normal (left) and defective (right) actuator. The dashed circle indicates the position of the motor.

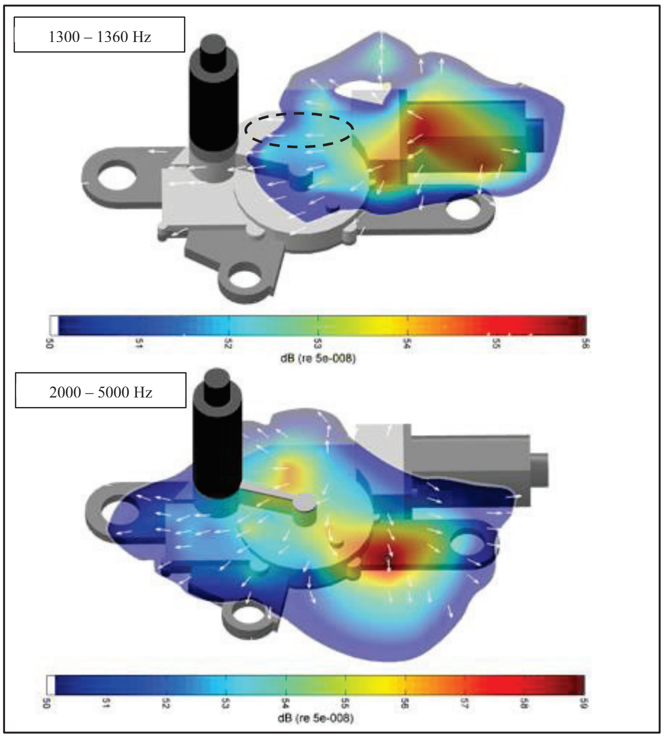

Figure 8: Particle velocity distribution along the Z-axis of the defective actuator. The dashed circle indicates the transmission of the gears.

Very close to a vibrating surface the sound field produces high levels of reactive intensity over active intensity. Besides mapping sound intensity distribution Scan & Paint 3D can also map particle velocity distribution, which can be used for more precise sound source localization. Figure 8 shows the particle velocity distribution along the Z-axis, close to the surface of the actuator for the frequency ranges 1300 Hz – 1360 Hz and 2000 Hz – 5000 Hz. Dominant noise sources appear at the motor enclosure and the mounting leg on the right side of the actuator.

Conclusions

The sound field produced by a complex structure has been investigated using a novel approach based on a 3D scanning method, measuring particle velocity and sound pressure. The areas with the highest noise emission are identified and ranked in order to localize the clicking noise and the operating noise of the motor.

The dashed circle in Figure 8 shows the position of the transmission of the gears, where low sound intensity levels are measured. This indicates that the source of the clicking noise is not related to defective gears. Instead the highest noise emission levels are measured around the motor enclosure and right mounting arm. It is stated that the noise is caused by a defect in the brushes of the motor, emitted through the areas of the actuator with low mechanical impedance, such as the black plastic mounting arm in the lower right corners as displayed in Figure 8.

The application described in this paper shows that the Scan & Paint 3D system is capable of mapping sound intensity and particle velocity distribution in a 3D space around an object. Results presented are obtained without an acoustically treated environment and therefore prove the Scan & Paint 3D system capable of accurate measurements in real operating environments. Real time automatic tracking of the probe and broad frequency range of the sensor make it a fast and flexible system for 3D sound field visualization and sound source localization.

References

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