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MEASUREMENTS OF ACOUSTIC RESPONSE OF CAR INTERIOR FOR STRUCTURAL EXCITATIONS

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Abstract

The transition from internal combustion to electric propulsion in cars presents component designers with new challenges in terms of noise reduction. Until now, components such as the suspension, its knocks were masked by the combustion engine or exhaust system. The absence of such significant sources, means that hitherto inaudible components are starting to become a nuisance. In order to reduce their noise, a number of optimisation solutions, both active and passive, are used. In order to do so, relevant measurements and data analysis must be carried out. This paper aims to present the acoustic characteristics of the interiors of two cars excited structurally in the vicinity of the front shock absorber mounting and by the operation of another component, the windscreen wipers on dry and wet windscreens. Measurements were made using 3D intensity probes based on acoustic particle velocity sensors. The results, in the form of both acoustic particle velocity and sound pressure characteristics and spectrograms, are presented comparatively for two types of car.

Keywords: NVH, automotive, electric car, sound intensity, diagnostics

1. INTRODUCTION

Today's automotive industry is investing more and more in electric technology and drive. The shift towards electric cars is mainly driven by climate change, which is affecting almost every aspect of our lives. The production of electric cars poses many design challenges, not least in terms of vibroacoustic optimisation [8]. Electric vehicles do not have the classic internal combustion engine, exhaust system that masked the noise of other components such as the suspension. The lack of the aforementioned masking and the quiet operation of the electric motor, places high demands on the other components that begin to dominate the vehicle interior. The following approaches can be used to reduce noise in the vehicle interior: optimisation of the component (source), use of active noise reduction systems or passive soundproofing materials. In order to carry out these noise reduction measures, appropriate measurements must be taken which, combined with a suitable analysis, are able to indicate the source location, its type and its effect on noise [14]. Multi-sensor spatial sound intensity measurements and appropriate signal processing can be used for this purpose. Improving the vibroacoustic comfort of a vehicle interior increases passenger satisfaction and undoubtedly translates into quality and prestige for the manufacturer. The main focus of the authors' research, is to propose a method of measuring inside the car using vector sound sensors. This paper is a continuation of the research conducted by the authors [10] and related to the use of *p-u* 3D sound intensity probes to identification (identifying which element is emitting the unwanted sound in car interior) and localisation (through the vector property of sound intensity or its component, the acoustic particle velocity). The technique of using vector sound transducers, not only sound intensity probes but also ambisonic microphones was of interest to the authors in the context of sound source identification in continuous environmental noise monitoring [4]. In noise, vibration, and harshness (NVH) tests inside cars, the typical ½' measurement microphones are often using [3, 6, 11, 12, 15]. Typically, microphones are mounted at the driver's or passenger's head. However, in a car, there are many sound sources with an interpenetrating time-frequency structure, and information from microphones recording sound pressure as a scalar quantity alone is difficult to interpret and identify the source. So, to obtain information about the significance and direction, measurements based on vector values such as sound intensity or acoustic particle velocity should be used [1, 2, 4, 5, 8, 10, 13, 15, 17, 18].

2. MEASURMENTS

Previous research by the authors [10] presented measurements of an automotive transient air cooler on the bench. Measurements were made using a 3D sound intensity probe WA301 Weles Acoustics based on direct measurement of acoustic particle velocity, in 3 planes in front of the radiator. Order tracking analysis was then performed for run-up and coast-down. The results in the form of selected orders of acoustic particle intensity and velocity were compared with classical results made with a microphone at the same locations of the measurement points. After verifying the feasibility of using 3D sound intensity probes to measure noise transients inside the car, structural measurements were made of the bodies of two passenger cars - BMW 3 (Fig. 1) and MINI Clubman (Fig. 2). Multiple repetitive impulse-type excitations made with a modal hammer were performed at the left and right front shock absorber mounting locations (left tower – Fig. 3b & 4b right tower – Fig. 3a & 3b).

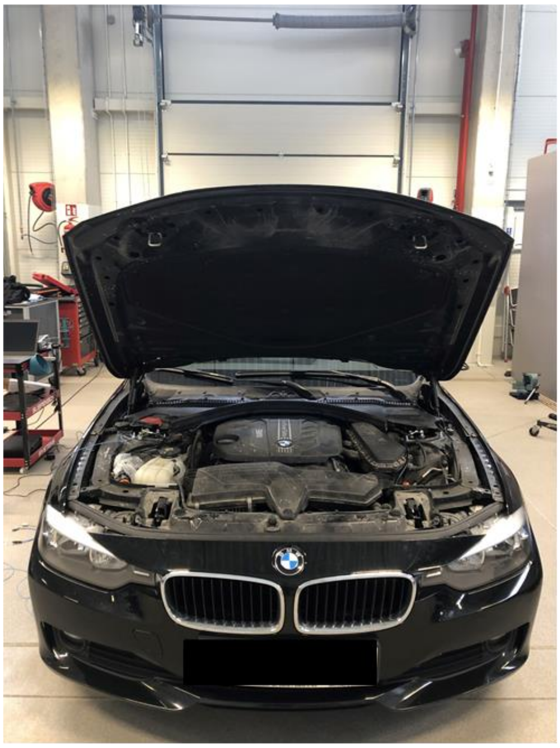

Fig. 1. Device under test (DUT) – BMW 3

Measurements were made at the driver's ear side using two spatial sound intensity probes - 3D Microflown USP (Fig. 5) and WA301 Weles Acoustics (Fig. 6). Fig. 7 shows the location of the probe in the test vehicle near the driver's headrest. The distance between the symmetry axes of the probes (z-direction) was 26 cm. This spatial sound intensity probes and accelerometer PCB type 356A15 (Fig. 3 & 4) as reference sensors were connected directly to the Siemens Simcenter SCADAS dynamic analyser with the Simcenter TestLab software, which enables synchronous data recording [7]. A sampling frequency of recording was 12.8 kHz, limiting the bandwidth due to the structural nature of the sounds, 20 averaging of both frequency response function (FRF) and cross-power spectrum of sound intensity was used. A spectral resolution of constant bandwidth equal to df=1.56 Hz was obtained.

Fig. 2. Device under test (DUT) – MINI Clubman

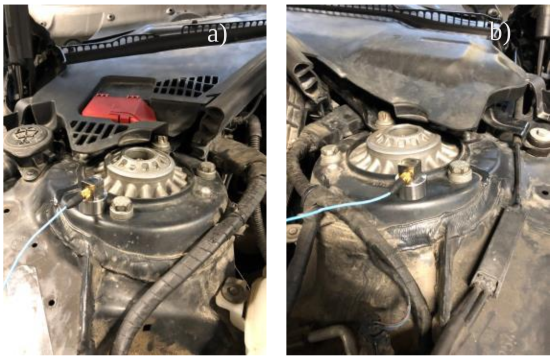

Fig. 3. Excitation sites – BMW a) right tower passenger b) left tower driver

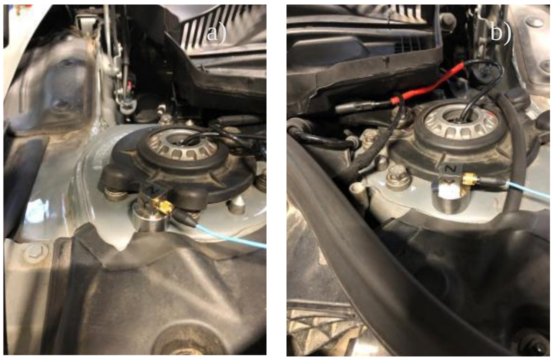

Fig. 4. Excitation sites – MINI clubman a) right tower passenger b) left tower driver

Fig. 5. Microflown USP sound intensity probe

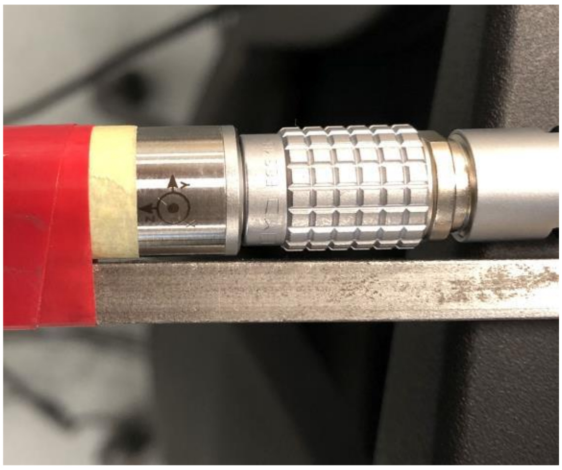

Fig. 6. WA310 Weles Acoustics sound intensity probe

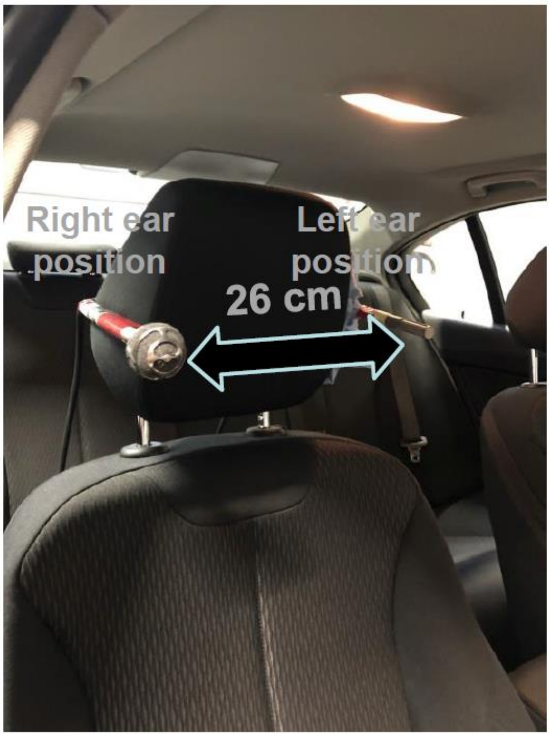

Fig. 7. View of the mounting of 3D sound intensity probes in the place of the driver's head. WA301 Weles Acoustics – right ear position, Microflown USP – left ear position

Examples of recorded waveforms in the operating conditions of the modal tests carried out are shown in the Fig. 8, which presents an example of the vibration recorded at the piston rod (top waveform) and at the right shock absorber mount (middle waveform), as well as noise inside at the driver head position (bottom waveform).

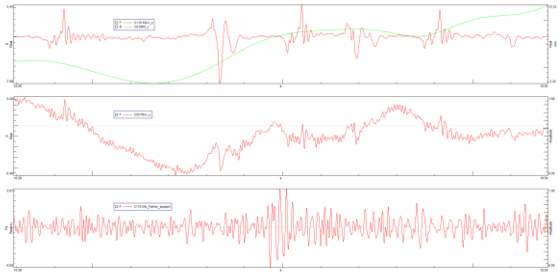

Fig. 8. Example of phenomenon in operational conditions (DUT - BMW) - example of vibration waveform on the piston rod (top) and on the right shock mount (middle), noise inside in the driver's seat (bottom)

Accordingly, the Fig. 9, 10, 13, 14 show the frequency response function (FRF) made for the sound pressure signal and the fig. 11, 12, 15, 16 show the FRF for the acoustic particle velocity. It is also possible to calculate and plot a cross - power spectrum for the analysed signals, Fig. 17÷20 form BMW car and Fig. 21÷24 for MINI Clubman respectively.

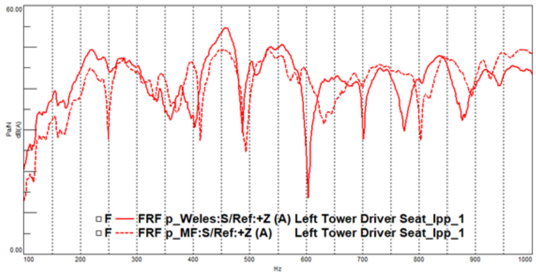

Fig. 9. Frequency response function (FRF) of sound pressure level for the driver's position for left tower excitation - BMW

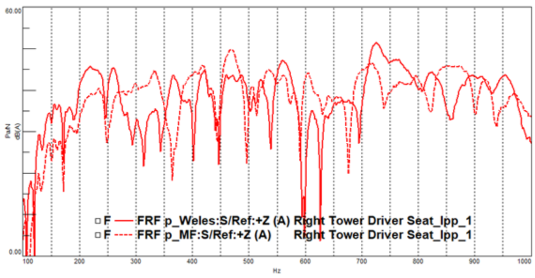

Fig. 10. Frequency response function (FRF) of sound pressure level for the driver's position for right tower excitation - BMW

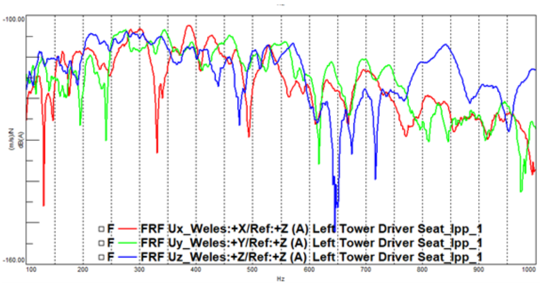

Fig. 11. Frequency response function (FRF) of acoustic particle velocity for the driver's position for left tower excitation - BMW

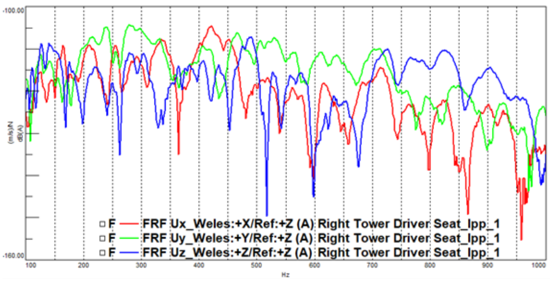

Fig. 12. Frequency response function (FRF) of acoustic particle velocity for the driver's position for right tower excitation - BMW

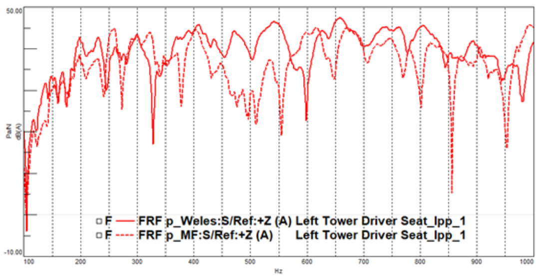

Fig. 13. Frequency response function (FRF) of sound pressure level for the driver's position for left tower excitation - MINI

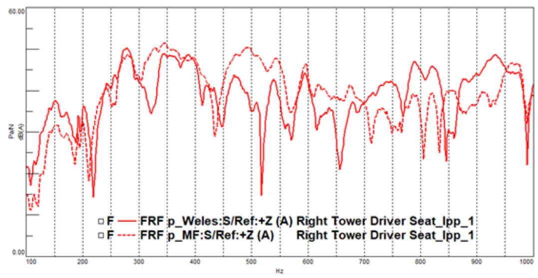

Fig. 14. Frequency response function (FRF) of sound pressure level for the driver's position for right tower excitation - MINI

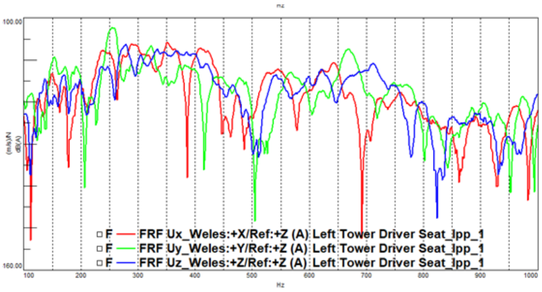

Fig. 15. Frequency response function (FRF) of acoustic particle velocity for the driver's position for left tower excitation - MINI

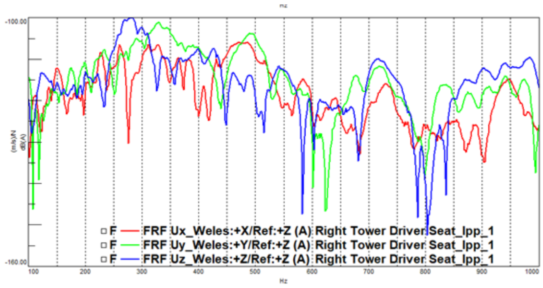

Fig. 16. Frequency response function (FRF) of acoustic particle velocity for the driver's position for right tower excitation - MINI

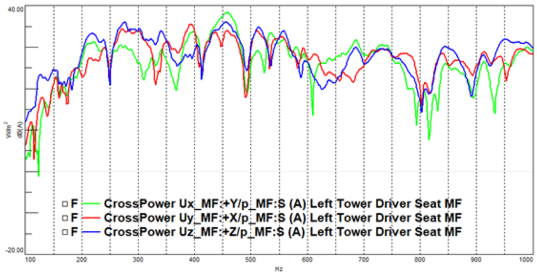

Fig. 17. Averaged cross-power spectrum of acoustic particle velocity recorded by Microflown USP, left tower excitation - BMW

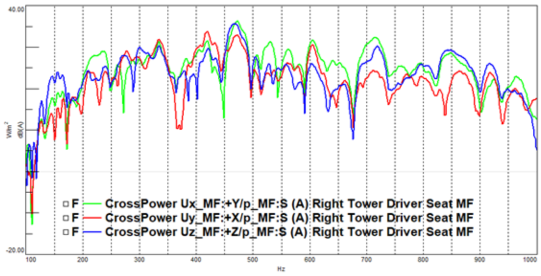

Fig. 18. Averaged cross-power spectrum of acoustic particle velocity recorded by Microflown USP, right tower excitation - BMW

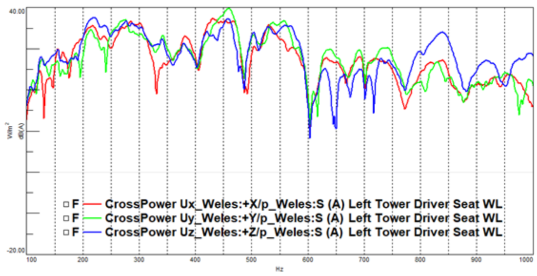

Fig. 19. Averaged cross-power spectrum of acoustic particle velocity recorded by WA301 Weles Acoustics, left tower excitation - BMW

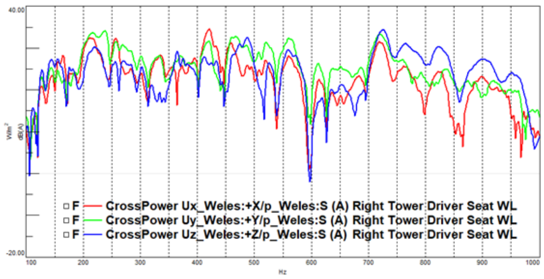

Fig. 20. Averaged cross-power spectrum of acoustic particle velocity recorded by WA301 Weles Acoustics, right tower excitation - BMW

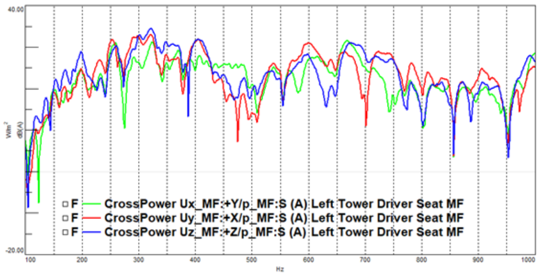

Fig. 21. Averaged cross-power spectrum of acoustic particle velocity recorded by Microflown USP, left tower excitation - MINI

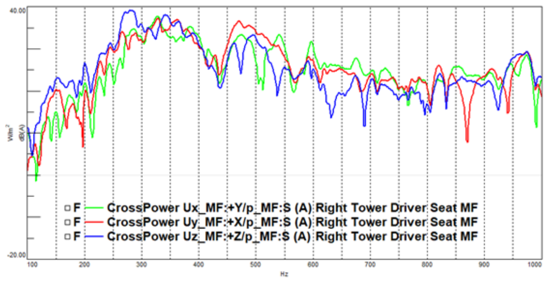

Fig. 22. Averaged cross-power spectrum of acoustic particle velocity recorded by Microflown USP, right tower excitation - MINI

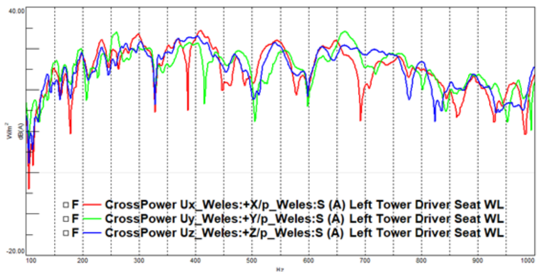

Fig. 23. Averaged cross-power spectrum of acoustic particle velocity recorded by WA301 Weles Acoustics, left tower excitation - MINI

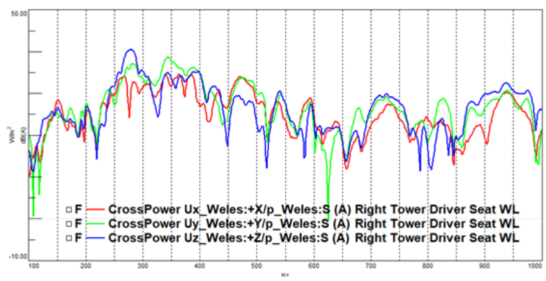

Fig. 24. Averaged cross-power spectrum of acoustic particle velocity recorded by WA301 Weles Acoustics, right tower excitation - MINI

Another independent test was to measure the performance of windshield wipers running dry in the context of the generated sounds penetrating the car cabin. The sampling frequency used was similar to that used in previous studies: 12.8kHz, resolution: df=1.56 Hz and an overlap in analysis equal to 75%. The fig. 25÷28 show the results of the analysis in the form of a time dependent cross-power spectrum.

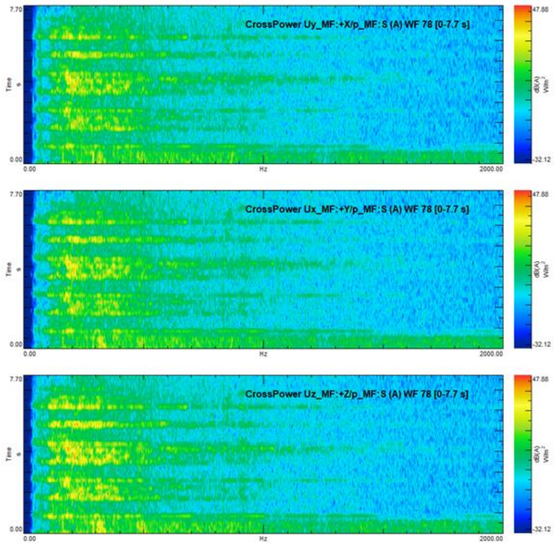

Fig. 25. Time dependent cross-power spectrum for working wipers in the driver's position, left ear - BMW

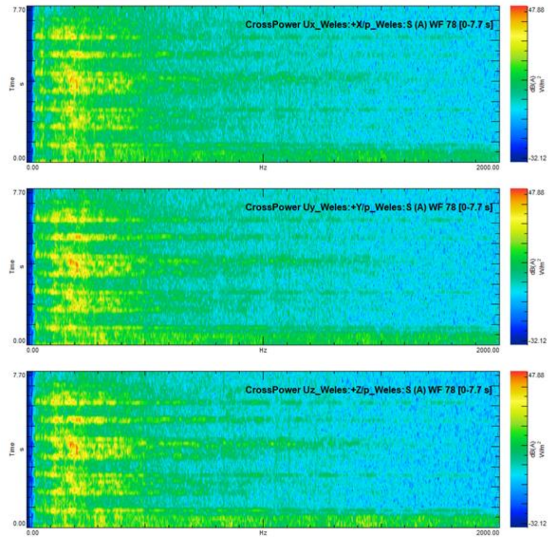

Fig. 26. Time courses of cross-power spectrum for working wipers in the driver's position, right ear - BMW

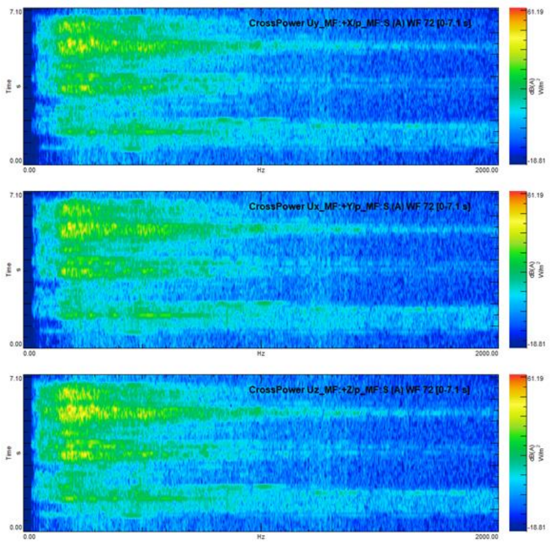

Fig. 27. Time dependent cross-power spectrum for working wipers in the driver's position, left ear – MINI

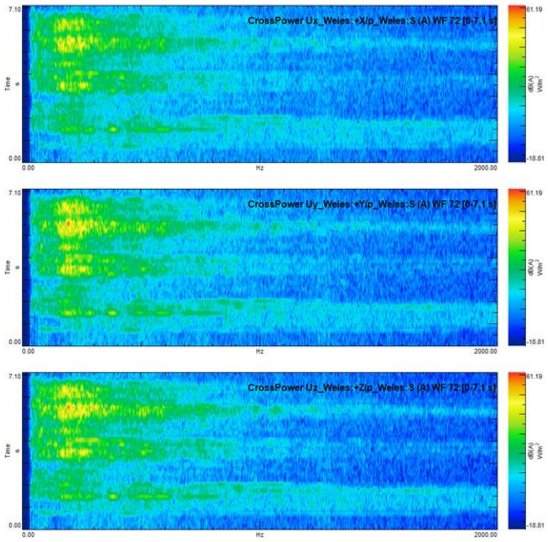

Fig. 28. Time dependent cross-power spectrum for working wipers in the driver's position, right ear – MINI

3. SUMMARY

- Recognizing the acoustic signatures of individual components inside a car, under operational conditions, using short-term sound intensity measurements is possible and allows sound source separation despite similar spectral structure,
- Development and validation of a signal processing method to identify and analyse acoustic signatures inside the car under operational conditions, using more than one 3D p-u intensity probe is possible but requires additional tests and analysis with other components such as: motors, fluid pumps, shock absorbers along with suspension components.
- Using of reference sensor like accelerometer allows to measure pressure and intensity values thus also direction even in nonstationary operating conditions
- FRF measurements presented in this paper also allows to measure and verify sensitivity of particular point inside cabin excited by shock absorber with additional information in form of directivity

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Declaration of competing interest: *The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.*

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