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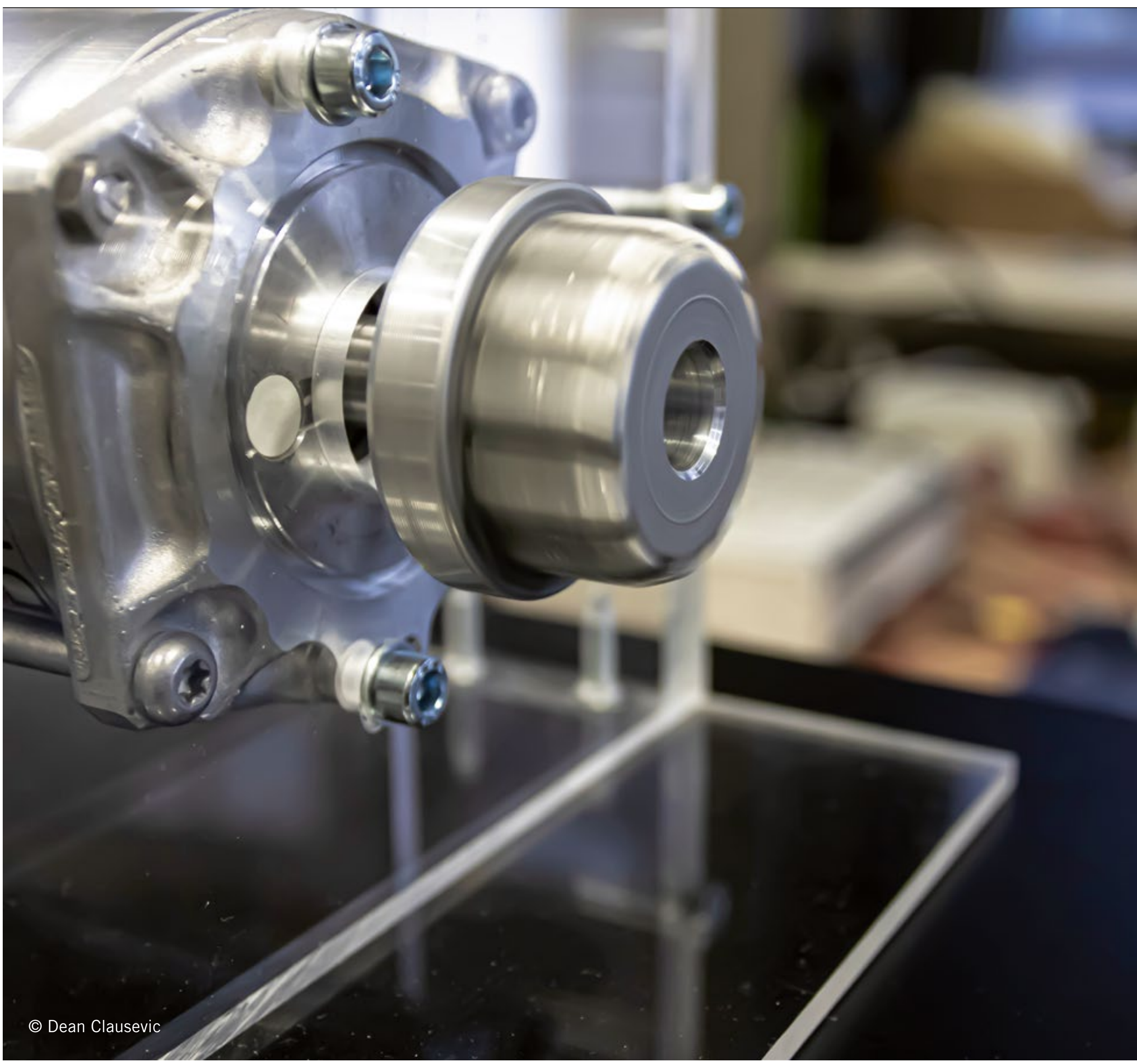
Using Electric Drives for Active Noise Generation

MdynamiX, the Affiliated Institute of the Munich University of Applied Sciences, is researching noise generation using electric drives in order apply this approach to acoustic function augmentation in the future. The electric motor virtually becomes a loudspeaker and can thus serve as a so-called Acoustic Vehicle Alerting System (AVAS). Without additional hardware, the applications developed can be used not only to realize the required warning signals for electric vehicles, but also to design brand-specific sounds. The basic functionality of electric drives is not affected or even disturbed.



1 INTRODUCTION

With electric drives, noises and sounds can be actively generated. For this so-called Active Sound Generation (ASG), there are first fields of application for developers of vehicles and vehicle systems, especially electric drives and components, following five years of research. This article explains the basic method and functionality and shows the effectiveness using two examples of possible series applications. In the first example, the electric drive of a steering system is used to generate warning signals so that very quiet electric vehicles approaching can be recognized by pedestrians. This enables the legal requirements for acoustic warning signals in electric vehicles (Acoustic Vehicle Alerting System, AVAS) to be met. The second example shows the possibility of emotionalizing driving noises in order to generate brand-typical sounds. ASG offers cost and weight advantages because additional airborne sound speakers are not required. High-quality pure tones generated by electric motors serving as acoustic actuators can be used for active noise compensation, similar to Active Noise Cancellation (ANC) systems applicable for loudspeakers. First successes are also visible here.

2 FUNCTIONING OF THE PROCESS

Electric motor control systems that directly control the electric flux-forming and torque-forming motor components are widely used and often already implemented along with the required hardware. Such a two-dimensional (rotor-fixed) motor control, which is well established in DC motors (armature circuit) and rotating field machines (field-oriented control), forms the basis of the ASG technology [1]. It can therefore be applied to synchronous machines, asynchronous machines and DC machines. The direct stimulation of these motor control components in radial and tangential direction (flux-forming and torque-forming current components) enables the excitation of radial and tangential internal forces, which in turn can be directly converted into perceptible vibrations or structure-borne sound by the mechanical impedances of stator and rotor. Depending on the application and the acoustic transmittance of the motor's connecting structures, the generated vibrations and airborne sound are radiated, **FIGURE 1**. A special feedforward control of the set point variables before and after the motor current controller enables the desired sound generation with electric drives. This approach allows independence from the motor current controller topology and avoids having to disclose the OEM or subsystem manufacturer's control technology that is worthy of protection. The patent of MdynamiX and the Munich University of Applied Sciences [2] describes the concept in more detail.

3 APPLICATION EXAMPLES

Using the presented method, a multitude of acoustic and tactile functions in vehicles or their subsystems can be realized without additional hardware. Typical sound design tasks such as the generation or emotionalization of engine sounds in the passenger compartment can be realized authentically at the power steering drive, since similar sound paths are used for the drive motor. Additional functions such as haptic feedback on the steering wheel for warning (lane-keeping) or for additional haptic reproduction of the electric motor status can also be realized. The range of possible signals stretches from simple test or warning tones to technical sounds, such as frequency sweeps, to complex sounds such as music or speech. Depending on the application and location, the structure used for sound radiation represents a significant factor influencing the achievable sound quality. For example, if the power steering drive is upgraded to a sound source, the sound is transmitted into the interior via the structure-borne sound path dominant for combustion engine sound; that is, via the front axle carrier to the body and into the interior. This makes it possible to create an authentic auditory impression for engine sound, for instance. Any challenges in the transmission path, such as resonance points or poor radiation behavior, can be compensated for in the respective application by adjusting the default signal.

Since the ASG technology can be implemented in almost any electric drive, it can also be applied to other mobility concepts. When used with the traction machine, for example, it is also possible to actively influence the sound of electric scooters. This allows an emotionalization of the driving experience to be achieved. In [3] the performance of the technology is shown when applied to an electric maxi-scooter.

4 ANALYTICAL DESIGN TOOL

The MXsounddesigner software was developed as an interface to the ASG function for detailed parameterization of a technical

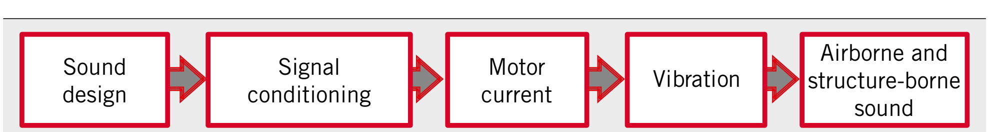


FIGURE 1 Representation of the chain of effects from sound design to sound as circuit diagram (© MdynamiX)

sound based on operating conditions. When selecting the design parameters, great importance was attached to technical proximity to the acoustic development (Noise, Vibration, Harshness (NVH) engineering). The software is executed exclusively based on NVH signal parameters. The resulting analytical model of the designed sound with a free parameterization is thus the core of the MXsounddesigner. Features range from order-based frequencies with optional Amplitude Modulation (AM), Frequency Modulation (FM) and phase noise modulation to configurable radiation characteristics of typical source geometries with adjustable natural frequencies. Additional noise sources, such as the inverter noise of power electronics, as well as audio or noise sources are also adjustable, **FIGURE 2**. Since no detailed knowledge of the mechanical properties of the target system is required, the tool can be used by acoustic engineers and by sound designers without special knowledge. The software can be used offline and linked to transmission path models or simulations [4].

5 APPLICATION FOR EXTERNAL NOISE GENERATION

According to Regulation (EU) No. 540/2014, electric vehicles must be equipped with an AVAS. **FIGURE 3** shows the potential of the ASG function for external noise generation based on the example of maximum external noise levels generated by the steering assistance motor on a prototype vehicle. These levels were determined in accordance with the standard specifications (stationary vehicle) and were measured at a distance of 2 m perpendicular to the longitudinal axis of the vehicle at a height of 1.2 m above sound-reflecting ground (asphalt) [5]. The steering assistance motor was used to generate individual tones as test signals at the respective third-octave center frequency. The vehicle was in a state not adjusted for this application. The one-third octave spectrum shows that the Sound Pressure Level (SPL) achieved is up to 66.7 dB after frequency adjustment for the human ear (A-weighting) and essentially meets or exceeds the legally required minimum sound pressure levels (EU and USA) in the relevant frequency range between 160 and 2500 Hz. In the frequency range 3150 to 5000 Hz, the required levels could not be achieved. The ASG technology combined with the power steering motor is therefore basically capable of replacing an additional external loudspeaker and meeting the level requirements for an AVAS (EU and USA). It should be noted that, depending on the actuator used, relevant sound can also be introduced into the vehicle interior. The potential of the ASG technology with a specific vehicle must be examined in each individual case.

6 USAGE ON SERIES HARDWARE

The ASG technology could also be retrofitted to a series control unit. For active sound generation, the steering assistance motor was used with the control unit of the series steering system. The range of functions was specially adapted to the acoustic requirements and hardware possibilities. It was possible to generate clearly audible sounds ranging from tonal excitation to broadband motor sounds, whereby the primary function of steering support was not impaired by this additional functionality [5].

7 POTENTIAL FOR ACTIVE NOISE CANCELLATION

Adaptive algorithms also make it possible to adjust the generated airborne and structure-borne sound in such a way that disturbing noises are actively reduced. The basic feasibility was shown in [7] and [8]. A synthetically generated noise was actively reduced on the driver's ear with the help of the electric steering assistance motor, **FIGURE 4**. A decisive advantage of this method compared to the airborne ANC systems with loudspeakers that are otherwise used is the targeted generation of structure-borne sound. Since modern motor vehicles have a large number of electric drives and these are attached directly to mechanical structures, it is possible to influence their vibration behavior. For example, resonance vibrations can be actively reduced, thus allowing direct access to the structure-born sound path of disturbing noises. In contrast to airborne ANC systems, the root cause of the noise is suppressed, resulting in a global improvement of the acoustic behavior and the vibrations that can be felt.

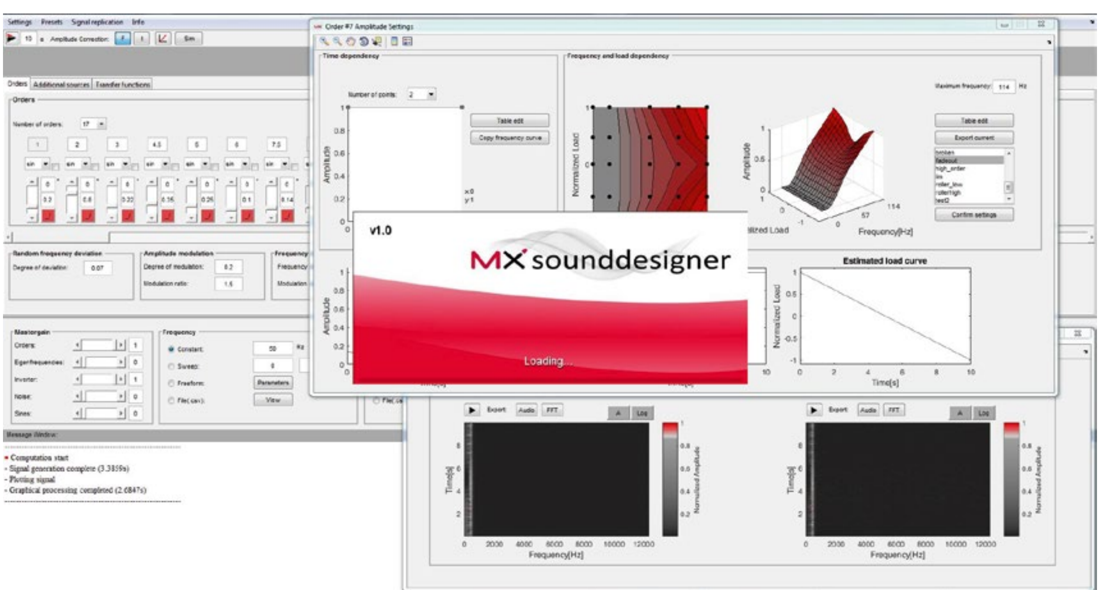


FIGURE 2 The MXsounddesigner user interface (© MdynamiX)

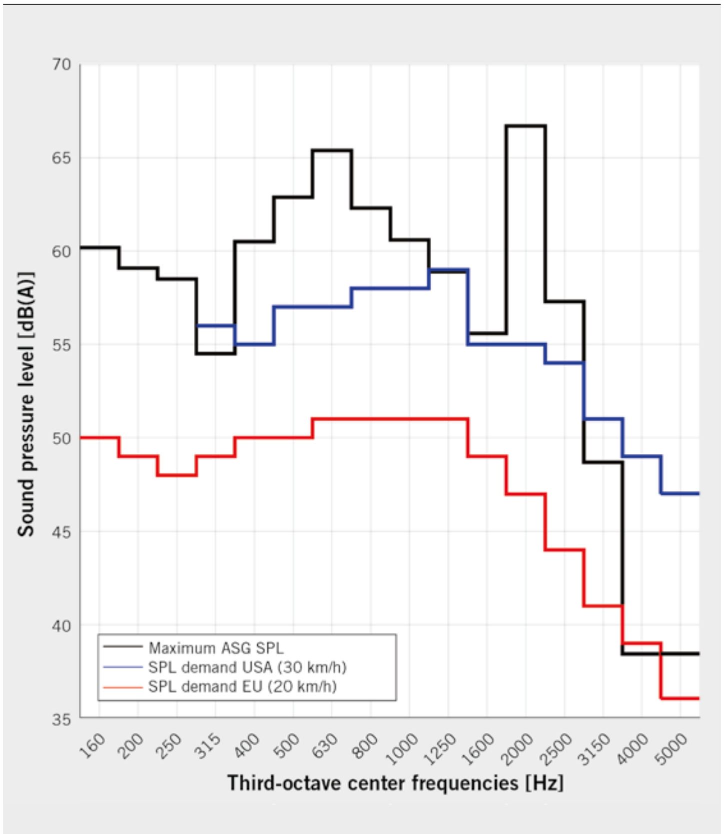


FIGURE 3 Maximum values at different measuring points around the vehicle compared to the requirements of the EU and the USA (© MdynamiX)

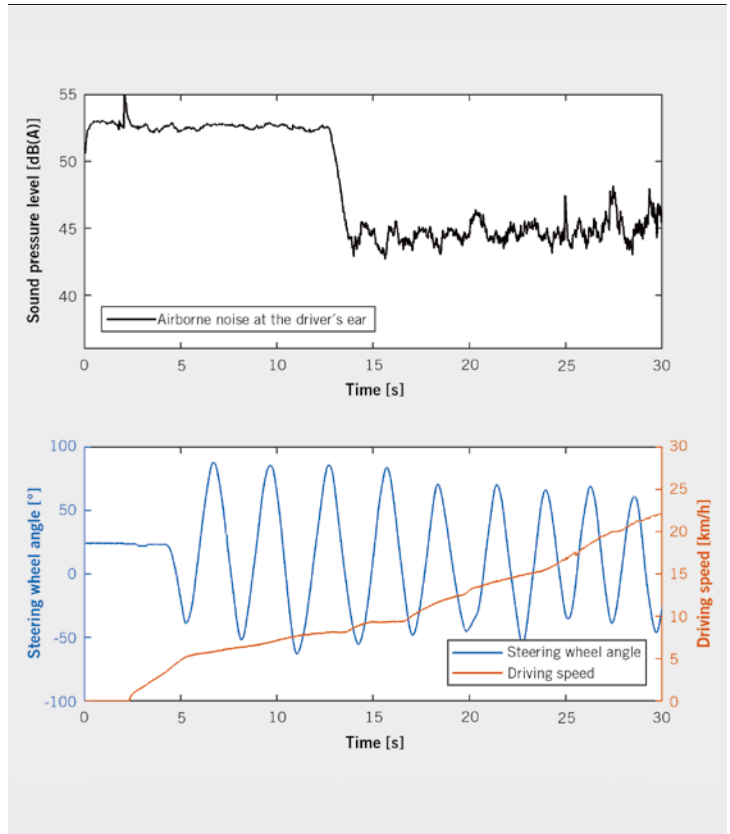


FIGURE 4 Sound pressure level (A-weighted) at the driver's ear during accelerated driving with sinusoidal steering movements (© MdynamiX)

A further application is the reduction of motor orders of electric drives. Here, the current component that forms the rotational torque can be superimposed with actively adapted harmonic vibrations in order to actively minimize the disturbing radiated airborne sound. In this way, electric drives are literally made quieter by themselves.

8 SUMMARY

For a variety of electric drives, the presented active sound generation MX-ASG from MdynamiX can actively influence the flux-forming and torque-forming current components in order to achieve a required noise or sound generation and also a desirable noise reduction. Due to the function augmentation of existing hardware, no additional components are required, weight and additional packaging space is saved. Typical sound design tasks for emotionalizing engine sounds in the interior can be realized authentically. The application supports the legally required AVAS function for the detection of approaching electric vehicles. By using already installed electric drives as sound actuators, additional exterior loudspeakers can be saved or completely avoided. Adaptive algorithms have already been used to adapt airborne and structure-borne sound in such a way that disturbing noises are actively reduced. This offers the possibility of active noise compensation similar to ANC systems that use airborne sound loudspeakers. The new MX-ASG technology is a basic innovation and will enable many more new vehicle functions in the future.

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