NVH ANALYSIS OF OUR CAR

Electric motors will generally provide maximum torque at Starting, which is precisely the opposite of what the NVH engineer would like. A significant challenge for the NVH Analyst is to provide a sufficient approximation to the ideal characteristics

The NVH simulation in **MATLAB 2019a** enables driving sounds to be engineered in the lab. The system combines a powerful signal processing and manipulating tool with an interactive display that simulates various driving environments. Road and wind noise components can be extracted and analysed using the **MPEG algorithm** and in this way we can determine the 'threshold of audibility' for additional noise signatures.

It is therefore possible to fully simulate the interior noise environment of an electric vehicle with speed-dependent road and wind noise, and with optional resonances, whines, booms and other error states. Once we have constructed a target sound and achieved an appropriate level of sign-off we then need to cascade that sound to component targets. Given a defined level of interior noise (that is a set of spectra dependent on road speed) we then apply these sounds to a set of transfer functions which then generates a set of targets which may be applied to the component. In fact, a series of transfer functions is required to enable us to specify sound pressure levels and excitation force levels for various zones around the vehicle.

Electric Machine whine

It is beyond the scope of this overview to provide detailed description of the noise-generating mechanisms of BLDC Motor, in this machine, the rotating part includes a set of permanent magnets and the stationary part applies a rotating magnetic field by means of electromagnets. In our case an alignment between poles and teeth occurs more often, since traction motors have higher numbers of poles and teeth. In the case of a development system at E-ATV, an alignment happens every few degrees resulting in a high order whine which we can hear as a whistle in the 2 to 4kHz region. Lower orders exist too, driven by imbalances in the magnetic fields and poles. The character of electric driving sounds will be discussed later, but it is worth noting that whines in this frequency range would traditionally be associated with transmission whines, and so would be thought of as an error-state to be eradicated.

Therefore, **sealing actions** were taken on the machine casing to reduce airborne noise, and a **palliative acoustic absorber (Roll Bar padding)** was fitted to outside of the casing. An alternative could be to improve the acoustic transfer function of the vehicle. However, careful
design of the rotor, stator, driving waveforms and transmission casing are the best way of curing the problem at source. Acoustic palliatives are tantamount to an admission of failure, and best avoided!

Sideband noise

Sideband noise is an artefact of the Pulse Width Modulation (PWM) technique used to control motor speed. The PWM waveform is generated by solid state switches in the inverter, resulting in a pulse-train whose duty cycle is defined by the instantaneous pulse width which is designed to generate a sine like flux density in the magnetic circuit of the motor. Figure 1 shows why PWM generates sideband energy which is equally disposed about the fundamental carrier frequency (since T1+T2=T). Since a PWM signal consists of pulses of varying width the distribution of sideband energy depends on the ratio of the pulse frequency to the modulation frequency. Rather than a single pair of sidebands, a real PWM signal will contain multiple harmonic sidebands. Figure 2 shows how the PWM signal is formed from the combination of a triangular carrier waveform (of a fixed, high frequency) and a sinusoidal reference signal (much lower frequency) which relates to the motor speed. This sinusoid is called the electrical speed of the motor and it is a fixed ratio of the actual motor speed depending on the motor design. The Fourier analysis in Figure 2 only extends to just above the fundamental frequency of the triangle waveform (the carrier frequency) and does not show the harmonics of the triangle waveform fundamental.

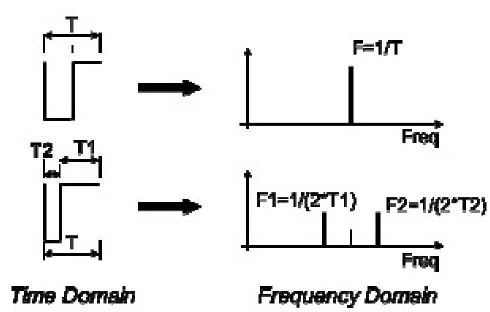

Figure 1

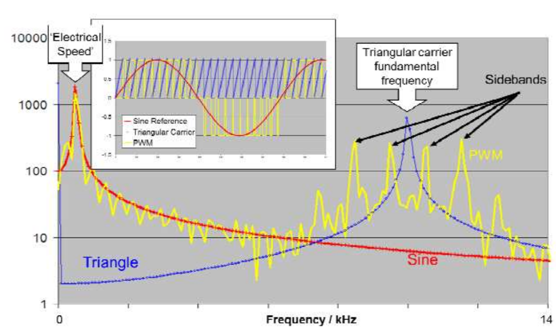

Figure 2

Sideband noise is unpleasant because of the rising and falling orders. If the falling order is most obvious it is distinctly counter-intuitive when the motor is accelerating. It is never a desirable noise, and is best avoided by siting the inverter in a position which has low noise sensitivity, and possibly via small vibration isolators.

Driveline Boom

The installation of an electric machine can generate new torsional modes, or modify existing modes of the driveline. Care needs to be taken that this inertia does not act upon the compliance of other driveline elements (shafts, DMF springs) to form a dynamically unstable system and so generate interior noise booms or vibration. It is normally possible to deal with driveline modes by the use of clutch slip (or torque converter slip) to increase driveline damping, or by application of absorbers. However, neither of these palliative solutions is ideal since they involve inefficiencies – clutch slip wastes power and absorbers add weight. In any case, it is impossible to fit absorbers at the antinode of the torsion mode when this is the rotor itself. A better solution is to ensure that additional inertias in the driveline are accommodated without introducing torsional modes, or that such modes are absorbed by other dynamic elements within the driveline. These actions must be taken by the transmission supplier at concept stage – they cannot be accommodated later in the vehicle integration stages.

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POINTS TO BE ADDED IN OUR SLIDE

- **Sealing actions** will be taken on the Motor and Controller casing to reduce airborne noise, and a **palliative acoustic absorber (Neoprene pads)** shall be fitted to outside of the casing.
- Siting the of Motor Controller in a position which has low noise sensitivity, and possibly via small vibration isolators.
- Ensuring that additional inertias in the driveline are accommodated without introducing torsional modes, or that such modes are absorbed by other dynamic elements within the driveline.