Transmission acoustics in the overall automobile system

Tobias Vöhringer[1], Axel Mors[1]
[1] *ZF Friedrichshafen AG, D-88038 Friedrichshafen, Germany, Email: tobias.voehringer@zf.com, axel.mors@zf.com*

Introduction

'If audible at all, the audibility of a transmission inside the vehicle must not be disturbing!' To achieve this development goal ZF Friedrichshafen AG uses a simplified TPA adapted to gear noise problems in the mid-frequency range. One important tool is the airborne-sound sensitivity *LSE* of the car body, which allows the supplier to characterise the system environment, onto which the transmission is coupled. With regard to many noise phemomena, an essential share of noise can be attributed to noise transmission. If, for example, gearing excitation on the transmission is present across a broad operating-speed range, then audibility within only narrow speed ranges is due to body-related structural resonances.

In a case study a 5-speed manual transmission is modified to give a high excitation level. In a standard drive vehicle, the intersections *gearbox mount*, *center bearing* and *rear axle subframe mount* are examined in vertical direction. The operational forces are estimated using a *method of the apparent mass*. At the *gearbox mount* two other methods for indirect force estimation are applied and compared. The forces are multiplied with the corresponding airborne-sound sensitivities to estimate the partial sound pressure of this three paths.

TPA adapted to gear noise

Most gear noise issues are in a mid-frequency range (standard FRF analysis setups at ZF R&D cover 200-4.2k Hz). For this frequency range an estimation of the contribution of each relevant intersection is performed in a very coarse but efficient manner. This approach includes

- inverse measurement of the airborne-sound sensitivity ($H^{LSE} = \frac{p}{F}$) of the car body
- measurement of the apparent mass ($H^{aM} = \frac{F}{a}$) at *gearbox mount*, *center bearing* and *rear axle subframe mount*
- measurement of acceleration during road testing (a_{road})
- multiplying the FRFs with road data to get the partial pressure of each considered path

$$p_{partial} = H^{LSE} \cdot H^{aM} \cdot a_{road} \qquad (1)$$

In this case study only the vertical direction ist studied, because it is most practical to excite this direction with a shaker in the apparent mass measurement. *LSE*-measurement and acceleration during road testing suggest, that the contribution of the lateral direction is in the same order of magnitude and that the longitudinal direction can be neglected.

Whereas the inverse measurement of the FRF H^{LSE} is established as a standard tool within ZF R&D, the *method of the apparent mass* for force estimation is applied for the first time. The error committed by the very strong simplification 'no cross-talk between coordinates and measurement locations' is checked comparing it to two other methods of indirect force estimation at the gearbox mount, using the mount stiffness data: *stiffness method* and *4-pole method*.

Results

Results are given for 2^{nd} gear coast down, 2700→1800 min^{-1}, corresponding to the frequency range 750→450 Hz, excited by the gear mesh order 16. Figure 1 shows the partial pressures of each considered

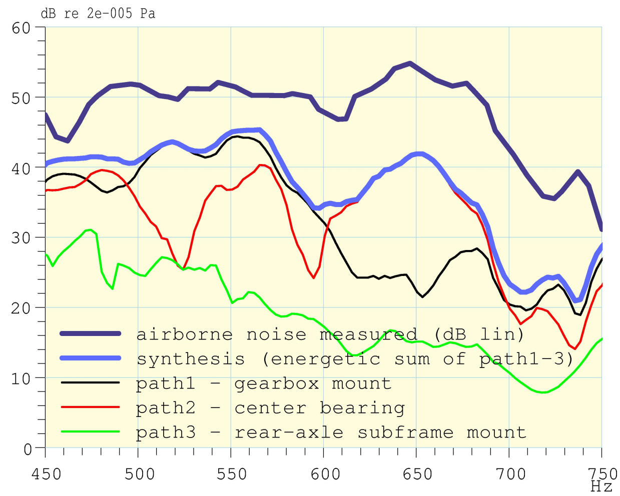

Figure 1: Synthesis of 3 paths in vertical direction using the *apparent mass method*.

path, the synthesis by energetic addition and the corresponding airborne noise measurement. The resonance in the measurement around 650 Hz occurs also in the synthesized data. In this resonance path2 *center bearing* can be clearly stated as dominant path. Towards lower frequencies path1 *gearbox mount* plays the key role in noise transmission. Path3 is not important at all.

The correlation between measurement and synthesis can be stated as good. The *offset* may be explained by the fact, that only the vertical component and only the right-hand side (in driving direction) of the symmetrically built powertrain coupling is regarded. The energetic addition is a simplification, the vectorial addition could lead to higher amplifications or attenuations at certain frequencies.

Development people in automotive industry often want to know: *Which is the critical path for noise transmission?*

The answer is, that generally there is not just one critical path. The dominance is frequency dependent.

Figure 2 shows the comparison of the three indirect force estimation methods at the *gearbox mount*, using the mount transfer and output stiffness data of a seperate laboratory measurement under original preload conditions.

$$F^{aM} = H^{aM} \cdot a_{road} \quad (2)$$

$$F^{stiff} = (s_{agg,road} - s_{kar,road}) \cdot k_{trans} \quad (3)$$

$$F^{4-pole} = s_{agg,road} \cdot k_{trans} + s_{kar,road} \cdot k_{output} \quad (4)$$

The stiffness parameters are measured by a specialist of Müller-BBM, Munich, using 5 elemnts in parallel.

The apparent mass at the three concerned intersections is determined by means of a shaker driven by white noise (bandwidth 200-4.2k Hz) and an impedance head. The road data is collected, using common accelerometers. Displacements are calculated by a double integration.

The force calculation seen in Figure 2c) combines laboratory and road data as given by equations 2-4. *Stiffness* and *4-pole method* because the mount is sufficiently soft. The isolation is good and the 2^{nd} term in equation 4 has no contribution to the transmitted force. The coarse *apparent mass method* overestimates the force, but it is still a quite good correlation to the other more precise methods, as it is a similar curve. Compared to the force curve the airborne-noise sensitivity of the car body in Figure 2d) shows a much higher frequency dependency and dominates the frequency behaviour of the resulting partial pressure.

Summary

From the example above the following can be concluded

- there is not just one critical path, it is frequency dependent respectively problem specific
- the *method of the apparent mass* can lead to force estimates similar to much more costly ones
- compared to the airborne-noise sensitivity *LSE* the force is a rather flat spectrum
- the frequency behaviour of the resulting partial pressure is mainly punched by the *LSE*
- if resources are scarce, it may be sufficient to perform the *LSE*-measurement to find problem specific critical paths in a qualitative manner

References

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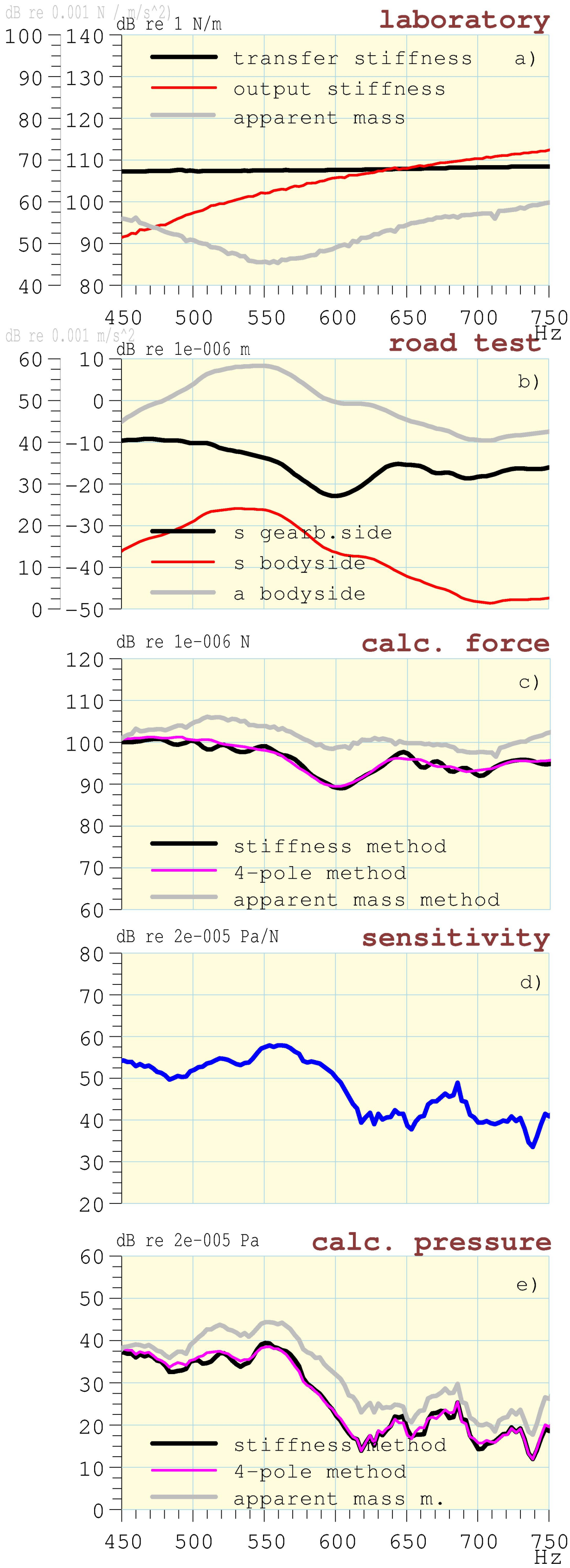

Figure 2: a) measurement of mount stiffness and apparent mass in laboratory; b) displacement and acceleration during road test; c) force calculation with indirect methods; d) airborne-noise sensitivity of the car body; e) partial pressure calculation;