Engine Transmission Noise Interaction

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Introduction

Due to their mechanical complexity, engine and transmission are typically developed in separate processes by the various departments before being integrated into a powertrain. At the end of the development work, engineers are often confronted with the phenomenon that, once assembled to one single unit, unexpected noise components occur.

For in-depth analysis of acoustical and vibrational interactions between engine and transmission, a numerical simulation model was created. With this model, the complete noise generation mechanism – comprising excitation, vibration transfer and noise emission – can be predicted. The computer software ADAMS Engine was used to simulate the excitation mechanisms of engine and transmission. The structures of the engine block and transmission box were flexibly modeled by the Finite Element software ANSYS. For verification of the calculations, sound measurements in an anechoic test cell were conducted as well. The computational and experimental investigations were conducted on a 4-cylinder car gasoline-engine with a 5-gear manual transmission.

Engine Transmission Interaction

The near field intensity measurements revealed that 70% of the powertrain's sound power is emitted by the engine and 30% by the gear box. Further investigations showed that the transmission influences the acoustical behavior of the engine at the meshing frequencies of the direct gear and the engaged gear. To investigate similar effects concerning engine-related excitation by the timing chain and vibrational transmission box reaction, the dynamical behavior of the engine gearbox unit was analyzed in more detail. The 19th engine order, i.e. the meshing order of the timing chain, could be identified on the transmission (**Figure 1**).

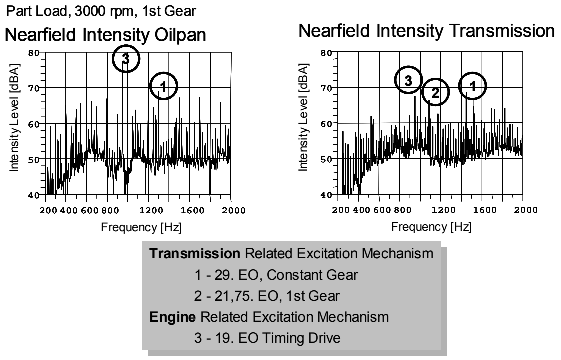

Figure 1: Interaction of Excitation Mechanisms

However, these excitation mechanisms are negligible for the overall noise level which is mainly influenced by engine-related combustion excitation.

The above-described interactions were also identified by numerical calculations. At FEV simulation techniques are used to analyze the engine transmission interaction in detail, as experimental investigations would be costly and time-intensive. To simulate the main excitation mechanisms of the powertrain, a combination of Multi-Body System Analysis (MBA) and Finite Element Analysis (FEA) was used. Finite Element structures of the housings and the shafts/gears were implemented into the MBA model to consider their flexibilities. The resulting simulation model is shown in **Figure 2**.

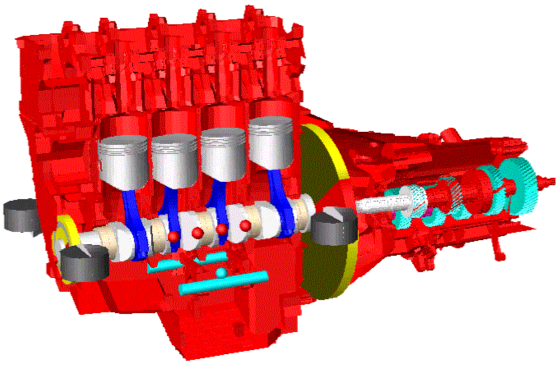

Figure 2: Simulation Model MBA/FEA

The calculations yielded the dynamic behavior of the powertrain's drivetrain. In addition, bearing reaction forces of the crankshaft and the transmission shafts were used as input for the FEA models of the powertrain housings. These models allowed analyzing the structural transfer behavior and the surface velocity distribution of the powertrain.

One important result of the numerical analyses was that the gear impact related structure vibrations are not transferred via the crank train, but primarily by the structures themselves. The calculations proved that the main running components, i.e. crank shaft and transmission shaft, do not influence the vibration transfer from timing drive to transmission nor the gear meshing from transmission to engine.

In this context, the double-mass flywheel acts like a low pass filter and cuts off the frequencies of the gear meshing and chain drive impacts. Direct comparison of one-mass and two-mass flywheel showed the latter to cause higher speed fluctuations at the crank shaft and lower fluctuations at the transmission shaft. With the one-mass flywheel, the total sound level of the powertrain was increased by 2bA (**Figure 3**).

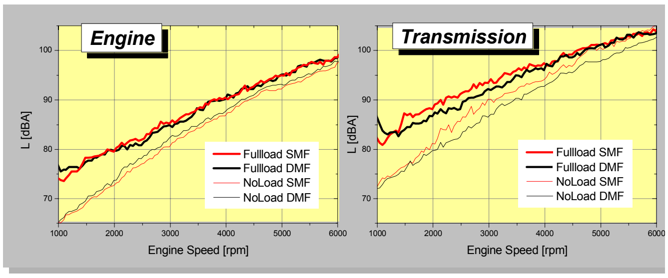

Figure 3: Single-Mass Flywheel vs. Dual-Mass Flywheel Sound Pressure Level, Far Field

Calculations yielded that the structure vibration behavior of the powertrain is primarily dominated by engine-related excitations. The only exceptions are the gear meshing impacts inside the gear box (**Figure 4**). These are lower with higher gears. This reflects the increasing tooth manufacturing quality of the higher gears. One exception to this rule is due to the 4th gear meshing frequency. Here, transmission excitation is on a level with engine excitation.

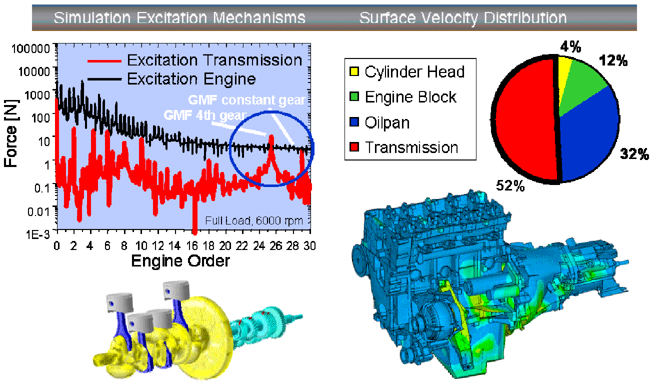

Figure 4: Simulation Excitation Mechanism and Resulting Surface Velocity Distribution

The coincidence with a transmission mode frequency leads to a singularity in the surface velocity level of the powertrain (**Figure 5**). The surface velocity shows an amplification at around 2.5 kHz.

In order to optimize the acoustical behavior, excitation needs to be reduced. Improving the structural transfer behavior cannot lead to significant level reductions because the excitation is order-related, i.e. it covers a large frequency range.

The analysis of the tooth geometry led to the conclusion that there is improvement potential regarding acoustics. Therefore the layout of the tooth profile was revised. The modified tooth profile considered e.g. flank corrections and aspects of the current production spread.

The effect of the modified tooth profile on the acoustical behavior of the powertrain is shown in **Figure 5**. It is obvious that with the optimized tooth layout the singularity caused by the gear meshing frequency of the 4th gear can be eliminated. Moreover, structural weakness is not increased.

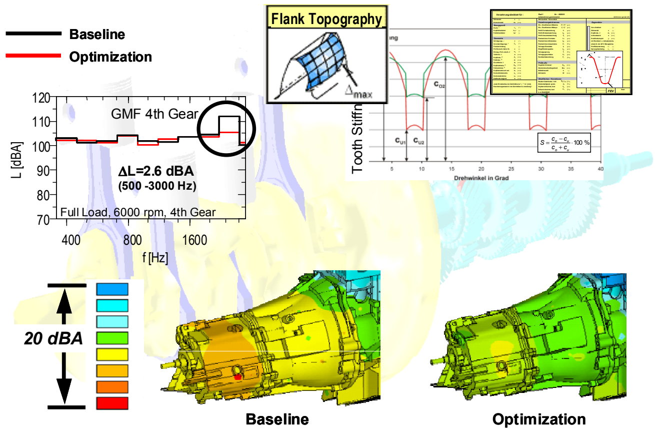

Figure 5: Optimization Process

Besides the main structure reactions due to teeth meshing frequencies, it can be important to understand the mechanisms of transmission box excitation and teeth impacts caused by crank shaft bending vibration. The results of corresponding MBA simulations revealed that the bearing forces of the transmission shafts are not significantly influenced by crank shaft vibrations in case of the investigated engine.

Summary

Considering all simulation and measurement results, it can be stated that today's computer programs for noise simulation model reality with a high degree of accuracy. With their help, acoustical interactions between engine and transmission were detected and analyzed. It was found that the teeth meshing frequencies of the transmission gears and the parametric excitation of the engine timing drive are transferred to the counterpart. The transfer of vibrations is primarily due to the main structures. The double-mass flywheel blocks related frequencies. Further more, it could be demonstrated that the simulation model can be used to optimize the powertrain's acoustical behavior.

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