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Powertrain NVH Development
Troubleshooting

Shortened Development Times

Development cycles for new powertrains have become shorter due to simultaneous engineering techniques. At the same time, the complexity of powertrains has increased and new engine technologies have been introduced to facilitate cleaner exhaust emission and higher specific power output. The risk of encountering NVH concerns towards the end of the development process has grown and so have delays of SOP.

FEV's Optimization Strategy

For over 25 years, FEV has been at the forefront of innovative powertrain NVH engineering. Starting with experimental engine NVH in the 1970s, FEV's NVH activities today comprise acoustic CAE (Finite Element and MBA analysis) as well as powertrain and vehicle NVH development. All market leading NVH soft- and hardware is utilized within FEV. So time and cost effective project handling is guaranteed including data compatibility to our clients. For fixing complex noise generation mechanisms, specific investigation methods are used such as monitoring of crankshaft and flywheel displacement, "Zero Clearance Piston" etc.

FEV's NVH troubleshooting projects stand for high flexibility and short reaction times based on well-proven improvement strategies. Successful NVH improvement approaches must take into account performance and emission targets, package and cost restrictions as well as series production feasibility. This is ensured by FEV's interdisciplinary expert project teams and close collaboration with the client and his component suppliers. Typically, hardware procurement is handled by FEV including a final NVH improvement check ("Sign-Off") on powertrain and/or vehicle.

NVH Concern Characterization

Troubleshooting usually starts with NVH concern characterization with respect to:

- critical operating condition(s)
- spectral content (resonances)
- impulsiveness, stochastics etc.

Evaluation Criteria

In the next step, evaluation criteria are established as the basis for proper target setting and reliable quantification of NVH improvement measures. Often conventional psycho-

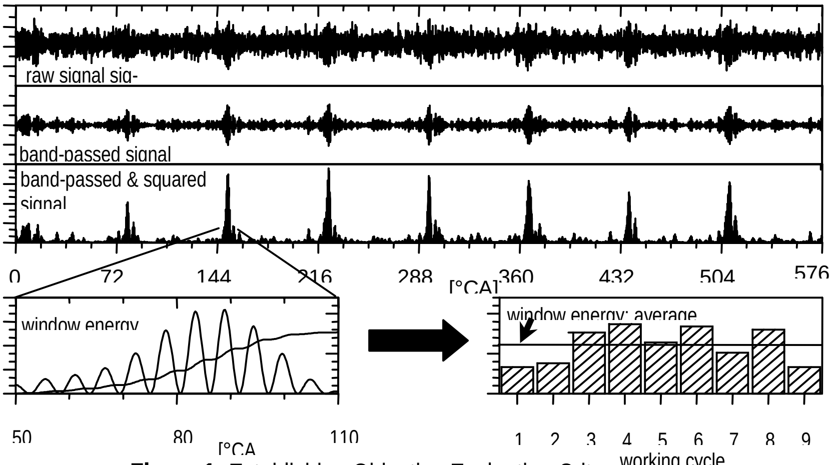
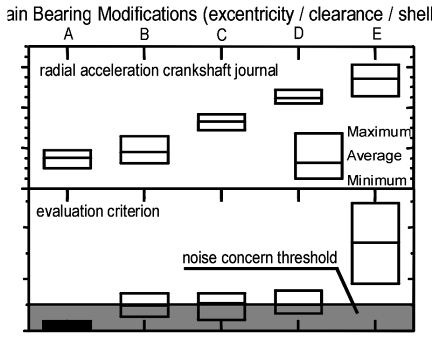


Figure 1: Establishing Objective Evaluation Crite-

acoustic parameters, such as roughness, impulsiveness etc., are not suitable for NVH concern characterization. Therefore, specific criteria have to be established for specific noise concerns.

Figure 1 illustrates the elaboration of such an objective evalation criterion: In case of a V-engine, an annoying periodic noise occurred once per engine cycle. A critical crankshaft journal acceleration resulting from rapid compensation of accessory drive belt tension force and cylinder pressure load was identified as the underlying noise generation mechanism. Depending on crank journal acceleration level and resulting oil film stiffness, the crankshaft vibration was introduced into the engine's structure. The objective evaluation parameter was based on time window energy analysis of band-passed structure vibration at a measuring position representative for the noise concern. Since redesign of the accessory drive layout was not feasible, main bearing clearances and shell design were modified. Figure 2 compares several modifications on the basis of crankshaft journal radial acceleration and the objective evaluation criterion. Noise assessments exhibited excellent correlation between subjective perception and established objective parameter.



Root Cause Analysis

After establishing the appropriate evauation criteria, experimental and/or analytical sensitivity analyses are performed within the Root Cause Analysis for identification of noise generation mechanism. For verification of the mechanism assumed, often laboratory type component modifications are applied: For example, in case of a 4-cylinder gasoline engine a stochastic high-frequency noise occurred in clearly defined load and speed ranges. Based on detailed experimental and analytical sensitivity analyses, axial impacts between conrod and crankshaft during compensation of gas and mass force before ITDC were suspected as noise sources. For verification, a test with zero clearance conrod using elastic shims as well as a test with the ignition timing retarded were performed. Both measures suppressed the noise concern effectively, thus confirming the noise generation mechanism (see Figure 3).

In consequence, the axial/radial clearance combination was optimized. The robustness of the improvement measure was confirmed by clearance sensitivity analyses.

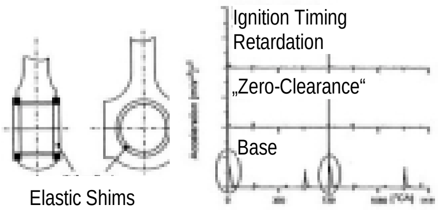


Figure 3: Noise Mechanism Verification

Elaboration of Improvement Measures

Successful NVH improvement approaches need to consider performance and emission targets, packaging, costs as well as production feasibility etc. As an example, the improvement of an oil pump whining noise concern is reported. Potential oil pump whining noise sources are shown in Figure 4. Detailed sensitivity analyses of oil pump component modifications, oil properties and engine oil circuit layout were performed. Time domain correlation analysis of simultaneously recorded noise, structure vibration and dynamic oil pressure inside the oil pump revealed the noise excitation mechanism: Cavitation at the begin of the discharge side opening generates gas bubbles which, due to consecutive pressure rise, implode again. This induces implosion shock waves resulting in oil pump structure vibration excitation characterized by high-frequency harmonics of oil delivery pulsation order. Consequently, the geometry of the discharge side was optimized to achieve a smoother opening phase.

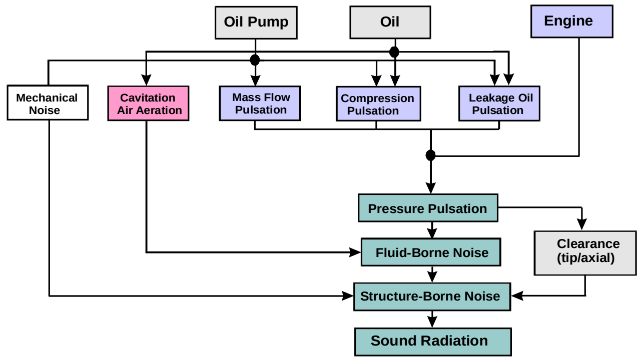


Figure 4: Potential Excitation Mechanisms for Oil Pump

However, the NVH modification had to be crosschecked, e.g. with respect to oil pump performance especially for high oil temperatures and low engine speeds. Therefore, tribological tests were conducted in parallel to optimize the oil pump geometry with respect to both engine oil supply requirement and NVH. Finally, a well-balanced compromise between both development targets was established and verified by engine and vehicle tests (see Figure 5).

There are plenty of examples of intelligent NVH engineering that could be cited: FEV's long-standing experience is reflected in an "NVH Check List" of typical acoustical failures, corresponding cause and effect analyses as well as effective countermeasures.

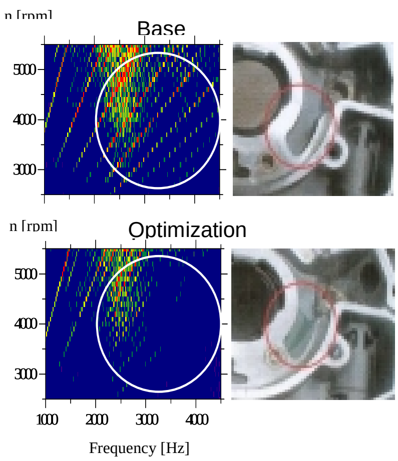


Figure 5: Base and Optimization

The effectiveness of powertrain component modifications with respect to vehicle interior noise can be predicted based upon FEV's Interior Sound Simulation. Thus cost-effective powertrain component optimization is ensured and "overengineering" is avoided.

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