You will find the figures mentioned in this article in the German issue of ATZ 7-8/2005 beginning on page 594.

**Akustik- und Schwingungs-
optimierung an Getriebeträgern**

Acoustic and Vibration Optimization

of Transmission Cross-Members

In addition to the traditional fields such as acoustic modeling for drive noises, minimizing wind noises or vibration optimization measures in the chassis and exhaust-system, structural components and connecting elements are also the focus of the engineers' attention during acoustic optimization. An example for this can be seen in engine and transmission cross-members, which support the drive in the body structure. To prevent undesirable sound and vibration transmissions, GF Automotive has introduced innovative NVH simulation processes, as well as high-sophisticated aluminum materials and sand casting technologies for transmission cross-members.

By Guido Rau

1 Introduction

Noises from or in motor vehicles pose both a problem and a challenge at the same time. Automobile manufacturers and suppliers have devoted considerable effort and expense to this phenomenon, which is usually characterized by the English abbreviation NVH for noise, vibration, and harshness. NVH improvements to motor vehicles are becoming increasingly important as a result of ever greater demands for comfort. GF Georg Fischer Automotive has introduced innovative modeling and simulation processes, as well as sophisticated materials and casting methods for transmission cross-members.

2 Acoustics and Haptics as Brand Values

Noises and vibrations almost always influence the riding comfort of a motor vehicle, a feature defined as the most important development target. Depending on the frequency range, the occupants perceive the vibrations either acoustically or haptically. These are manifested in various phenomena, such as clattering, rattling, squeaking or whistling, especially during travel. This is simulated on the vibration test benches, **Figure 1**, of automobile manufacturers to switch off these causes. The nomenclature given to the individual phenomena is not uniform and generally takes onomatopoeia as its basis.

A typical haptic perception is represented by the low-frequency longitudinal oscillation of the entire vehicle in load alteration effects. Other body stimuli primarily arise from the combustion engine, but may also stem from the transmission, from the wheels or ancillary components of the vehicle. The main cause of acoustic effects is represented by the powertrain, with increasing traveling speed also the roll resistance of the tires and the aerodynamics of the body. In addition to this, electrical and electronic components have an increasing effect on the overall acoustic impression in regard to a vehicle.

Positive acoustic and oscillation phenomena from a technical standpoint are the exception rather than rule. Nevertheless, it has been demonstrated that vehicles appear less dynamic subjectively when certain acoustic thresholds are not attained. Sports drivers, in particular, expect an appropriate acoustic response from the engine after depressing the accelerator [1]. This state of affairs is taken into account in the sound engineering, where acoustics experts model the drive and exhaust noises and create an acoustic pattern perceived as typical for the brand or model. The effects on steering represent another example. Electrically-assisted power steering systems are therefore able to extensively filter road stimuli en route to the steering wheel. Nevertheless, many drivers find steering wheel feedback on the status of the road to be informative, giving them a better "feeling" for the road.

The company Porsche, for example, has been devising a specially defined engine sound for its engines, which is to be associated with this brand. For this, subjective noise components were also modified within the statutory regulations, as well as the objective level acoustics. Thousands of hours in development time are associated with this. It will come as no surprise to the specialists, if a Porsche Carrera S has to spend another 1,800 hours on the acoustic test bench before its characteristic driving noise on the road is attained. The reason for this is simple: like no other manufacturer, the sound of the vehicle forms the "core of the brand value", in the words of Rolf von Sivers, Head of Vibration and Acoustic Engineering. And this is "just as important as the appearance and sports car quality of a Porsche".

Engineers working on luxury limousines are using the same test equipment to achieve a sound with rather more refined and elegant qualities. Psychoacoustic studies are helping to assess how the target group perceives this. Indeed, nothing can act as a greater deterrent than a "whimpering window lift". That "ruins trust in the reliability of each car", states von Sivers.

3 Approaches to Solving Complex NVH Tasks

Noise and vibration problems are normally not dealt with via one individual area of focus, but instead represent an inter-disciplinary task across the traditional areas of vehicle physics. Nevertheless, NVH aspects have meanwhile been receiving considerable attention there, as they represent an important customer-relevant criterion playing a crucial role in purchase decisions. This is supported by the fact that the interior noise level of passenger cars during stationary motorway driving has, on average, been cut by around half in the last few years [1]. This is despite the trend towards lightweight design and engines with greater torques, a development, which renders components and bodies more prone to vibrations.

As a result, the problems surrounding NVH will continue to represent one of the most important tasks confronting development engineers in the future. Experts estimate that up to 50 % of all development expenses in the automobile industry are directly or indirectly related to noise and vibration optimization [2]. This is not surprising considering that the field is extremely complex. Moreover, many aspects cannot be defined rationally as people are subjective in the way they perceive noises. The actual opponent of the sound engineer is therefore not technology, but rather the subconscious behavior of buyers, **Figure 2**.

In addition to noise and vibration measurements on the test bench, the tools available to the NVH specialists also include computer-assisted processes such as multi-body simulation (MBS), finite element methods (FEM), interior noise simulation or transfer path analysis. Although measurements remain essential in the longer term, numerical processes are gaining increasing importance [3]. Transfer path analyses identify reliable engine orders and noise quotas, while vibrations can be simulated very well with FEM and MBS models. The acoustic properties are ascertained in the low-frequency range with FEM analyses and in the range above 500 Hz using statistical energy analysis [4].

With BMW for example, developers have been using calculation and simulation methods in the early phases of the product development process to optimize the acoustic properties of the entire vehicle [5]. After this, the vehicle is dissected virtually into the components relevant to acoustic and vibration engineering and then described. A core aspect focuses on determining the body series structure in respect to the air and structure-borne sound properties. Next, the components are designed using the FEM in such a way that resonances in the visible range are avoided. At the same time, the engineers determine the rigidity of the body in the low-frequency range on the basis of structural calculations. The requisite damping and absorption measures can also be calculated from the air-borne properties ascertained. No significant deviations from the target valuations should then occur in the subsequent tests with real prototypes. The finishing acoustic and vibration modifications to the preproduction vehicles are made a year before the series start.

Approaching the noise and vibration phenomena with the aid of a metrological analysis in the automobile is expensive [6]. This is because many components act simultaneously as sources of stimulus, with the result that the role they play in the phenomena to be examined frequently cannot be measured directly and hence cannot be considered separately. Moreover, the measuring results do not provide any indication concerning the interactions between the individual components. Low noise and vibration drives are therefore typically used on the test bench, so as to avoid undesirable effects on other components. An additional problem is posed by conflicting targets between the vibration response and the structure-borne sound insulation properties [1]. Where it is desirable to connect the drive unit to the body very rigidly, a stiff engine suspension transmits excessively loud engine noises to the interior. This conflict can only be solved through a more expensive suspension concept.

4 Development of Transmission Cross-Members

To ensure safe and comfort-oriented support for the transmission, GF Automotive has developed and produced transmission cross-members made from aluminum sand casting – amongst others for Audi, Volkswagen, and Porsche. They are bolted to the body and, as a cross-member, reinforce the body in the front area. The support thus forms a connection between the drive train and body, and transfers vibrations and sound from the drive train to the interior. To diminish the effects of this transfer path, hydro and rubber mounts are installed between the transmission and the cross-member.

An exact adjustment of the structural rigidity as well as natural vibration and damping response to the subsequent vehicle environment also requires smooth running. When developing the transmission cross-member for the Audi A4 and Audi A6, GF Automotive optimized these factors in close coordination with the company Audi. The automobile manufacturer provided data at an early stage on the requisite strength, structural rigidity and natural frequencies in the overall system. The natural frequency of the transmission cross-member must not on any account lie within the frequency range of the drive train, as it would otherwise heighten these vibrations. A very rigid support with high natural frequency reduces a humming in the low frequency range. In the following two transmission cross-members are described in detail.

4.1 Transmission Cross-Member for the Audi A4

An initial concept idea for the Audi A4 envisaged an open, fined aluminum profile for the transmission cross-member produced through pressure die-casting. However, this design does not fulfill the requirements for the vibration response. The decision was therefore taken to opt for a hollow construction made with sand casting, **Figure 3**. The advantages of this production technology are the variable wall thicknesses (with the Audi A4 they vary between 3.2 and 6 mm) and the geometrical design freedom. Aluminum flows through the sand cores only where it serves the rigidity and fatigue strength under vibratory stress.

Further advantages are the problem-free functional integration and low space requirements. This is important, as such components in the engine compartment generally have less and less space, while the requirements for vibration properties are becoming increasingly strict. To comply with the different drive variants of the Audi A4, GF Automotive has developed three cross-member variants – for automatic transmission, manual transmission and different motorizations [7]. They were produced in Garching near Munich (Germany), **Figure 4**.

The first development phase involved the definition of the representative load conditions of the component which are based on load excesses as a result of various driving methods and operating statuses – such as load alteration effects, switching and start-off processes. On the basis of this, requirement profiles were defined and optimized through simulation tests for the cross-member. The finite element method and other simulation processes were used in this phase. The first casting and solidification simulations began parallel to this, so that geometry improvements and casting processes could be validated at the same time. The final phase of component tests also included natural frequency tests, **Figure 5**. The engineers induced the cross-member to vibrate for this. A Piezo quartz served as an acceleration sensor. With the aid of an amplifier and an oscilloscope the vibrations around the vertical axis and in the direction of travel were documented.

4.2 Transmission Cross-Member for the Audi A6

When developing the transmission cross-member for the Audi A6, GF Automotive benefited from the expertise it had gained while working on the cross-member for the Audi A4. Although other border conditions were extant for the component of the middle-class vehicle Audi A6, it soon became evident that an aluminum sand casting design represented the best solution here as well, **Figure 6**. This option was chosen, as it would not be possible to achieve the required rigidity during normal cross-section fining with pressure die-casting. The sand casting version with variable wall thicknesses has a large geometrical moment of inertia at a low mass and almost has the effect of a tensile or compression bar. This makes the cross-member extremely stable, while enabling effective casting and an economical production process.

GF Automotive turned to examples in nature when optimizing the structure of the transmission cross-member [8, 9]. The FEM program used for this creates the component geometry according to the same principles as the growth of a tree, which forms a root and branch system of maximum strength utilizing a biomass reserve restricted by its environment [10]. When applied to automobile technology, the bionics software can be used to develop components with an optimum ratio of mass to rigidity, as the structural optimization is no longer based on the traditional principle of trial and error.

The maximum possible bulk volume of the transmission cross-member was first ascertained and subdivided into more than 160,000 FEM elements. The program then calculated the optimum course for the load paths. The elements with a load under the limit value were removed from the structure and deleted, as they contributed practically nothing to the strength and stability. Each iteration loop eliminated further elements. In the end, the cross-member only consisted of elements, which ensured a suitable ratio of mass to rigidity and hence supported a high load. In this way, the transmission cross-member was able to fulfill the requisite strength and vibration requirements with minimum use of material. The engineers then incorporated the simulation results in the casting and solidification simulations.

5 Conclusion

Transmission cross-members made from aluminum sand casting are the optimal solution for fulfilling exacting demands in relation to acoustics and vibration properties. Moreover, they are also highly suitable for improving the acoustic conditions in the interior and the vibration response of motor vehicles. In addition to the Audi A4 and A6, GF Automotive also produces such components for Audi A8, Porsche Cayenne and VW Phaeton.

For other models with longitudinally-mounted engines which currently still have transmission cross-members made from sheet steel or pressure die casting, the Swiss company is developing corresponding solutions made from aluminum sand casting, too. As there is an increased need for comfort in the compact class as well, Volkswagen has opted for such a cross-member to support the transversely mounted engines of the VW Golf V.

References

[1] Braess, H.-H.; Seiffert, U. (Hrsg.): Vieweg-Handbuch Kraftfahrzeugtechnik. 3. Auflage. Vieweg-Verlag, Wiesbaden, 2003

[2] Steffen, T.: Analyse von Geräuschen und Möglichkeiten der Geräuschoptimierung am Beispiel der Pkw-Bremse. Vortrag auf einem Hochschul-Kolloquium der FH Oldenburg, Ostfriesland, Wilhelmshaven in Emden am 22. Januar 2003

[3] Wiedemann, J.: Akustik im Gesamtfahrzeug. Wohin geht die Entwicklung? Forum der Meinungen. In: ATZ 104 (2002), Nr. 11, S. 1002 ff

[4] Glettler, A.; Hauer, I.; Jalics; K., Priebisch; H., Bartosch, S.; Fankhauser, C.: Geräuschberechnung an Kraftfahrzeugen mit statistischen Methoden. In: ATZ 106 (2004), Nr. 12, S. 1116 ff

[5] Thoma, G.: Akustik im Gesamtfahrzeug. Wohin geht die Entwicklung? Forum der Meinungen. In: ATZ 104 (2002), Nr. 11, S. 1004 ff

[6] Reitz, A.; Biermann, J.-W.; Schumacher, J.; Kell, P.: Spezielle Prüfstände zur Untersuchung von NVH-Phänomenen des Antriebsstrangs. 8. Aachener Kolloquium Fahrzeug- und Motorentechnik, Aachen, 1999

[7] Fehrenbach, I.; Rau, G.: Getriebequerträger aus Aluminium-Sandguss. Einfluss der Bauteilstruktur auf Betriebsdauer und Komforteigenschaften. In: Giesserei 91 (2004), Nr. 1, S. 72 ff

[8] Kerz, P.: Natur als Vorbild. Gestaltoptimierung hoch beanspruchbarer Fahrzeugteile. In: Giesserei 92 (2005), Nr. 1, S. 30 ff

[9] Nachtigall, W.; Blüchel, K. G.: Das große Buch der Bionik. Neue Technologien nach dem Vorbild der Natur. Deutsche Verlags-Anstalt, Stuttgart, München, 2000

[10] Mattheck, C.: Design in der Natur. Der Baum als Lehrmeister. Rombach Wissenschaft. Reihe Ökologie. Band 1. Rombach-Verlag, Freiburg, 1992