

BMW Group

Corporate and Governmental Affairs

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Acoustics — intelligent solutions for more efficiency, comfort and dynamics.

New, intelligent measures in acoustic lightweight construction not only insulate against undesirable noises in the passenger compartment in an especially efficient manner, but also reduce weight and thus contribute to the total efficiency of the vehicle. But, at BMW, a high degree of comfort is not everything – not by a long shot. A current research project at the BMW Research and Innovation Centre focuses on the actively designing engine sounds in the passenger compartment, making driving dynamics even more tangible — the so-called Active Sound Design.

In order to be able to drive comfortably and efficiently at the same time, the developers look for solutions in acoustic lightweight construction with acoustically effective components for increasing comfort and also yielding benefits in weight and installation space through intelligent material concepts. In this way, the customer gains a functional advantage with lower weight and more pleasure for lower fuel consumption and CO₂ emissions. The minimisation of background noises normally requires the use of heavy insulating and dampening materials. This minimises surface vibrations. Nowadays engine parts are becoming lighter and lighter through new materials, while efficiency requirements rise, which means that crankcases, for example, are being made out of aluminium and there is a lack of material insulating against disturbing combustion noises. Intelligent measures are in demand for maintaining driving comfort. Acoustic engineers achieve this through systematic reinforcement of the crankcase, among other things. The procedure known as "ribbing" systematically minimises disturbing emanations and the crankcase remains, all in all, very lightweight. In addition, the engine is partially encompassed by an acoustic capsule. These absorber or insulation components require little installation space, are lightweight and at the same time quite effectively reduce noise emanation. Absorption and insulation directly at the engine has additional benefits to efficiency: if disturbances are reduced directly at the source, no

Company
Bayerische
Motoren Werke
Aktiengesellschaft

Postal Address:
BMW AG
80788 München

Telephone:
+49-89-382-11491

Internet:
www.bmwgroup.com



BMW Group

Corporate and Governmental Affairs

Media Information

Date 19 May 2010

Subject Acoustics — intelligent solutions for more efficiency, comfort and dynamics.

Page 2

costly, difficult insulation of the passenger compartment is necessary. This helps reduce material, weight, and fuel consumption.

Another method of acoustic lightweight construction for increasing comfort and efficiency is the integration of acoustic functions in the existing vehicle parts. In the undercarriage structure in use with current BMW models, which improves aerodynamics, a LWRT (lightweight reinforced thermoplast) replaces the former subframe made of polypropylene, which was heavier and fitted with more absorption material, and took up more space. With the new undercarriage structure, the absorption function is already integrated into the surface of the subframe. This reduces weight and installation space, while considerably enlarging the absorption surface at the same time. Only two to eight millimetres thick, as opposed to the previous maximum of 30 millimetres, the new structure is significantly thinner than before and only half as heavy as the previous structure of subframe plus additional shock absorber.

While the acoustic lightweight construction helps to fine-tune vehicle acoustics and increase comfort, active systems, such as Active Sound Design, ensure that the engine produces a dynamic sound during acceleration, because vehicle dynamics are an auditory phenomenon. With Active Sound Design, engineers can create the sound that best fits the vehicle character or even fulfil drivers' individual auditory desires.

"To create the desired acoustic patterns, we're refining the natural character of the engine with an electro-acoustic system so that acceleration becomes a special audio experience and provides even more pleasure."

(Albert Kaltenhauser, Manager for Airborne Sound, Acoustics and Vibrations)

Presented in a MINI prototype for petrol engines in 2009, Active Sound Design now also helps diesel engines achieve a sporty sound that wasn't possible for this type of engine until now. The sporty performance characteristics of modern diesel engines and their high torque, especially when starting up and



BMW Group

Corporate and Governmental Affairs

Media Information

Date 19 May 2010

Subject Acoustics — intelligent solutions for more efficiency, comfort and dynamics.

Page 3

accelerating, contradict the acoustic sensation of diesel vehicles. Harsh ignition impulses during combustion, which are inherent to diesel engines' function, are responsible for their characteristic noises — commonly referred to as "knocking". This undesirable acoustic characteristic of diesel engines has been brought to a very low level at the BMW Group through intelligent acoustic lightweight construction. This makes room for Active Sound Design, which supports a sporty sound quality. It makes outstanding driving performance audible.

In order to have a special audio experience and for a diesel vehicle to sound really sporty, sound designers have to optimally adjust the sound to the vehicle and its engine performance. Too much sound with too little engine power would make a negative impression. The engine sound must constantly provide for a harmonious driving experience. The particular challenge is allocating the right dosage of sound in all driving situations and creating an authentic audio character. An active system allows for significantly more systematic and finer adjustments than classic sound design, which is oriented on the intake or exhaust system.

"Even small changes to vehicle sound can have a big impact, since human hearing subconsciously evaluates acoustic surroundings like a high-performance analyser and all changes are continuously registered in the brain."

(Dr. Alfred Zeitler, Acoustic Psychologist)

The test vehicle, a BMW 635d, is sound-optimised by means of sound design and has its own very dynamic audio character. The noise typical for diesel vehicles disappears and instead, the driver hears a sporty, superior sound. The entire rpm range is accompanied by harmonious, varied and consistently appealing acoustics that make the enormous torque audible at lower rpms and also provide for fun at high rpms. Through Active Sound Design, diesel engines finally achieve the engine sound that their performance deserves.



BMW Group

Corporate and Governmental Affairs

Media Information

Date 19 May 2010

Subject Acoustics — intelligent solutions for more efficiency, comfort and dynamics.

Page 4

Acoustic lightweight construction — the added value is in the interplay.

One of the main tasks of vehicle acoustics in the premium segment is to eliminate undesirable noises and to fine-tune the sound in order to be able to shape it fittingly to the vehicle. Nothing must buzz, groan, squeak, whistle or rattle, and disturb the driver. The measure necessary to achieve this normally increased vehicle weight and thus increased fuel consumption and elevated CO₂ emissions. BMW is taking another route with intelligent measures in acoustic lightweight construction. New, integrated solutions that unite several functions not only insulate against undesirable background noises in the passenger compartment, but reduce weight at the same time, contributing to the vehicle's overall efficiency.

In order to be able to drive comfortably and efficiently at the same time, the developers research possibilities to improve the acoustic functions of different parts in acoustic lightweight construction and to yield concepts for additional benefits to both weight and installation space through intelligent functional integration. For this reason, engineers are first trying to take full advantage of available system solutions with respect to acoustics. An absolute basic requirement for this is an integral understanding of the vehicle's acoustic interrelationships.

"The in-vehicle acoustic causal loop is highly complex. However, once you understand it, numerous possibilities for optimisation reveal themselves — in terms of optimal and efficient vehicle design."

(Tomasz Jedraszek, Manager of Airborne Sound Team)

The objective of the engineers is to combine components that are as lightweight as possible with the optimal fulfilment of various and often conflicting requirements for parts related to driving operation. For acoustics, this specifically means that the correct insulation and absorption materials must be effectively



BMW Group

Corporate and Governmental Affairs

Media Information

Date 19 May 2010

Subject Acoustics — intelligent solutions for more efficiency, comfort and dynamics.

Page 5

put to optimum use for their purpose, because not all insulating material is the same. Different materials have different properties, which means that they're not all suitable for every purpose.

Intelligent use of materials — in the end it's the total weight that counts.

The first step to an acoustically-optimised vehicle is the minimisation of background noises. This is normally accomplished through the use of insulating and dampening material against bothersome vibrations. A heavy part doesn't vibrate as much as a light one and thus emits or transfers less sound. But the old acoustic rule "mass is only replaced by more mass" is outdated thanks to intelligent acoustic lightweight construction. Systematic acoustic measures that act at the source, intelligent sound insulation concepts, and the use of highly absorbent materials in vehicle construction refute this old rule. These intelligent measures permit tangible increases in comfort without significant additional costs. The customer benefits from better acoustics at a lower weight — more pleasure with lower fuel consumption and CO₂ emissions.

"We're not creating a light structure at any cost. It's more about intelligent use of materials with a simultaneous increase in efficiency, dynamics and comfort."

(Tomasz Jedraszek)

In body construction, extremely hard steels are used in places where high rigidity standards must be met. For larger parts, lighter materials are used, such as aluminium. Attention is paid to ensure that the right material is always used in the right place, depending on intended use. If, for example, only aluminium was used, it would be necessary to apply additional material to places that are exposed to more noise to attain the desired dampening result. This would cause the weight advantage over steel to be lost. This method would even entail considerable disadvantages with regard to costs and installation space.



BMW Group

Corporate and Governmental Affairs

Media Information

Date 19 May 2010

Subject Acoustics — intelligent solutions for more efficiency, comfort and dynamics.

Page 6

Ribbing against background noises.

In order to attain the lightest structure possible, the drive engineers strive to systematically employ light materials. That's why crankcases are now being made of aluminium instead of grey cast iron. This material reduction, however, also means that the crankcase walls are thinner, which increases the emanation of sound. Acoustic engineers counteract this through systematic reinforcement of the crankcase — so-called ribbing. Long reinforced bars run along the entire crankcase. These rigidity measures serve to systematically stabilise the surface and thus reduce bothersome emanations, without negating the benefit to weight. Intelligent use of materials combines the benefits of weight reduction with acoustic insulation and dampening of a structurally-reinforced crankcase.

Noise dampening directly at the source.

Engineers are constantly searching for new possibilities for optimisation, with the goal of achieving a solution that is as integrated as possible. They apply the principle of working as closely to the source as possible. For instance, instead of increasing noise-dampening at the wall between the engine and passenger compartments, the engine is fitted with efficient absorption materials. These materials are easy to apply and minimise emanation of bothersome noises quite effectively. This is advantageous not only for vehicle occupants, but also the environment. This technology is likewise applied in other places. Absorption materials ensure that minimal noise emanates from the wheel housing into the passenger compartment and vehicle surroundings. The more sound that is absorbed at the source, the less it must be dampened on the way to the interior. This helps reduce materials and weight, and decreases fuel consumption. Furthermore, the dampening can have extremely positive effects on other aspects, such as the storage of residual engine heat for the next engine start.



BMW Group

Corporate and Governmental Affairs

Media Information

Date 19 May 2010

Subject Acoustics — intelligent solutions for more efficiency, comfort and dynamics.

Page 7

Acoustic functional integration makes something that's good even better.

Another method of acoustic lightweight construction for increasing comfort and efficiency is the integration of acoustic functions in existing vehicle parts. This might entail, for example, reworking the entire undercarriage and developing a compelling solution for functionality and acoustics. Here, the fields of aerodynamics and acoustics unite their knowledge. Until now, a relatively heavy polypropylene subframe was used. For diesel engines, it was also fitted with a large noise-dampening absorption pad. With the new undercarriage structure, which is used in all BMW models, the absorption function is already integrated into the subframe, which reduces weight and required installation space. The new LWRT subframe (lightweight reinforced thermoplast) has an open-pored surface with an absorbent core. Only two to eight millimetres thick, as opposed to the previous maximum of 30 millimetres, the new structure is significantly thinner than before and only half as heavy as the previous one, which was composed of the subframe and additional shock absorber. The entire surface of the undercarriage is used, whereby the absorption surface is overall significantly larger and the increase in comfort is greater. In addition, the material is flexible and can be pressed down to two millimetres at the connecting points to the body. This allows all functions (aerodynamics, undercarriage protection and acoustics) to be optimally integrated and at the same time space and weight is reduced.

Noise-dampening is mandatory — sound design is freestyle.

But at the BMW Group, a high degree of comfort is far from everything. A current research project of the BMW Group's acoustic engineers concerns not only the acoustic fine-tuning of the vehicle, but also enhancing the driving experience through Active Sound Design.

Diesel engines present a special acoustic challenge with regard to background noises and audible dynamics. The combustion process in a diesel engine is not



BMW Group

Corporate and Governmental Affairs

Media Information

Date 19 May 2010

Subject Acoustics — intelligent solutions for more efficiency, comfort and dynamics.

Page 8

as homogeneous as in a petrol engine. The ignition sequences in the combustion chamber are more intense and louder. This is transferred to the adjacent parts and emanates into the surroundings and causes the "knocking" sound that is typical of diesel engines and inherent in their design. Due to the harsher firing pulses, a diesel engine is considered more unpleasant to the ear than a petrol engine.

In order to compensate for these acoustic disadvantages, dampening could be increased. However, use of heavy materials on the engine housing negates the benefits to efficiency of the lightweight aluminium engine block. Acoustic engineers demonstrate how to make an efficient diesel engine still sound comfortable and even dynamic through acoustic lightweight construction in combination with Active Sound Design.

Design the sound experience with active sound design.

Although the acoustic lightweight construction helps increase vehicle comfort and efficiency, engineers at BMW always carefully ensure a special driving experience as well. After all, the brand name stands for "driving pleasure". Since insulation makes the engine's operation less perceptible, this first of all means a "loss in sound" and a drop in discernible driving dynamics. As tests show, besides physically measurable longitudinal and lateral acceleration, the sound of acceleration also makes a decisive contribution to the sensation of driving dynamics.

With the use of active systems for sound design, engineers can actively shape and optimise interior sound and thus systematically influence "heard" dynamics. In order to produce the desired sound patterns, the natural sound of the engine is intelligently refined with an electro-acoustic system. A digital signal processor interactively generates additional sound components based on constantly updated driving data so that a harmonious overall impression is formed. Initial research projects have already shown how effective that is. In a MINI prototype presented in 2009, a four-cylinder engine can be made to sound like a powerful



BMW Group

Corporate and Governmental Affairs

Media Information

Date 19 May 2010

Subject Acoustics — intelligent solutions for more efficiency, comfort and dynamics.

Page 9

V8 engine or superior straight-six engine. Besides the fun factor presented by individualisation, Active Sound Design also has very serious applications, such as helping diesel engines attain even sportier sound characteristics.

An experiment demonstrated what potential this has. The BMW engineers took two identical vehicles and adjusted one of them using sound design such that the sporty qualities of the engine were clearly audible. Subsequent test drives showed that test persons, despite measurably identical longitudinal dynamics, judged the driving performance of the vehicle with integrated Active Sound Design to be better. The subjective in-vehicle impression was comparable to the sensation of an accelerating car with a stronger engine. This means more fun while driving with identical driving behaviour and equivalent fuel consumption.

Sound design for diesel vehicles — never before attained sporty sound.

The augmented dynamic experience should now benefit drivers of diesel vehicles as well. While diesel engines are highly efficient, in acoustic terms they aren't considered the epitome of dynamics and driving pleasure. And that is although a modern diesel engine has very sporty performance characteristics and is measurably superior to comparable petrol engines thanks to its high torque at starting and acceleration.

Diesel engines' harsher firing pulses during combustion, which are inherent to their functionality, are responsible for the characteristic sound. This undesirable acoustic characteristic of diesel engines has been brought to a very low level through intelligent acoustic lightweight construction. This makes room for Active Sound Design, which supports a sporty sound quality. In this way even objective aspects of driving performance are able to be heard.



BMW Group

Corporate and Governmental Affairs

Media Information

Date 19 May 2010

Subject Acoustics — intelligent solutions for more efficiency, comfort and dynamics.

Page 10

"Today's diesel engines are capable of a lot. They're efficient, highly effective and high-torque, but until now they were lacking the right sound. With Active Sound Design, they're finally achieving the sound that they deserve based on their performance characteristics."

(Albert Kaltenhauser, Manager for Airborne Sound, Acoustics and Vibrations)

Good sound is hard work.

In order to produce a special audio experience and allow a diesel engine to sound as sporty as it feels, the sound designers optimally adapt the sound to the vehicle and its engine performance with great attention to detail. Too much sound with too little engine performance is just as undesirable as minimal time delays, because the human ear is very precise. The engine sound must constantly provide for a harmonious driving experience. The particular challenge here is allocating the right dosage of sound in all driving situations and creating an authentic character.

Active Sound Design allows for significantly more systematic and finer adjustments than classic sound design, which is oriented around the intake and exhaust systems. "Even minimal changes to vehicle sound can have a big impact, since human hearing subconsciously evaluates acoustic surroundings like a high-performance analyser and all changes are continuously registered in the brain." Through their know-how and experience, the BMW Group's sound experts know exactly what sound properties must be changed to attain the desired result. At the BMW Group, specialists from Sound Design and Psychoacoustics cooperate closely with the engineers from Engine Development. With a clear idea of a sporty diesel sound, they've created an entirely new and impressive audio character for a sport coupé with a diesel engine.



BMW Group

Corporate and Governmental Affairs

Media Information

Date 19 May 2010

Subject Acoustics — intelligent solutions for more efficiency, comfort and dynamics.

Page 11

The result is convincing.

The sound-optimised test vehicle, based on the BMW 635d, has its own very dynamic audio character. The noise typical for diesel vehicles is eliminated and instead, the driver hears a very sporty, superior sound. The entire rpm range is accompanied by harmonious, varied and ever-appealing acoustics that make the high torque audible at lower rpms and also provide for fun at high rpms. Active Sound Design emphasises the existing driving dynamics of the engine and makes them immediately audible and tangible.

"The actively designed diesel sound is hard to put into words — it's unmatched. It has a strong character that sounds pleasant and provides for driving dynamics and pleasure across the entire rpm range.

(Dr. Alfred Zeitler, Acoustic Psychologist)

A team of physicists, engineers, sound designers and psychologists are working on Active Sound Design. Although they employ electronic tools and machines from analysis to simulation and test drives, in the end the human ear is the ultimate measure.

Dynamics and efficiency through acoustics.

Through the combination of measures for acoustic lightweight construction with Active Sound Design, the customer experiences a completely new vehicle sound and can enjoy the benefits of a modern diesel engine's dynamics and efficiency even more. The noise level remains low at constant driving speed, such as during a long trip. The driver only hears gentle rolling and wind noises. In dynamic driving segments, like acceleration, the engine emerges from the background and demonstrates its performance to the driver. The driver experiences driving dynamics with all senses, along with increased driving pleasure.



BMW Group

Corporate and Governmental Affairs

Media Information

Date 19 May 2010

Subject Acoustics — intelligent solutions for more efficiency, comfort and dynamics.

Page 12

For questions please contact:

Katharina Singer, Technology Communication, Spokesperson Research and Development
Phone: +49-89-382-11491, Fax: +49-89-382-28567

Internet: www.press.bmwgroup.com
E-mail: presse@bmw.de

