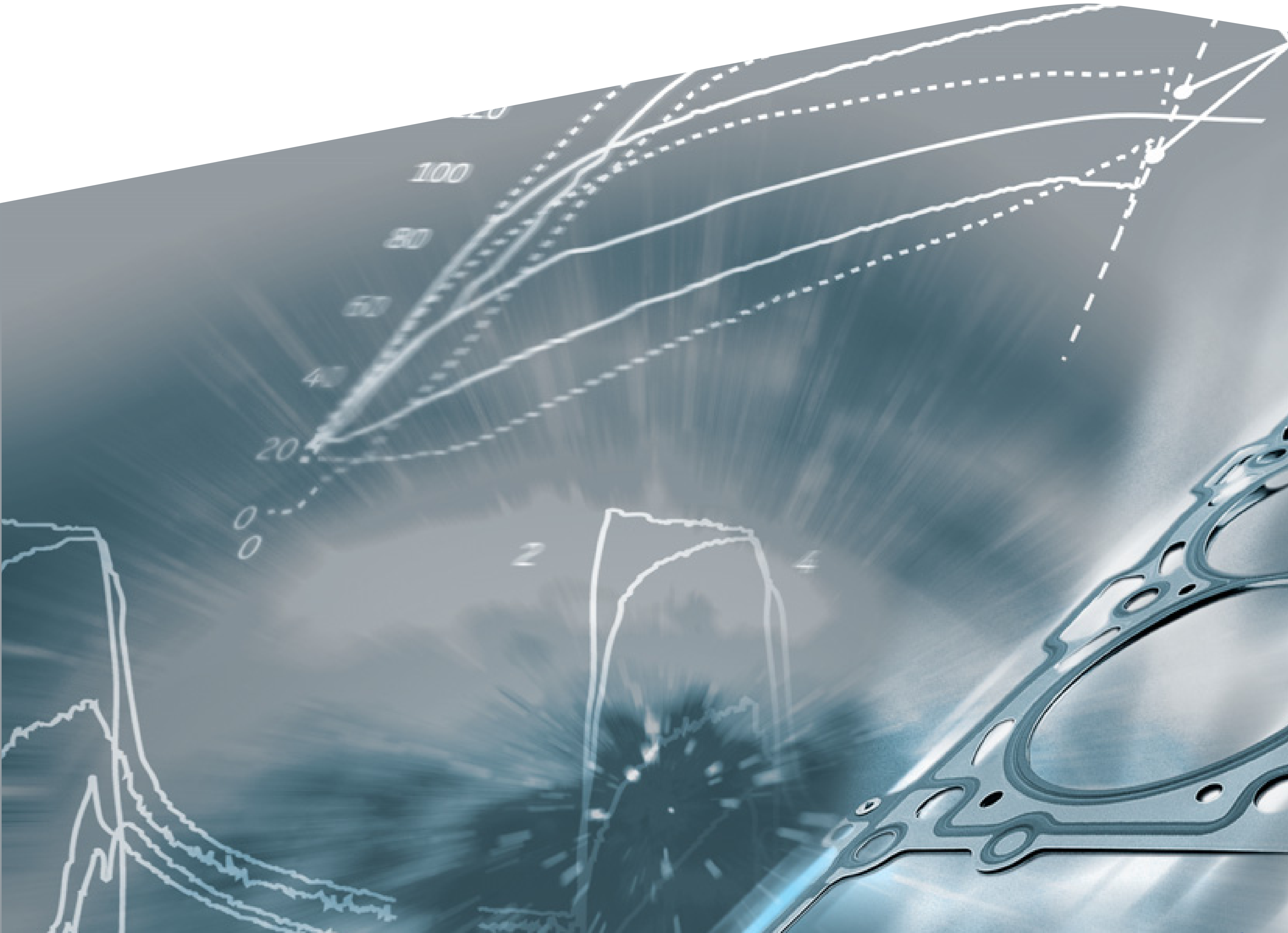

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Enhanced Functionality for Cylinder Head Gaskets
Advanced Development of the Wave-Stopper

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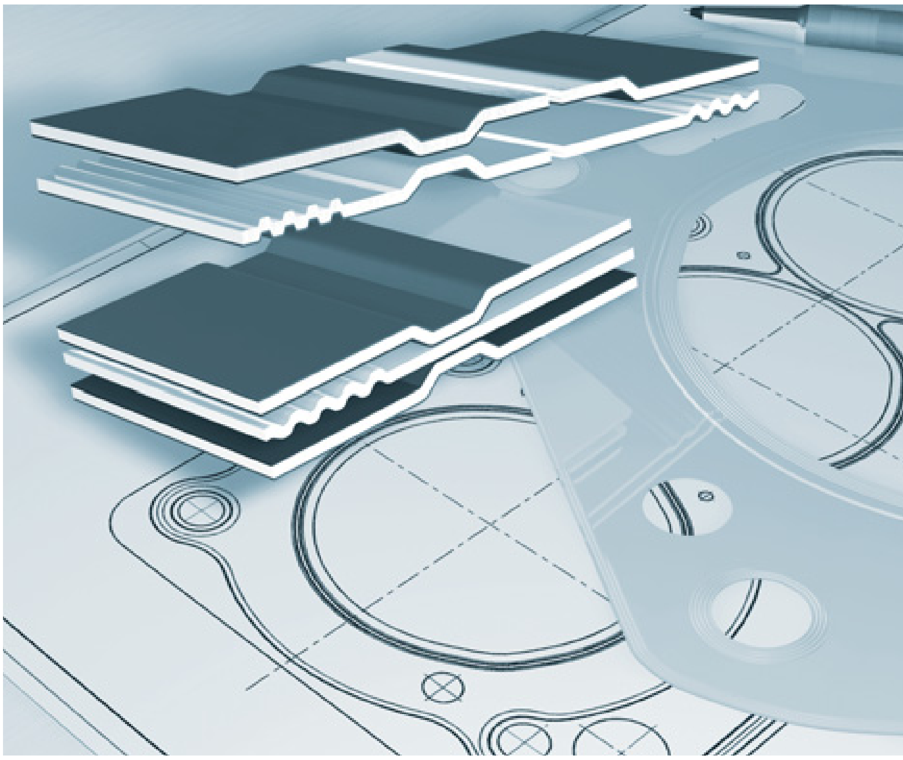
Enhanced Functionality for Cylinder Head Gaskets: Advanced Development of the Wave-Stopper

In numerous production ramp-ups, the Wave-stopper developed by VICTOR REINZ has shown that it offers numerous design and functional advantages in modern engines. The gasket adapts perfectly to the given clamping, temperature, and stiffness conditions, making optimum use of the available space. Recognizing the versatility of this sealing component, VICTOR REINZ is consistently pushing its advanced development. Meanwhile, the new technology is being applied with great success in combination with single- or multi-layer steel (SLS, MLS) cylinder head gaskets for diesel and gasoline engines of all power ratings.



1: Introduction

Development efforts at VICTOR REINZ target aligning stopper height and stopper stiffness (i.e. surface pressures) with the sealing beads and engine operating conditions. This new Wave-stopper generation will open up further applications, improving distortion combustion chamber and the shaft bearings to minimize oil consumption, blow-by, and friction.

Today's MLS cylinder head gaskets consist of several functional components that, only if optimally harmonized, will ensure the durability of the sealing quality. Coating and beads provide both micro- and macro-sealing by means of defined plastic and elasticity properties. The stopper present the bead from relaxation too rapidly, as it provides a maximum deflection, which also has a positive effect on the sealing gap vibrations in the engine. Both of these functions are achieved solely by the stopper height. Previous stopper design have a rigid and no adaptability characteristic. This is the main reason why such stoppers have acquired a poor reputation: the general opinion is that they cause deformation of components and induce distortions in the engine with a detrimental impact on engine operation. In terms of sealing technology, a stopper is essential for most MLS cylinder head gaskets, as it has a decisive effect on the sealing gap and the function of the bead - and therefore on the entire sealed joint assembly. With its innovative Wave-stopper, VICTOR REINZ is the first manufacturer to introduce an elastic-plastic stopper component which differentiates from all other stopper designs through its superior conformability and excellent design freedom, thus opening up new and successful approaches in engine sealing.

2: Extended Design Potentials with the Wave-Stopper

Modern engine designs call for increased performance and higher torque at lower component weights and using smaller engine dimensions. However, this also results in a reduction in the effective sealing surfaces for the cylinder head gasket as well as demanding tensional conditions *Figure 1* which place highest demands on gasket design, especially in the web areas. With the new Wave-stopper, development engineers are now able to make optimum use of the available packaging space. The parameters depicted in *Figure 1* and the number of waves can be adapted very flexibly to the various engine-specific requirements. For example, the waves can be reduced at the web areas and the valve pockets to match the available space, (*Figure 2).* In particular, this permits the benefits of a stopper also in narrow areas. The bead is assisted by two stoppers with a reduced number of waves, which protect it equally well against over-compression as around the combustion chamber, (*Figure 2).* Not only can individual waves be allowed to taper out in narrowest areas, the (wave-stopper) technology also makes shapes other than the standard circular contours feasible. This enables the wave-stopper to be shaped to fit around a valve pocket, for example *Figure 2.* Apart from its width, the wave-stopper height is also extremely variable. Stopper standover can be adjusted between 0.04 and 0.19 mm with variable stiffness. Furthermore, the wave-stopper was developed to be adaptable to topographies, *Figure 3.* Within the above limits, this allows the stopper height to be varied at specific locations, as required. As this height profiling is an integral part of the (forming) stamping process, it is completely save in manufacturing process. In addition, with MLS gaskets the wave-stopper ensures symmetric stopping action at the designed height for the beads integrated in the different gasket layers. Depending on the gasket design, varying stopper direction to top or bottom can be specified *(Figure 4).* With a non-symmetric distribution of stopper heights on the beads used, (these operate different forces) in different stress areas due to the non-linear curve characteristic. Within a multilayer gasket, this can lead to an increased risk of individual beads cracking. Compared with previous designs, the new wave-stopper not

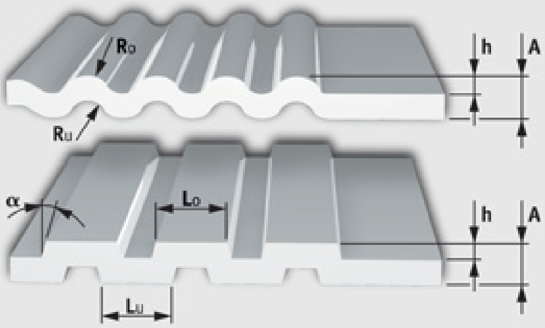


Figure 1: Geometric features of wave and trapezoidal stoppers.

Figure 2: Alternatives for wave-stopper design.

only offers a significantly wider range of design alternatives, it is also a process-save technology with a great potential for cost reduction thanks to the savings in materials and manufacturing operations.

3: Functional Features of the Wave-Stopper

Rigid stoppers such as welded rings or folded sheets have an extremely low elasticity gained solely from the material used. Due to the high elastic modulus of the steel employed for rigid stoppers, their elasticity is limited to fractions of a µm at the loads used in engines. Experience shows that this stiff behavior leads to non-uniform load distribution around the combustion chamber [2]. Similarly, this behavior also occurs over the stopper width, since the stopper cannot adequately accommodate component deformation. Static stoppers with an integrated topography achieve uniform pressures around the combustion chamber, because the engine components adapt to the stopper topography under bolt force. However, an adequate uniformity of load is only achieved conditionally and is designed for a specific operating point.
In contrast, the wave-stopper has a wide and variable elasticity range, *(Figure 5)*, which is directly related to its geometric shape. And varying the parameters shown in *Figure 1* allow the stopper's elasticity to be adapted suitably. Under compressive load, the gasket conforms to the component by as much as 30 µm, bringing the Wave-stopper in line with the given engine stiffness. As a result, the load peaks are equalized for every operating condition, and the load at the components are harmonized.
Due to the very small contact surface, when in direct contact with softer component materials at operating temperatures, the wave design could cause load peaks higher than the yield point. In order to act directly on the surface load, thus allowing a reduction of the load amplitudes, a trapezoidal stopper (shape) was developed in addition to the standard wave-stopper design. This modified wave-stopper also exhibits a pronounced elastic-plastic behavior while simultaneously reducing the surface load.
Consequently, the contact area can be adapted to the requirements and the load distributed appropriately. The different design variants of the modified wave-stopper are depicted in *Figure 6*: the contact areas can be adapted symmetrically or asymmetrically as desired. A stiffness comparison between the wave-stopper, trapezoidal stopper, and rigid stoppers shows clear differences, (*Figure 5)*. The amount of deformation corresponds to the conformability potential of the respective stopper type. Even without topographical height profiling, the elastic-plastic stopper will always allow a more balanced pressure distribution around the combustion chamber [2]. Moreover, a uniform load pressure across the stopper width is achieved due to the elastic response of the individual waves. *Figure 7* shows FEM (finite element method) results of a direct

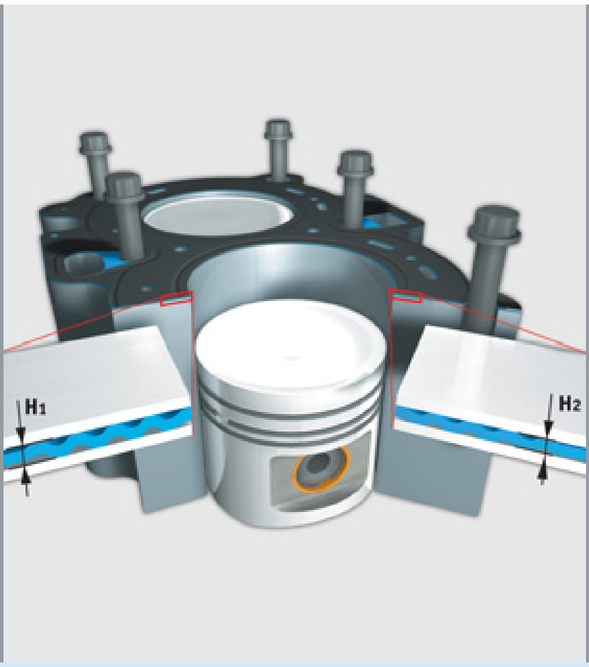


Figure 3: Topographical height adaptation with wave-stoppers.

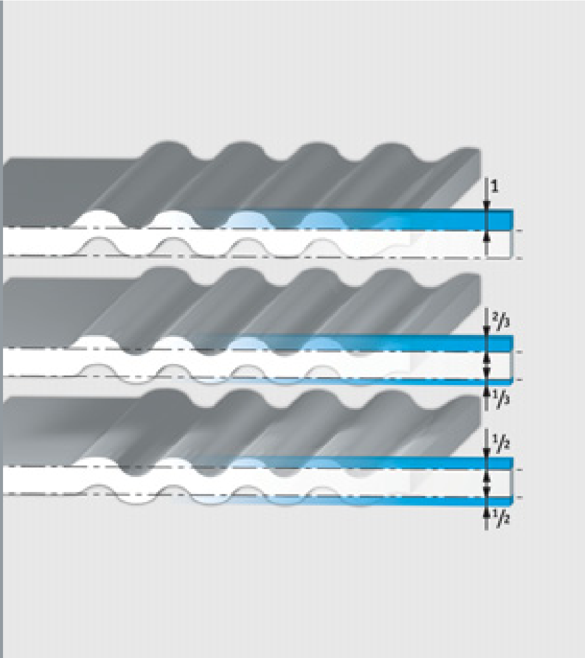


Figure 4: Possibilities of symmetric stopper distribution in MLS gaskets.

comparison of component stresses across the stopper width for different stopper variants. The calculations were carried out for aluminum blocks and cylinder heads. As opposed to rigid stoppers, trapezoidal and standard wave stoppers provide numerous sealing lines with very even load levels. Rigid stoppers exhibit great load variations across their width. This generates high stresses at some areas of the component, which taper off the closer to the combustion chamber they get: the result of insufficient elasticity.

To ensure permanent and reliable functioning of a sealed joint assembly, the elastic deformations of the stopper must be kept within certain bounds. However, modern engines place considerably higher demands on the stopper's conformability. In order to make full use of the elastic stopper's advantages around the overall combustion chamber, an additional height profile is worked into the wave-stopper. For example, the stopper height is reduced in the areas close to the bolts, thus directing the surplus force from these points into the areas between the bolts. Nonetheless, the full elastic conformation is maintained also at the different heights. Combining these two features enables a very even load distribution, which has a positive effect on the sealing gap and bore distortion. When optimizing the load distribution, the FE method is an important tool for analysis of the load distribution and deformations of engine components and the head gasket [3,4]. In FEM analysis the new wave-stopper designs with trapezoidal shape are first examined two-dimensionally, *Figure 7,* and the optimized shape then applied to a 3D engine calculation.

The trapezoidal shape is modeled in great detail for an optimum match of trapezoid stopper heights, contact areas and stiffness to the engine conditions. *Figure 8* shows the 3D simulation of a stopper with its adjacent components.

Used in all-aluminum engines, the trapezoid shape allows the wave-stopper to be integrated into an active layer facing the engine components, thus saving a layer of gasket material.

Today, single-layer cylinder head gaskets with integrated stopper can be deployed in all aluminum engines with smaller displacement and correspondingly low movement of the sealing gap. When using elastic-plastic and topographical stoppers, it is also necessary to adapt the beading engineering. For example, beads which exhibit a low spring characteristic in the active operation range limited by the stopper have now been developed. *Figure 9* sets out the force/displacement ratio of a combustion chamber bead. Stopper height and the reduction in the topographical area are marked. For different stopper heights, the difference in load on the full beads is only slight and can be ignored after the beads have settled. Moreover, this beading technique allows the effect on the non-linear spring characteristic to be actively manipulated, resulting in uniform load also on the full beads. Principally, the correct balance between stopper height and bead force must be found for all stop-

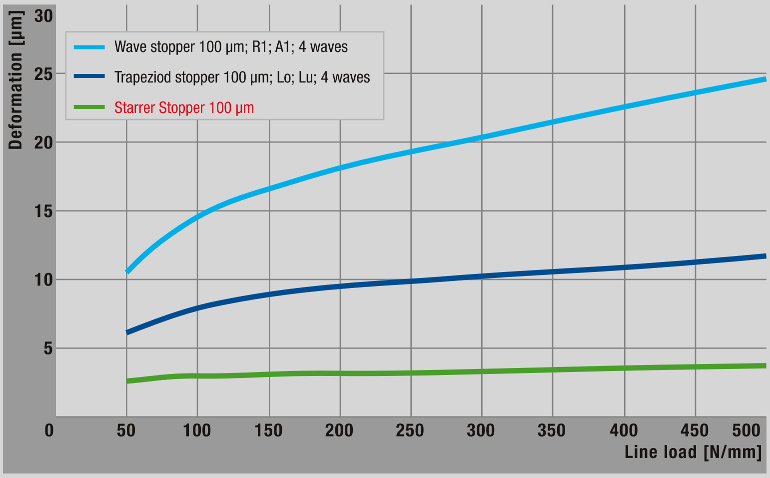


Figure 5: Static distortions of different stopper designs at uniform line pressures.

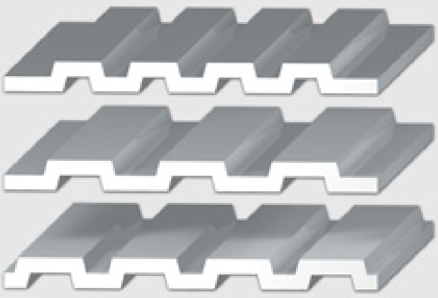


Figure 6: Variants of the new trapezoidal shape.

per versions. The new functional elements described in this article offer an ideal basis for uniform and balanced pressure distribution.

4: Extending the Wave Principle to Reduce Distortion

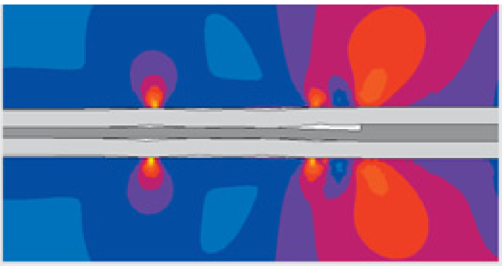
Both of the stopper functions mentioned in the previous sections - the maximum deflection level of the combustion chamber bead and component tension - are ensured by a single feature: the stopper height. Both are elemental parameters and have a decisive impact on the sealing potential and service life of the joint assembly. The possibility of separating these two elemental functions enables a reduction of component distortions caused by the high bolt forces that are transferred through the gasket. For this application, the wave-stopper principle offers a versatile solution that can be implemented without extra material outlay.

Additional supporting waves are built into selected regions of the head gasket's backland, *Figure 10*. As opposed to the combustion chamber stopper, these waves have a reduced height and can be produced with any height profiles. Thus, the overall stopper height at the combustion chamber defines the maximum compression of the combustion chamber beads, providing protection for the beads. The different heights between the two stoppers determine the tensioning gap, thereby influencing the sealing gap vibration and the distortions that can be expected. When designing the backland wave, engineers can rely on established methods and functions of wave-stoppers, thus fully exploiting the design potentials.

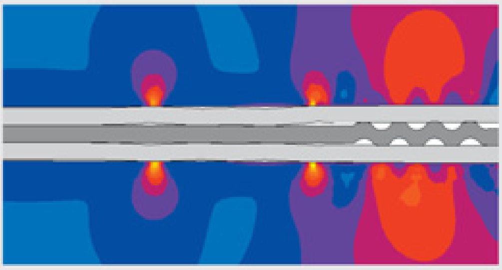
The backland wave is deployed wherever the greatest potentials for distortion optimization can be found. For example, the outer cylinders are supported in the backland of the head gasket, thus counteracting cylinder head flexure and increased combustion chamber distortion, *Figure 11*. This effect results from the asymmetric distribution of bolt forces, which are higher at the ends of the cylinder head. Several OEMs are attempting to combat this asymmetry by using bolts of lower strength or with reduced diameters at the outer cylinders. However, this results in higher sealing gap movement, because the weaker bolts exhibit increased elastic-plastic deformation under load. Even with reduced bolt force in the backland, the cylinder head will still flex at the gasket level if no stoppers are used. As the gap is equivalent to the full stopper height at this location, reducing the bolt force around the outer cylinders will have only a marginal effect on cylinder head flexing. Similarly, reduced bolt forces will hardly affect combustion chamber distortion of the outer cylinders.

Not only wave height and topography but also the position and shape of the backland wave are contingent on component stiffnesses and are determined by means of FEM. Applying FE methods allows the pressures on the beads and the stoppers to be evaluated, which is crucial for cylinder head gasket function [3,4]. Furthermore, the FEM results permit cylinder distortions and flexing of the main bearing axis to be evaluated and optimized.

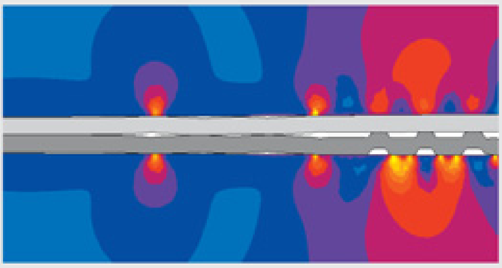
Tests to examine the behavior of the backland wave were carried out on a high-performance diesel engine with high bolt forces. Head gaskets with and without backland wave and an installation with reduced bolt forces at the outer cylinders were benchmarked. In all three solutions, the pressures on the full beads and the combustion chamber stopper were sufficient to



3 layers with rigid stopper



3 layers with wave stopper



2 layers with trapezoid stopper

Figure 7: Comparison of component stresses with different stopper designs.

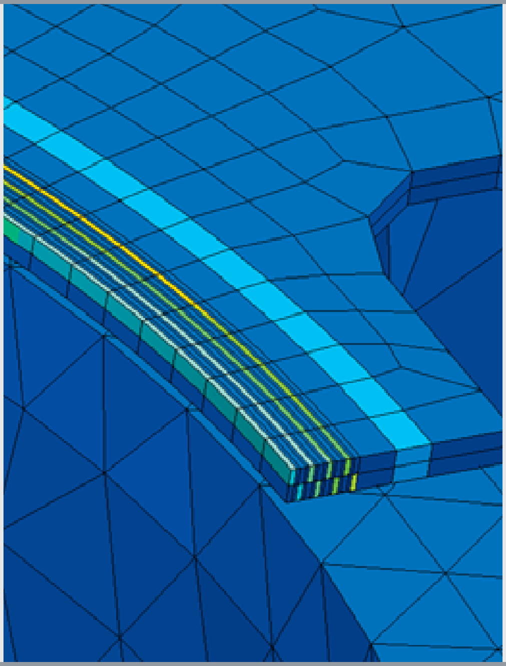


Figure 8: 3D engine simulation with finely modeled trapezoidal stopper.

ensure reliable sealing of the head gasket. However, the installation with reduced bolt forces was close to the minimum permissible limits. Therefore, the evaluation focused on cylinder distortions and the camshaft bearing axis.The greatest influence of the backland wave was found to be on cylinder head flexing due to the additional support at the head ends. The distortions along the bearing axis shown in Figure 12 are improved by up to 74 % if a backland wave is used, compared with an improvement of 60 % due to reduced bolt forces. In combination with a suitable topography of the combustion chamber stopper, correctly matched backland waves enable identical pressure levels to be achieved for all cylinders.

The same effect of the backland wave is shown for the cylinder shape. The additional support results in lower distortions: in one case, the cylinder shape of an outer cylinder was improved by up to 42 % compared with the original condition. Similarly, the impact of reduced bolt forces is less in terms of cylinder distortion. Cylinder shape was improved by 23 %, with a simultaneous reduction of sealing potential.
A targeted distribution of bolt forces between the combustion chamber stopper and the backland wave achieves a significant reduction in the effective stopper height, which leads to optimized distortion. However, under internal pressures and temperatures, the elastic-plastic behavior of the bolts remains symmetric. This offers the best conditions to ensure a good seal of the dynamically loaded head gasket. Yet, correct matching of this system to the backland wave can only be determined by means of FE methods, as this allows all component stiffnesses to be taken into account.
Numerous gaskets with backland waves have already been tested, and the information gathered confirms the calculations described here. This new application of the wave principle offers development engineers new possibilities for reducing oil consumption and friction in the engine.

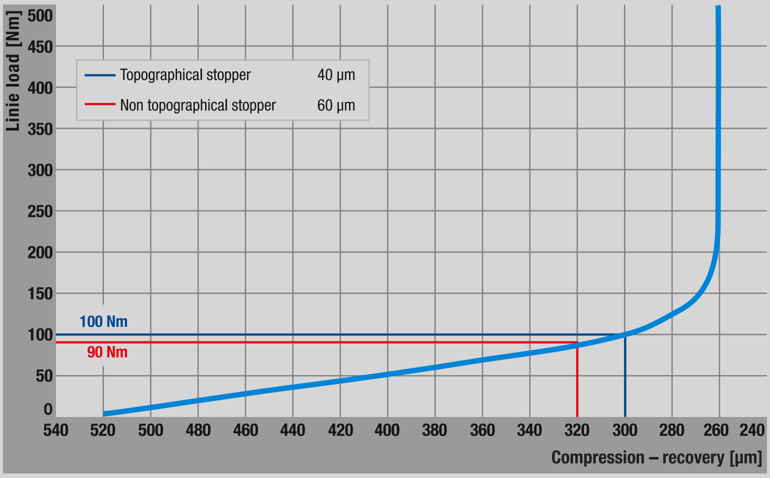


Figure 9: Bead characteristic curves showing the pressure distribution of topographic stoppers.

Figure 10: Stopper position with topographic backland wave.

5: Conclusions

Three years ago, the introduction of elastic-plastic wave-stoppers by VICTOR REINZ raised high expectations. The first generation was able to meet the demands of those days without any problems, as was proved in countless volume production applications. Wave-stoppers are used in all performance classes of diesel and gasoline engines. They are found equally in automobile and motorcycle engines and are manufactured to consistently high quality levels worldwide, e.g. in the USA, Japan, and Germany.

For VICTOR REINZ, this success represented a challenge to optimize the wave-stopper and to open up new application areas.

The second generation of wave-stoppers is now ready for future engine and material concepts. Accordingly, VICTOR REINZ is pursuing a policy of continual facelifting. For example, this has led to the trapezoidal stopper with variable geometry, which has also resulted in single- and double-layer gaskets for allaluminum engines. With the new backland wave, cylinder head gaskets now perform innovative tasks in the area of deformation optimization, while reducing oil consumption and friction in the engine.

Thanks to the systematic evaluation of market and technology trends, VICTOR REINZ is today in a position to provide suitable gasket concepts for tomorrow's engines. To learn more about cylinder head gaskets with integrated temperature sensors, see (SensoriCS®) in MTZ 12/2002. Innovation and speed are the driving forces behind the VICTOR REINZ brand name, enabling automotive visions to become realities.

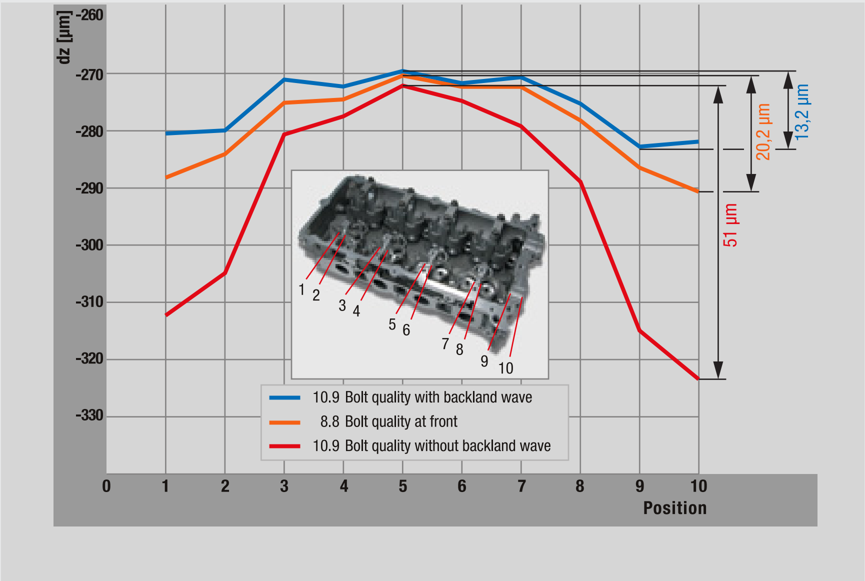


Figure 11: Comparison of the cylinder shape without additional measures and with integrated backland wave.

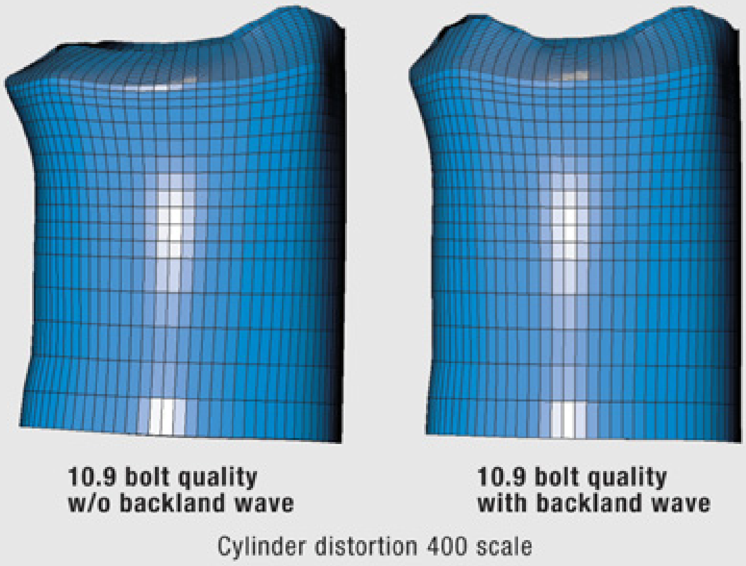


Figure 12: Distortions in the camshaft bearing axis.

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