Exactly Calculated

Concept and CAD-based simulation in engine development

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____ Shortened product life cycles and thus significantly reduced development times on the one hand, highest customer expectations in terms of development quality on the other: the engine development process of Porsche Engineering proves that these demands are not necessarily mutually exclusive, thanks to the early integration of the simulation activities in the development process.

For decades, components and modules were developed on the basis of the experience and simplified calculations of the designers. Until the first prototype was tested, it remained an open question whether the theory would work in practice.

With the introduction of computer-aided engineering software, the developers have been provided with powerful tools that enable them to push the design to the limits of the physical laws and material properties. The traditional time-consuming development loops, based on the trial-and-error process, can be therefore dramatically reduced and the mechanical and durability tests can be limited to the validation of the final design.

In the early design stage, however, the simulation has to cope with a critical trade-off: on the one hand a reasonably mature design status is the prerequisite for starting the calculation activities; on the other hand, waiting until the final design is ready would lead to enormous time losses. In fact, the simulation process consists of a series of necessary sequential steps from the meshing to the calculation and finally to the post processing, each of which requires a certain amount of time. Moreover, the results of the simulation may determinate design modification; the time necessary for this activity must also be planned. Staggered component release can only mitigate the problems: in a complex mechanical system, such as a combustion engine, the components are mutually interdependent and must be developed simultaneously. The key word to solving the issue is frontloading.

Time saving through frontloading

In the near future, no major calculation-time reduction for highly sophisticated computer-based simulation, is expected. Thus, in order to optimize the efficiency of the development process, it is crucial to accurately coordinate the design and simulation activities. For years, engine development at Porsche Engineering has resolutely followed the path of frontloading, through an early integration of simulation in the development process as well as the systematic implementation of CAD-based calculation.

The frontloading strategy is based on four pillars. The first stage consists of simple math-based programs for the preliminary component dimensioning. At Porsche Engineering, these programs are often developed during an internship or a master's thesis and they offer the students the possibility of coupling the theoretical knowledge to the practical application.

The second pillar is represented by the CAE tools—finite-element (FE) methods or computational fluid dynamics (CFD)—that are embedded in the CAD environment and operated directly by the designer. This minimizes the effort and the risks of the model conversions. Furthermore, it facilitates the work load distribution between the simulation and design groups, enabling the team to handle larger projects without additional support. Here again, the aim is to reduce development loops, limiting the time and cost intensive fully-fledged simulation to the final design. The relatively simple-to-operate CAD-based simulation tools have been intensively validated by Porsche Engineering through calculation comparisons and component tests; they can be reliably used for preliminary calculation up to a certain degree of accuracy.

The third pillar consists of fully fledged simulations that are executed in a dedicated software environment and run on powerful computers. Yet, again using such high sophisticated software, there is potential for project schedule tightening. In particular, for structural questions, for example the cylinder head and block system, an early FE calculation can help identify critical areas and provide additional information for the cylinder head gasket design. Since, at this stage, the maturity of the design is typically low, a great deal of experience is required to interpret the calculation results properly and derive the right conclusions. For this task, the engine department is supported by a vast database of similar projects that have already been calculated with the same methodology. Even if a wide range of fully-fledged CAE tools is methodically employed, the backbone of a development strategy is not represented by the software capabilities, but rather by the expertise of the engineers who continuously question the output of artificial intelligence and systematically proof the plausibility of the simulation results.

Structural optimization of components and assemblies

The last pillar is structural optimization. This practice is particularly effective at the very beginning of the development process, in the concept phase. Especially for innovative components, with no comparable predecessors, the structural optimization makes it possible to design solutions that lie in close proximity to the theoretical optimum from the beginning. ›

Using CAE tools minimizes the effort required for and the risks of the model conversions.

The conceptual design of completely new components and systems is both the most rewarding, and the most challenging, task for an engineer. Assuming a certain set of expected loads, the task is to find the best possible material distribution within a given design space. Recalculations of older designs proved that very experienced engineers can achieve impressive results even without CAE support. The die-cast crankcase of the original 911, for example, represents a perfect example of harmonious design and homogeneous stress distribution. But, even if stiffness and deformation behavior can be correctly imagined by experienced designers, more complex topics, such as the acoustic behavior of complex structures, lie beyond the limits of intuition. Using simulation-based structural optimization, it was also possible to lighten the old 911 block by several hundred grams, without compromising the functional characteristics and acoustics.

Structural optimizations generally impact component design significantly. With reference to the initial design, a weight reduction of 10 to 20 percent can be typically achieved or, alternatively, the stiffness of the component can be improved by the same factor. However, the related drastic design changes are only possible in the early concept phase. Later design changes generate major additional costs and increase development risks: test results from previous design stages are, often, no longer relevant to the improved design. This is the most important argument in favor of the use of structural optimization right at the beginning of the development process.

Structural optimization can also be useful in the context of further development of existing products. New vehicle generation or periodical updates usually aim towards vehicle mass reduction, each area having to provide its contribution. For engine and transmission, structural components frequently offer optimization possibilities, which are particularly interesting when the parts can be considered as closed systems and when the mounting points remain unchanged.

In the context of structural optimization, it is crucial to perform the simulations in a systematic and standardized fashion. At Porsche Engineering, at the beginning of each engine development project, the potential components for structural optimization are identified and scheduled for calculation. The systematic use of this method makes it possible to perform a structural optimization within a single work day, if the boundary conditions are defined and available. This makes it possible to work on unplanned components on short notice, if necessary. At best the simulation is run overnight, so that the next morning the results can be directly implemented in the design.

The term structural optimization refers to and summarizes different techniques such as

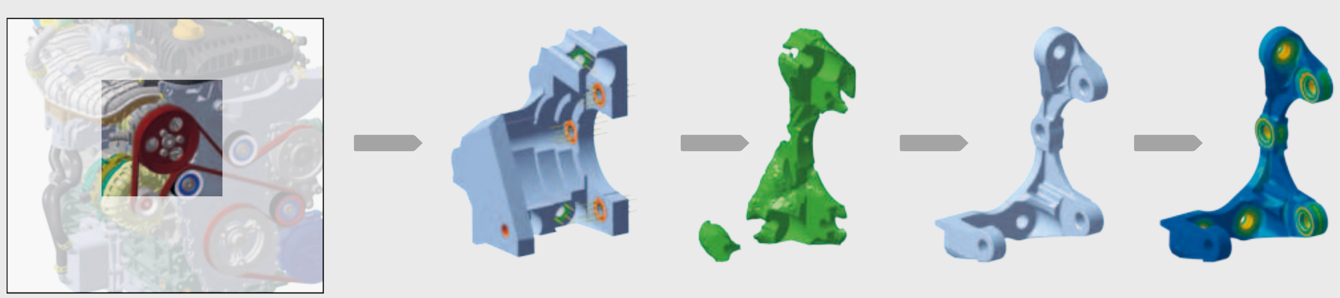
– topology optimization, which focuses on achieving the maximum stiffness with the minimum use of material, in a given design space,

– form optimization, which is particularly appropriate for high-stress component details,

– cross-sectional optimization, which represents a valuable support for the surface design (such as tailored blanks).

CAD-based simulation

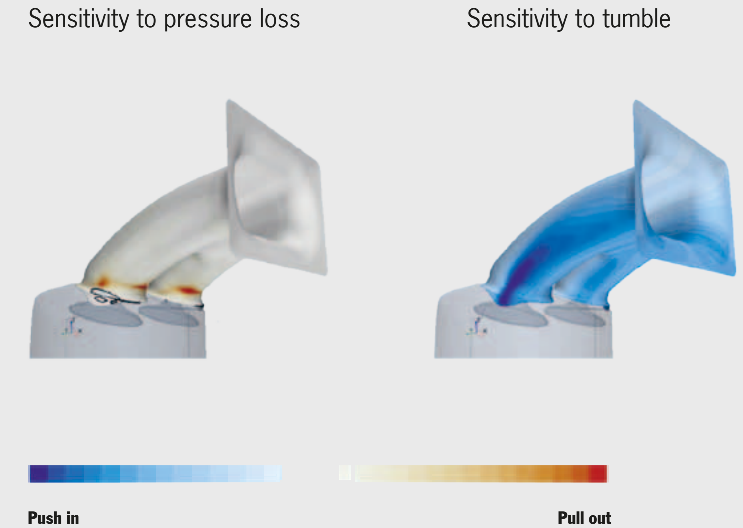
Lightweight design through structural optimization



Design space | Optimization result | Production feasible design | FE validation

Intake port optimization

The optimization tool is used to evaluate the sensitivity of the intake port geometry with reference to pressure loss and tumble.



By pulling out the red areas and pressing in the blue regions, the pressure loss in the port can be reduced while increasing the tumble.

Various application options in engine development

The applications of structural optimization in engine development at Porsche Engineering are usually related to the improvement of component mass and/or stiffness as well as the NVH behavior, targeting specifically defined component eigen-frequencies. The dedicated software allows production-related issues such as ensuring a defined minimum wall thicknesses and avoiding undercut for cast and forged components to be taken into account.

The concrete application options for structural optimization in engine development are extremely varied. The typical examples are load-bearing components such as engine mountings and brackets, but also geometrical details such as oil return passages, connection of the main bearing walls to the block structure and camshaft bearing cap designs are systematically optimized. Beyond the actual technical improvements of the components, an additional side-effect has been noticed: through the constant practice with structural simulations and results analyses, the designers develop an improved sensibility to estimate load cases and predict structural behaviors. These experiences produce, therefore, a beneficial effect in completely different components and applications and, in particular, they help the engineers to quickly identify critical areas and recognize structural weaknesses.

But even with all this, the uses are far from exhausted: in a recent example, during the concept definition of an engine family with a high degree of commonality, structural optimization was used for a DOE (design of experiments) cascade focused on concept-related questions. To put that in more detail, the effects of the bore-to-stroke ratio on engine overall dimensions, engine weight, and crankshaft stiffness have been evaluated and the results have been compared against comparable existing engines.

Enormous development potential

At Porsche Engineering, simulation and design methodologies are continuously updated in coordination with each other. New methodologies, such as the recently developed adjoint-based intake port morphing, show great potential to further shorten development times, while improving, at the same time, the quality of the development process.

The time and quality benefits of the early integration of CAE simulations in engine development—and not only there—are plain to see. To fully exploit this potential, the users are required to have a great deal of experience in order to properly assess and interpret simulation results based on early, and therefore not fully mature, component design. ■