Multibody simulation helps DaimlerChrysler improve valve trains

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Through the use of three-dimensional, dynamic multibody simulation, DaimlerChrysler-Mercedes Benz engineers are making substantial improvements in the design of valve trains. The one-dimensional codes previously used to analyze valve trains have a number of limitations such as forcing the assumption that the stiffness of valve components is perfectly linear.

LMS DADS, the forerunner of LMS Virtual.Lab Motion, has overcome this limitation, making it possible to simulate important performance characteristics, such as valve acceleration versus cam angle, to a level of accuracy that closely matches physical measurements. The simulation results allow engineers to iterate to an optimum design in far less time and at a much lower cost than would be involved in building and testing a prototype.

The valve train, consisting of the camshaft, rocker arm, valve lifter, and valve spring, plays a huge role in the performance of a diesel engine by controlling the opening and closing of the valves. In the typical finger-follower style design used by DaimlerChrysler, the cam pushes against a rocker arm that is pivoted on one side by a hydraulic valve lifter. The hydraulic valve lifter itself is fixed in the cylinder head. The other side of the rocker pushes against the valve stem through a valve spring that is designed to maintain constant contact between these two components. The valve disk opens and closes the port based on the motion generated by the assembly described above. Valve train engineers are charged with developing the valve train geometry, calculating the loads and providing the desired valve lift. This task is far more complicated than it might seem at first because the high speeds at which the engine operates introduce very complicated dynamic effects. For example, the real acceleration of the valve, rather than being a simple curve that follows the geometry of the cam, actually involves dynamic excitation and oscillations that play a big role in engine performance and in the loads placed on valve train components.

Valve train engineering challenges

The valve train engineers are responsible for meeting various functionality, durability and cost goals. They typically begin with the simpler kinematic analysis but quickly move into a much more accurate dynamic design process. In the early phases, valve train engineers work with the engineers responsible for the overall engine development to obtain performance goals and basic geometrical constraints. Later in the process, valve train engineers provide the targeted kinematic and dynamic valve lifts to the engineers who generate performance and gas exchange calculations. They receive in turn the valve time and gas forces that create loads on the valves and are needed for durability measurements. Finally, when hardware is available, valve train engineers work with the prototype testers by providing measurement objectives and obtaining results needed for validating and fine- tuning of simulation models.

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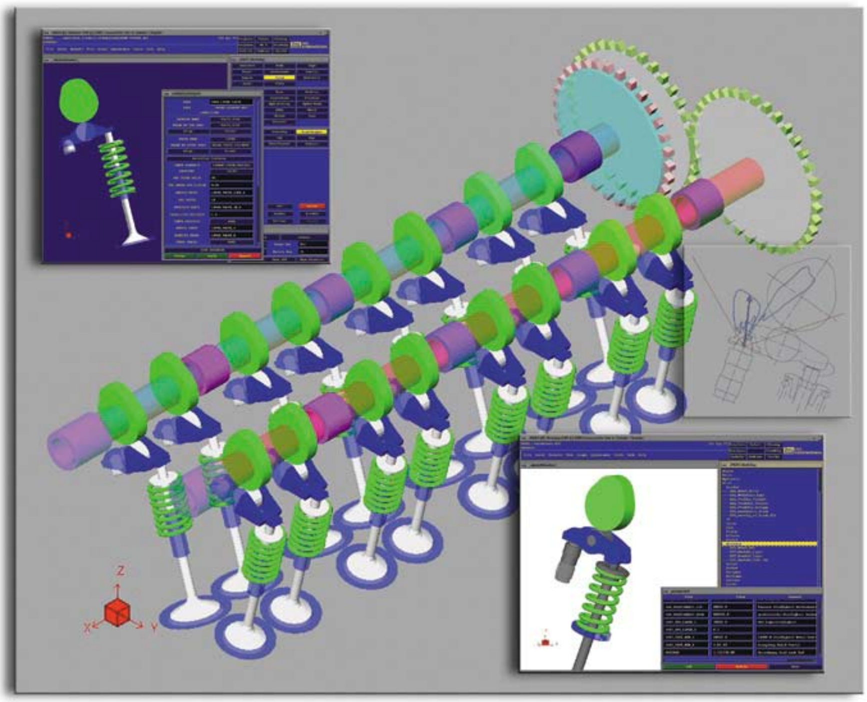
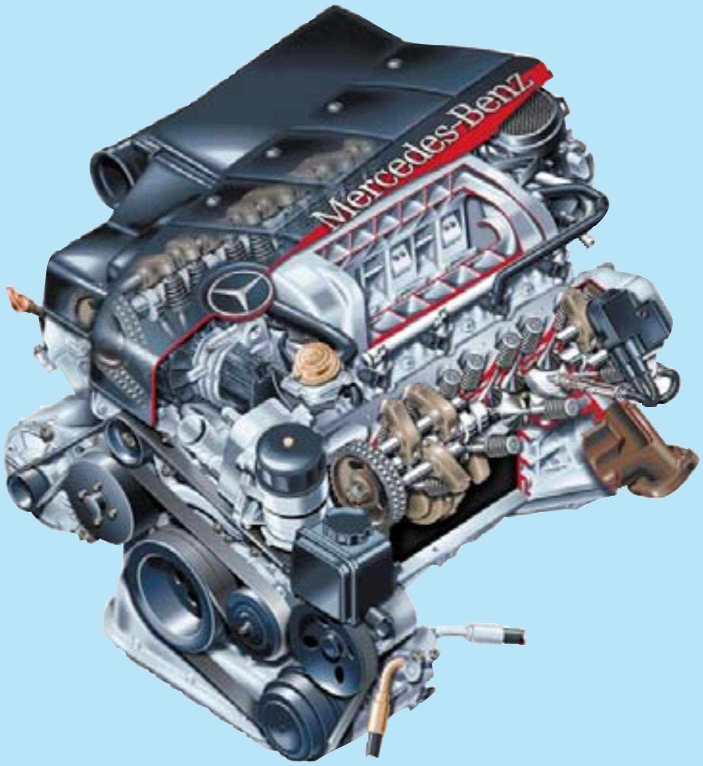


The DADS model very accurately simulates the performance of valve train designs while allowing engineers to easily modify the model for evaluating various design alternatives.

DaimlerChrysler selected LMS DADS/Engine

The DaimlerChrysler valve train engineers selected LMS DADS because it provides the necessary special features such as a cam contact element, a combustion force element and a helical spring model. The software allows a 3D system to be modeled or imported from major CAD packages, such as CATIA, Pro/ENGINEER, and I-DEAS. Engineers are able to define joints, constraints and forces on the system. DADS automatically solves the nonlinear equations of motion and reports loads, positions, velocities, and accelerations at each time-step of the simulation. Results are viewed in graphs and as photo-realistic 3D animations that enable engineers to visualize the flexible deformation of engine components in motion.



The model can be used to calculate the critical speed of the engine: the rpm rate at which the valve train components lose contact with each other and beyond which the engine will be damaged.

Valve train modeling process

DaimlerChrysler engineers model the valve train in LMS DADS by defining a cam body that is connected to the cylinder head by a bushing element. The cam drives the rocker by a cam contact element. The rocker is pivoted on the ball representing the hydraulic valve lifter on one side and a contact element connects to the valve stem on the other side. This allows the rocker and valve stem to separate and impact intermittently. The valve is divided into two bodies that are connected with a translational spring-damper element (TSDA) that provides a basic means to account for valve stem compression and friction effects. Another contact element represents the rocker interaction with the valve seat. In modeling the valve spring, a TSDA element is used in early development and a more sophisticated helical spring element is used in the later stages. Typically, when components need to be treated as deformable in the simulation, the structural mass and stiffness information is imported from commercial finite element programs to accurately solve for component deformation in modal coordinates. While the helical spring is certainly deformable, variations to the standard scheme are implemented which account for geometric nonlinearities, coil-to-coil contact, and ease of use. The helical spring is created in the coil preprocessor, which acts as a mesh preprocessor and FE solver, eliminating the need for commercial FE codes to define the spring. The basic spring data such as material properties, dimensions and centerline of the coil are entered.

The spring is then defined with beam elements arranged along the centerline. This provides a precise model of the spring but can also require considerable computational resources to solve, especially for a complete valve train system. Therefore, the preprocessor creates a coarse model that is simpler but still has the correct dynamic behavior. The coarse model is a one-dimensional flexible body with mass points connected by springs and dampers. The coil preprocessor calculates the mass distribution and stiffness. The gas forces acting on the valve disk are modeled with combustion elements. DaimlerChrysler engineers have developed algorithms to describe the stiffness of the oil and air cushion inside the hydraulic valve lifter, and implement them using user-defined subroutines. Masses and moments of inertia are calculated using the CAD model. Later in the design process, finite element modeling is used to determine stiffness of various components, particularly the lever.

Simulating valve train performance

The result is a model of the complete valve train that can be used to simulate the performance of the valve train very accurately. Once testing results are obtained, engineers compare the simulation data with valve acceleration measurements taken from prototypes. The initial measurements usually correlate very well but engineers can use them to fine-tune the model and obtain an even closer match. Once the model is validated, it can be used to evaluate the valve train design, compare the effect of suggested improvements and optimize the valve lifts.

For example, the model can be used to investigate the contact force on the hydraulic valve lifter ball, the spherical area that takes the brunt of the force from the lever. Problems can occur in this area, such as abrasion of the ball if stress is too high, or slippage if side forces are too high. The simulation provides information that can be used to detect these problems, which are nearly impossible to measure, and evaluate possible solutions. In another example, the model can be used to calculate the critical speed of the engine: the rpm rate at which the valve train components lose contact with each other and beyond which the engine will be damaged. This is another parameter that cannot be accurately measured during physical testing. It is determined by measuring the percentage of a single valve cycle during which the valve train remains in contact and is typically defined as the point where contact drops below 95% of the cycle.

All in all, the DADS model very accurately simulates the performance of valve train designs while allowing engineers to easily modify the model for evaluating various design alternatives. The speed and accuracy of this approach allows numerous significant design improvements that would have been impossible or extremely time-consuming using the old methods. DaimlerChrysler engineers are working to further improve these methods, for example by building an interface to a kinematic program designed specially for cam design. ■

LMS INTERNATIONAL
Researchpark Z1, Interleuvenlaan 68
B-3001 Leuven [Belgium]
T +32 16 384 200 | F +32 16 384 350
info@lmsintl.com | www.lmsintl.com

Worldwide For the address of your local representative, please visit www.lmsintl.com/lmsworldwide

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