Multiphysics sparks innovation in engine design

Low fuel consumption is a universal goal, and a system that shows great promise is the fully variable electromagnetic valve train (EMVT) that replaces the camshaft. Dethrottling an engine with an EMVT system leads to a fuel savings of possibly 18% compared to camshaft-driven engines. Further, the EMVT can achieve the low-end torque typically known only in diesel engines. Even though EMVT systems are well known they have not yet been brought to market. TRW Automotive in Barsinghausen, Germany, is investigating innovative solutions such as optimizing the system's electromagnets with COMSOL Multiphysics.

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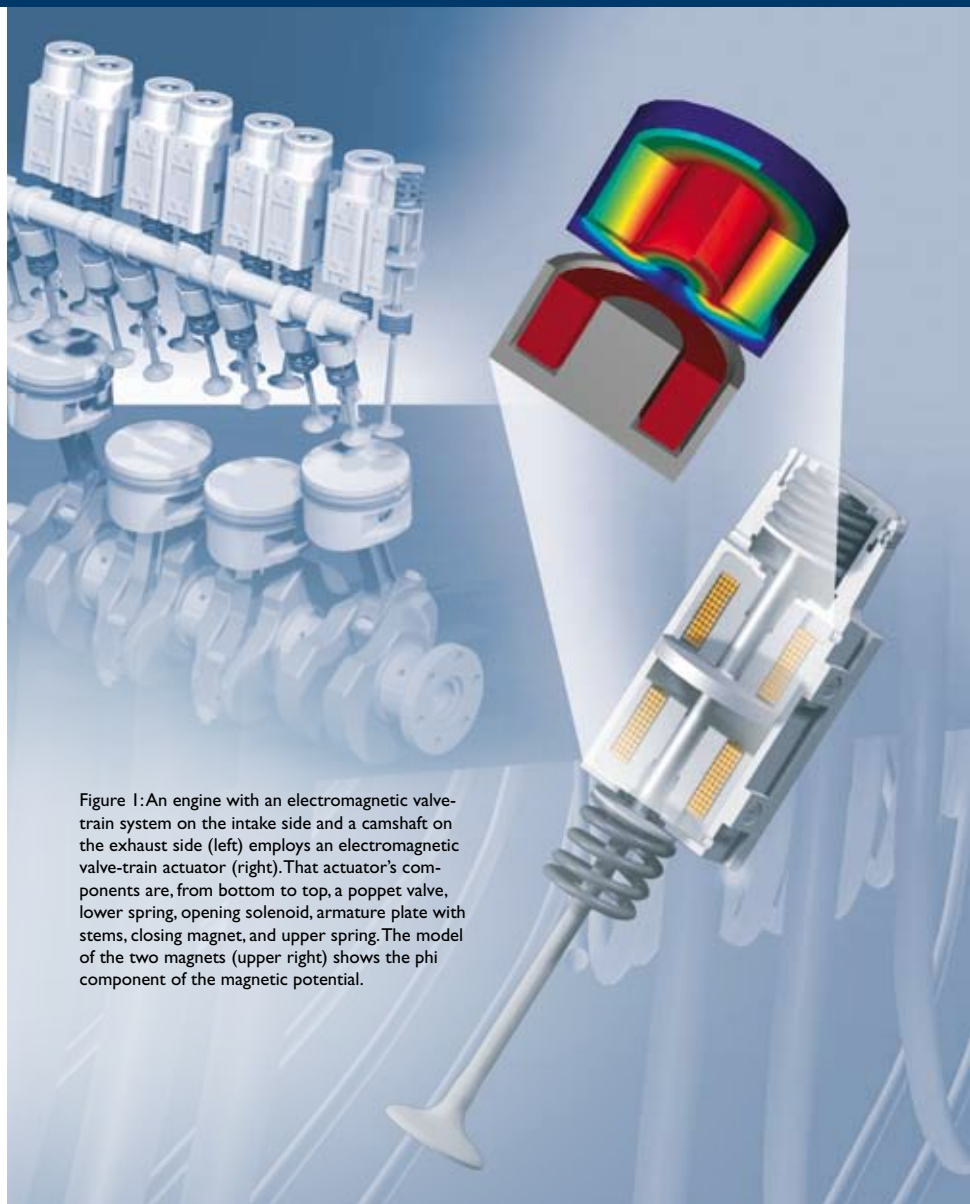

Figure 1: An engine with an electromagnetic valve-train system on the intake side and a camshaft on the exhaust side (left) employs an electromagnetic valve-train actuator (right). That actuator's components are, from bottom to top, a poppet valve, lower spring, opening solenoid, armature plate with stems, closing magnet, and upper spring. The model of the two magnets (upper right) shows the phi component of the magnetic potential.

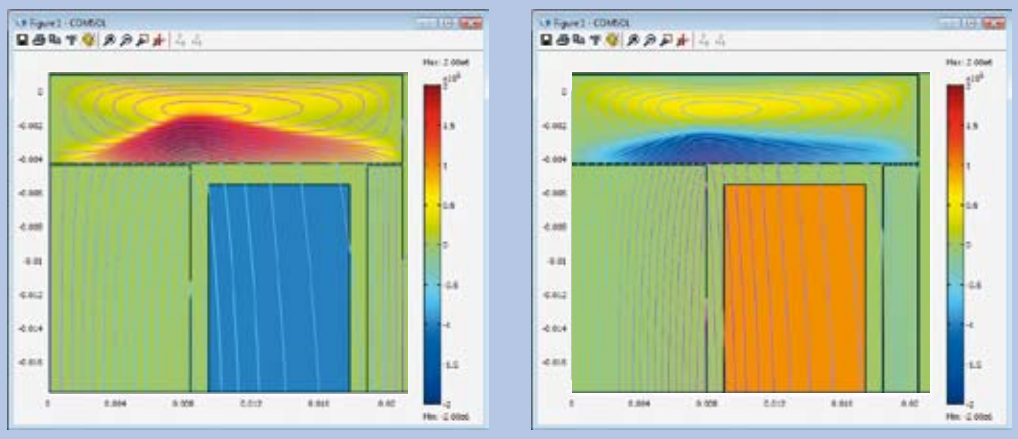

Figure 2: Distribution of eddy currents in the armature plate 2 ms after switch-off of the upper electromagnet, shortly before being caught by the energized lower electromagnet, here shown for two cases: when the currents in the two coils have the same orientation (left) and the opposite orientation (right). The color plot shows the current density.

The electromechanic drive

An EMVT actuator consists of a mechanical oscillator and two electromagnets that hold the valve and the armature open and closed. The transition time from open to closed must be short enough to allow valve timing and control strategies even at high engine speeds. This is achieved through a lightweight design. An appealing solution is the electromagnetic intake valve train (Figure 1). With it, all intake valves can operate individually whereas the exhaust valves are operated by a camshaft. This system has 90% of the advantages of a full EMVT system while avoiding the worst drawbacks.

Nevertheless, the limited space in a cylinder head requires an efficient electromagnetic actuator with a high force density and low losses. For this, COMSOL Multiphysics allows the easy calculation of static force-stroke-current characteristics, which are the starting point for the geometry optimization. Nonlinear material parameters can be provided by tables or functions, and this feature is very useful for examining different soft magnetic materials and reduces the number of prototypes.

Dynamic simulation

Energizing the magnets generates alternating magnetic fields and also induces voltages, which can cause undesirable eddy currents that cause losses and deteriorate system dynamics. Thus the soft magnetic core is laminated to reduce eddy currents. However, the thin armature plate cannot be laminated because doing so would impair mechanical rigidity. Eddy currents can be reduced only by making the material's electrical resistivity high and by disturbing their paths.

A transient simulation calculates the eddy currents as well as the equation of motion and the coupling between them and thereby calculates the electrical power transfer into the actuator. We can identify the distributions in copper losses, eddy current losses, and mechanical losses as well as analyze the impact of material parameters for various soft magnetic materials.

Another interesting experiment is this: The armature is released from one side and accelerates towards the other. When it gets close to the catching magnet, the eddy currents have not decayed. There are two ways to energize the catching magnet: where the current has the same or the opposite orientation as in the releasing magnet (Figure 2). In one case the magnetic field rises more slowly; if the armature plate approaches at a high speed, a control engineer would chose that current orientation to reduce the mechanical impact. The other case could be applied if the armature has been slowed down, such as by gas forces in the cylinder. ■

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