Electromotor Valve Drive

- Developing continuously variable, electromotor valve actuators
- Institut für Automatisierung und Informatik Wernigerode in cooperation with Harz University
- dSPACE prototyping system

The Institut für Automatisierung und Informatik Wernigerode (Institute of Automation and Informatics, IAI) in Germany has been working with Harz University for some years now on a linear engine concept for operating gas exchange valves in combustion engines. Their research has produced an electromotor valve gear that combines the advantages of variable mechanical valve gears with those of electromechanical valve gears. A dSPACE prototyping system was used for laboratory tests.

For many years, automobile manufacturers have been working on designing variable control times and variable lift in gas exchange valves. The introduction of fully variable mechanical valve drives demonstrated that the efficiency of a combustion engine can be considerably improved by variable valve control times. In addition to reducing fuel consumption and pollutant emissions, variable charge changing also has the potential to boost engine torque in the lower speed range. In multicylinder engines, fully variable valve control allows individual cylinders to be switched off, so that the active cylinders work at high operating points, which improves combustion. By combining cylinder switch-off under part load conditions with variations in valve control times and valve lift, consumption can be reduced by up to 16%.

▲ The basis of the valve test bench is a part of a production cylinder head. The gas forces effective on the valve are simulated by air pressure.

Our Project

At the IAI, we worked together with Harz University to investigate the use of various linear motor concepts. The investigations were funded by the InnoRegio program of grants run by the Federal Ministry of Education and Research. The result was a linear actuator based on the moving magnet principle and characterized by high dynamics, low moving mass, low power requirement, and small installation dimensions. The concept allows both partial valve lift and electronic valve clearance compensation to be implemented. This actuator combines the advantages of fully variable mechanical valve gears with those of electromechanical valve gears.

- With partial valve lift, the valve gap has a positive effect on the gas mix state in the cylinder (mechanical, continuously variable valve gears)
- The variable valve overlap allows favorable thermal preparation of the gas mixture by means of hot residual exhaust gas (electromechanical valve gears)

The precision that the valve gear components need for continuously variable, mechanical valve gears, and the hydraulic valve clearance compensation elements that are commonplace today, are both replaced by the electronic control. Variability at the inlet valve allows defined control of the quantity of fresh gas, or in other words, it performs the function of a throttle valve. The ability to switch individual valves in and out reduces the energy consumption involved in charge changing under partial load conditions and prevents the cylinders from cooling down.

The Actuator

The valve actuator is characterized by stationary coils between which permanent magnets are moved. As soon as current starts flowing through the stator coil, a magnetic flow forms in the iron core. This is the same as the magnetization direction along one iron pole of the permanent magnets, and opposite to it along the other. The resultant variable flux exerts a vertical force on the permanent magnets. When the direction of current is reversed, the force also changes direction. Valve lift is supported by a classical valve spring in conjunction with two additional springs mounted on the armature. The force curves resulting from finite element calculation manifest intense nonlinearities, which contribute to the high dynamics of the valve gear. In a first approximation, the force behaviors for the range that is relevant to the control can be described by adding a sinusoidal and a linear component. This is adjusted to process conditions by stacking basic elements. The actuator's dimensions fit into the available installation space. The resultant installation height is lower than that of camshaft-based systems.

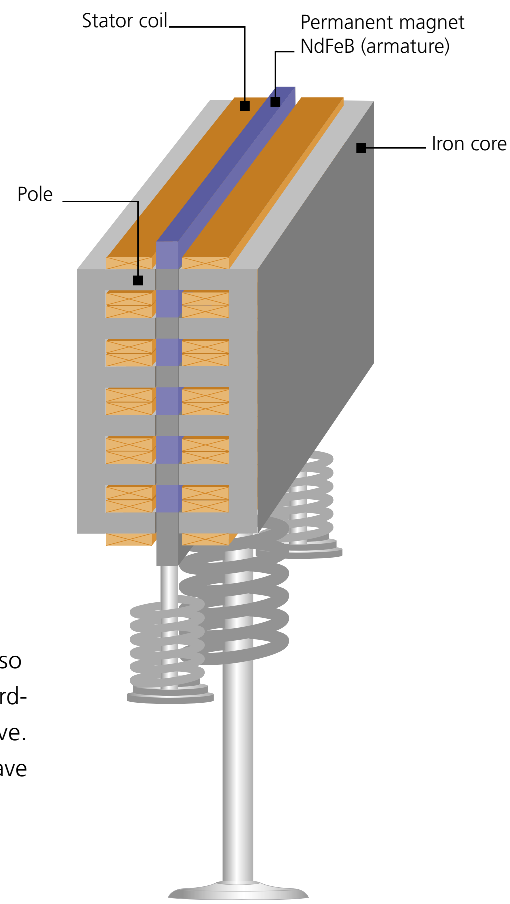
The Control

For the control of the valve gear, we chose a cascade structure consisting of an analog current controller and a digital position controller. The position controller was first implemented on the basis of MATLAB®/Simulink® and then ported to the dSPACE hardware. In addition to the actual controller, we also used the DS1103 PPC Controller Board to measure various process variables, which we visualized with ControlDesk. The DS1103 also generates reference valve lift curves, compensates nonlinear force components, and performs further monitoring functions. A sampling rate of 20 kS/s (samples per second), which provides a resolution of approx. 2° crankshaft angle at an engine speed of 6000 min-, leaves 50 µs for

> *"The seemingly unlimited computing power of the DS1103 allows us to process even complex control algorithms at a high sampling rate in real time."*
> ***Steffen Braune***

computing all functions. The efficiency of the ported algorithms is therefore vital. We are currently testing alternative control concepts. By simply porting previously simulated control algorithms to put the first laboratory sample into operation, we gained great flexibility, and it proved to be an extremely time-saving approach. Process data capture with the DS1103 and visualization with CalDesk allowed fast data evaluation and enabled us to make direct comparisons with previously simulated structures. The seemingly unlimited computing power of the DS1103 allows us to process even complex control algorithms at a high sampling rate in real time.

▶ The moving magnet principle provides high forces at a small installation volume. The 6-pole actuator generates forces over 600 N at a current density of 20 A/mm².



In addition to research on operating the actuator on the 12-V vehicle electrical system, we are currently also investigating halving the hardware requirements per valve. Tests on the fired engine have yet to be carried out.

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Glossary

Finite element computation –
Numeric procedure for an approximative solution to differential equations.

Valve gear –
Controls the gas cycle in combustion engines.

Valve clearance –
Small distance between the camshaft and the valve to ensure the valve will close securely even if it expands when warm.

Moving magnet principle –
Permanent magnets are moved by a stationary coil.