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Integrating a piezoelectric actuator with mechanical and hydraulic devices to control camless engines

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ABSTRACT

The paper deals with some interdisciplinary aspects and problems concerning the actuation control which occur in the integration of a piezoelectric structure in an aggregate actuator consisting of a piezoelectric, a stroke ratio displacement, a mechanical and a hydraulic part. Problems like compensation of the piezo hysteresis effect, scaling force-position to obtain an adequate displacement of the actuator and finally the control of such a complex aggregate system are considered and solved. Even though this work considers a particular application, the solutions proposed in the paper are quite general. In fact, the considered technical aspects occurring in systems which utilize piezoelectric technologies can be used in a variegated gamma of actuators integrating piezoelectric technologies. A cascade controller is proposed to combine a Feedforward action with an internal and an external PI-Controller. The Feedforward Controller is based on the model of the whole actuator, so particular attention is paid to the model structure. The resulting Feedforward action is an adaptive one to compensate hydraulic pressure faults. Real measurements are shown.

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1. Introduction and motivations

Conventional valve train systems with camshafts have no variability with respect to an optimal adjustment of timing for part-load and full-load of the engine. The resulting compromise can be bypassed with a variable valve timing. The variation of the timing can be performed precisely using controlled actuators instead of a camshaft. Contributions such as [1–3] present electromagnetic structure to realize camless engines but these kinds of actuators are typically very difficult to be controlled because of their electromagnetic nonlinearity. The presented hybrid actuator uses a piezoelectric actuator (PA) combined with a hydraulic aggregate. The combination of these technologies allows us to exploit the advantages of both: the high power of the hydraulic aggregate and the speed and precision of the PA. In order to control properly the hydraulic aggregate via a servo piston driven by the PA, a transmission ratio is needed since the used PA allows displacements of max. 0.18 mm only, practically even only 0.1 mm because above that the force is too low. This transmission ratio is an important part of the actuator and is realized hydraulically. The hydraulic drive that opens and closes the valve is realized with an adjustable axial piston pump. On the test stand, the oil flow rates and hydraulic pressure are variable over a dSpace motor development control unit. Fig. 1 shows the principle of the combustion engine valves to be controlled. The intake valve

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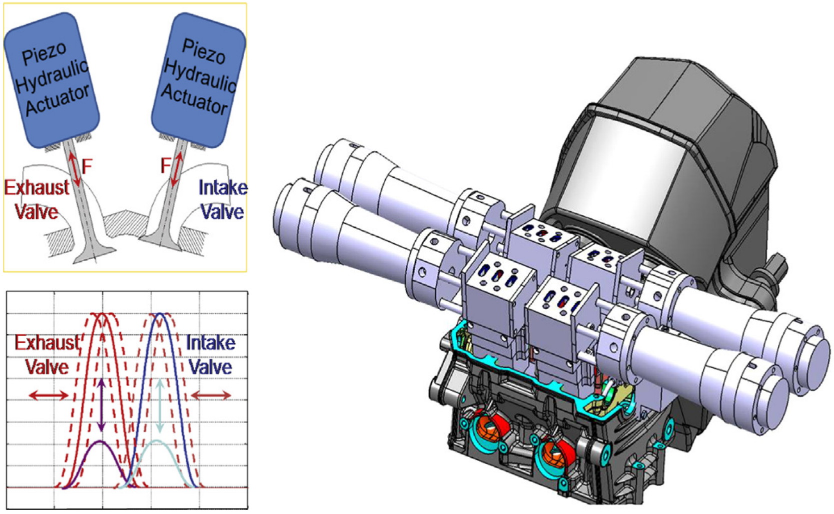

Fig. 1. New structure of the engine.

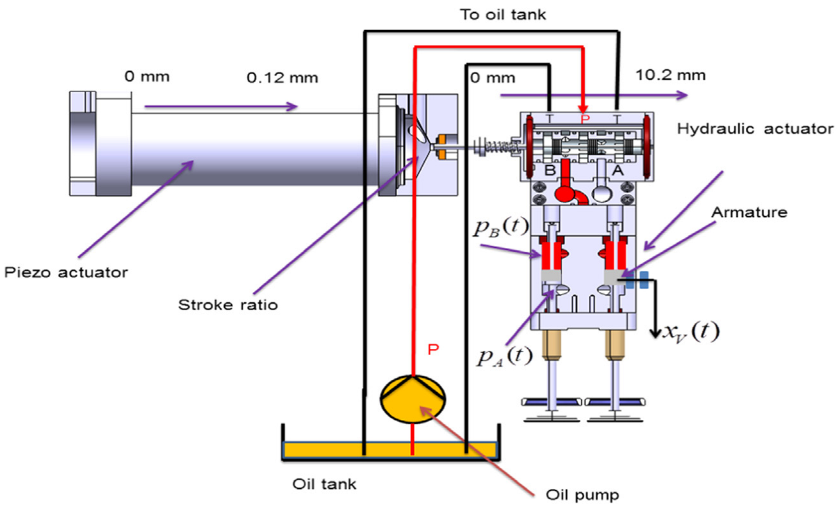

Fig. 2. Model of the whole actuator.

allows air and fuel to rush into the cylinder so combustion can take place. The exhaust valve releases the spent fuel and air mixture from the cylinder. Fig. 1 shows the diagram of the positions of an engine intake and exhaust valves. In this figure the intake and the exhaust valve position profiles are indicated. Fig. 1 demonstrates the new engine structure with, evidently, four piezo actuators. An overview on the complete hybrid actuator is depicted in Fig. 2. The piezoelectric actuator has been used in precise positioning applications such as, for instance, atomic force microscopy [4]. The main advantages of PAs are nanometer scale, high stiffness, and fast response times. However, since PAs have at least one nonlinear property, which is the hysteresis effect, position control with a high precision and high performance are problematic. Nonlinear models for the PA are presented in [5–7].

1.1. Background and contribution of the paper

In [8] an inverted Prandtl–Ishlinskii model as a Feedforward compensator is used for hysteresis compensation of piezoelectric actuators. Nevertheless it is known that a nonlinear inversion, if it is possible locally, can generate numerical problems in its implementation in microprocessors. In [9] an inverse Prandtl–Ishlinskii model is utilized for the Feedforward compensation of hysteresis nonlinearities in a piezomicropositioning stage. The exact inversion of the model holds under some conditions and is applied as a Feedforward compensator for compensating hysteresis nonlinearities of a piezo micropositioning actuator at a range of different excitation frequencies between 0.05 and 100 Hz. In [10] a framework for relating non-monotonic butterfly-shaped hysteresis maps to monotonic simple (single-loop) hysteresis maps is proposed.

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