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An Adaptive Resonance Regulator for an Actuator using Periodic Signals in Camless Engine Systems

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Abstract: The paper deals with an adaptive control strategy based on the resonance concept to minimize the regulation energy of a new generation of actuators for intake valves of camless engines. The new actuator consists of different parts, but basically it consists of a piezo part and a hydraulic one. Even though this work considers a particular application, the solutions proposed in the paper are quite general. The regulator consists of a cascade structure which combines feedforward actions with an external resonance controller strategy. The resonance controller guarantees that the hydraulic part of the actuator works at the frequency given by the velocity of the revolution of the engine. The parameters of the controllers change adaptively in accordance with the change of the velocity of the revolution of the engine. Simulations on the valves of a camless engine are shown.

Keywords: Actuators, adaptive control, motion control, resonance control.

1. INTRODUCTION

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. The presented hybrid actuator uses a piezoelectric actuator (PA) combined with a hydraulic aggregate. The combination of these technologies allows 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 stroke displacement ratio is needed since the used PA allows displacements of max. 0.18 mm only, practically even only 0.1 mm because the force is too low above that. This stroke displacement 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. Figure 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. These trajectories are periodic ones and their structures are shown in Fig. 2. Figure 1 demonstrates the new engine structure with, evidently, four piezo actuators. An overview on the complete hybrid actuator is depicted in Fig. 3. Robustness against disturbances and parameter variations are essential issues for motion control. Recently

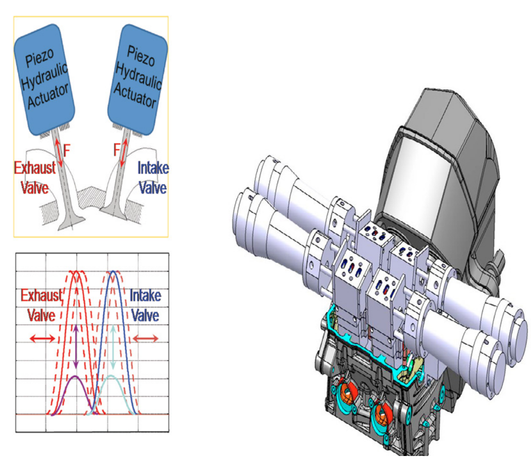

Fig. 1. Intake and exhaust trajectories. New structure of the engine

the problem of positioning has been considered in the light of a classical approach, but using new techniques is proposed. For instance, in Maeda and Iwasaki [2014] a novel feedback controller design on the basis of a circle condition for the fast and precise positioning of mechatronic systems is presented. In Maeda and Iwasaki [2015] a robust controller design against resonance fluctuations is proposed. In Ruderman and Iwasaki [2015] the friction observer within the linear feedback loop is shown and the required system identification and design of a controller are

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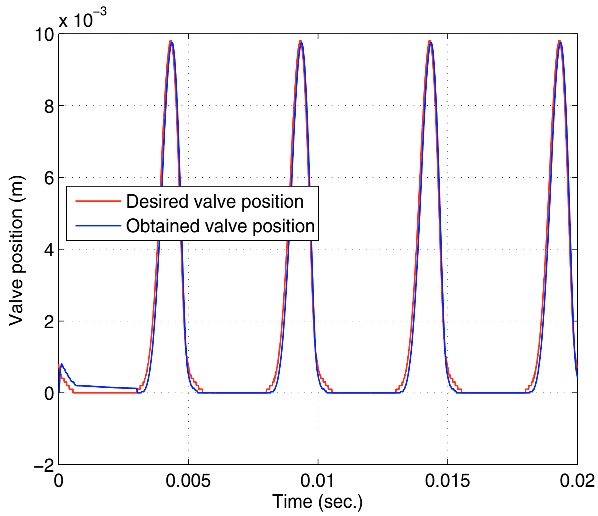

Fig. 2. Periodic trajectories

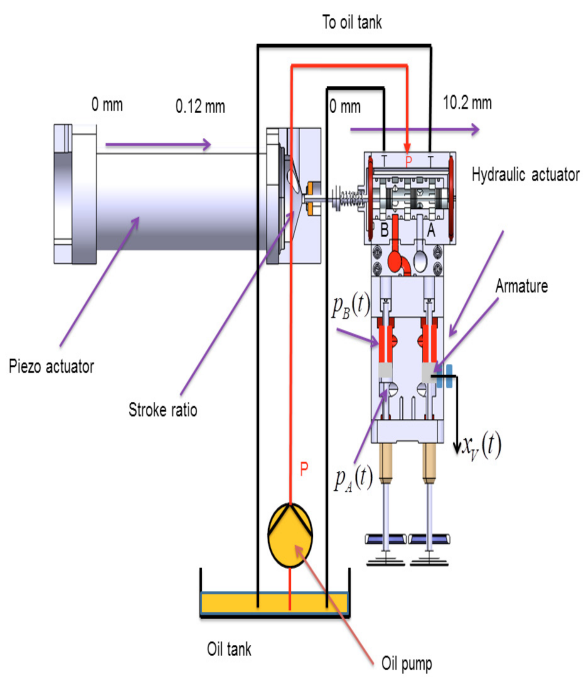

Fig. 3. Structure of the whole actuator

analysed. These results allow to obtain effective controller for motion control tasks. Wang et al. [2014] proposes a position estimation error reduction using a sliding mode approach and Ginoya et al. [2014] proposes a control in presence of uncertainties using a disturbance estimator based on sliding mode approach. A very interesting general approach in this sense is presented in Du et al. [2013] where the problem of designing globally finite-time convergent observers is considered. To conclude, the main contribution of this paper consists of proposing a Feedforward controller for the servo piston and an "external" resonance control combined with another Feedforward controller for the servo valve. The scheme of the control structure is shown in Fig. 4. The paper is organised in the following way. Section 2 shows the modelling of the servo piston and its Feedforward control. In Section 3 the models of the servo and valve piston are proposed and a cascaded

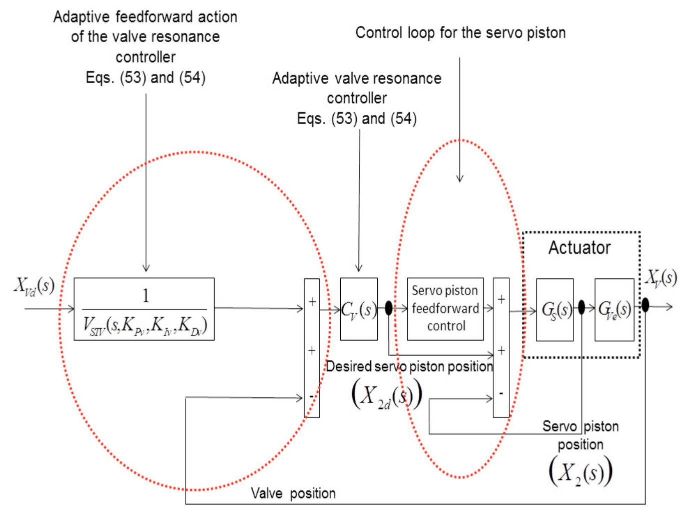

Fig. 4. Control scheme

resonance control scheme is presented. Simulations and Conclusions close the paper in Sections 4 and 5.

The main nomenclature

K_{FL}: stiffness constant
K_{FL1}: stiffness constant related to a large surface of the stroke ratio
K_{FL2}: stiffness constant related to a small surface of the stroke ratio
A_1: large surface of the stroke ratio
A_2: small surface of the stroke ratio
$V_{in}(t)$: Piezo input voltage
$V_z(t)$: Active piezo input voltage
K_x: internal piezo stiffness constant
D_x: piezo factor
$D_x K_x = T_{em}$ transformer ratio
$F_z(t) = V_z(t) D_x K_x$: motor piezo force
m_{SK}: mass of the servo piston
M_v: mass of the servo valve
$x_1(t)$: piezo position
$x_2(t)$: servo piston position
$x_{2d}(t) = V_z(t) D_x$: motor piezo movement
$x_V(t)$: valve piston position
K_{SK}: servo piston spring constant
D_{SK}: damping factor of the servo piston spring
K_{Pv}: coefficient of the P-controller for the servo valve resonance control
K_{Iv}: coefficient of the I-controller for the servo valve resonance control
K_{Dv}: coefficient of the D-controller for the servo valve resonance control
$C_v(s)$: transfer function of the valve resonance control
V_M: steady-state factor of the mechaniacal system
V_H: steady-state factor of the hydraulic system
$p(t)$: pressure
Q_{th}: volumetric flow
A_{VP}: surface of the servo piston
A_L: leakage flux parameter