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Design of a hybrid magnetomotive force electromechanical valve actuator

Key words: Permanent magnet; Electromagnet; Variable valve timing; Camless engine; Magnetomotive force

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Motivation

- Traditional engines use a camshaft for valve timing (intake and exhaust). The camshaft lifts a poppet valve to a fixed displacement and time for a limited operating range
- The present VVT systems lack continuous timing change, add complexity to the engine, and above all offer only limited improvement in engine torque
- A linear electromagnetic motor based camless engine valve train has problem with requirement for constant high power to generate a large force during the valve opening operation
- Rotational motor (RM) based actuators have been proposed and prototyped, rotational to linear linkage for pushing the valve open and closed. The high force needs high current dissipation and accurate linkage design

Motivation

- Camless engine valve trains also include hydraulic electronic valve actuators (HEVAs) ; an added load of a pump is put on the engine, thereby reducing the engine efficiency. Hydraulic fluid performance is affected by temperature and dust. HEVAs are expensive to prototype and hydraulic fluid is flammable, which discourages bulk production
- Piezo electric actuated valves add hysteresis to the system and therefore are not applicable for position control
- Recently, fully flexible double solenoid valve actuators (DSVAs) have been prototyped, but none has yet been commercialized due to inherent problems of acoustic noise, high power consumption, complexity, control, and mechanical wear.

Method

- A novel modified cylindrical core, axis-symmetric, low-inductance and hybrid PM/EM actuator is proposed
- Power consumption can be reduced by the use of a hybrid permanent magnet (PM) and electromagnet (EM) valve actuator
- Mechanical wear prevails due to the absence of cylindrical motion and torsional vibration. Mechanical wear is limited by employing a symmetric armature (Albert *et al*., 2009)
- PM flux is oriented parallel to the EM coil flux with parasitic air gaps to avoid demagnetization of the PM
- Parallel coil reduces the resistance, and thus increases the current response time, and also the force response time

Analysis

- The MHVA holding force depends on the dimensions of the armature, yoke, yoke cover plate, yoke base plate, PM, and air gaps
- Optimal values of construction parameters are refined by 2D static analysis in ANSYS Maxwell
- MHVA and DSVA are analyzed comparatively. MHVA has better performance by generating a high force-to-volume ratio at a similar value of current, and thus has a better power-to-force ratio.
- DSVA requires a constant application of current, whereas the current supply required to hold the valve open diminishes with MHVA

Results

- Static tests were performed for DSVA and MHVA. The results of static testing of DSVA are depicted in comparison with those of its finite element analysis (FEA) simulation (Fig. 10). A maximum force of 129 N was generated by DSVA at 1500 Aturn current excitation (Fig. 10a)
- Results of static testing of MHVA are depicted in Fig. 11. The force generated by MHVA decreased experimentally with the decline in armature displacement from the valve seat (Fig. 11a). The excitation current complementing the PM flux of MHVA showed promising behavior

Results

- Another studied aspect of the behavior of MHVA was weakening of the PM flux by inverse excitation of the coils. The minimum holding force at the armature seat was produced by 1450 Aturn, as concluded from FEA results. Experimental data showed minima at 1500 Aturn current excitation reduced to 17.70 N. The reduction at different inverse current excitations is shown in Fig. 12.
- We deduce from the static behavior experimental results of MHVA and DSVA that the desired performance can be achieved. MHVA had a larger force-to-volume ratio for the same current compared with DSVA. The transient time of the armature from the lower to upper solenoid seat (and vice versa) is dependent on the time constant of the spring and the mass of the armature assembly (armature, armature stem). A smaller time constant facilitates system performance. The friction and damping coefficient of the system increase the time constant of the spring and armature assembly mass system.

Results

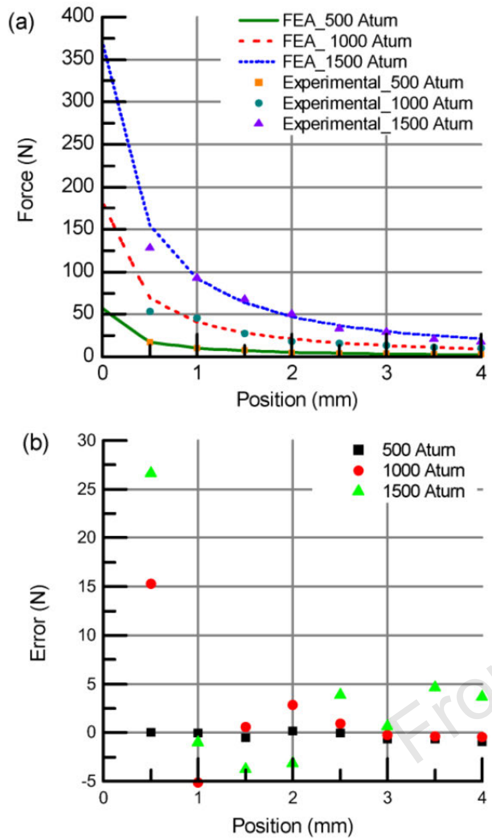

Fig. 10 Static test results for DSVA: (a) force variation with position; (b) force error variation with position

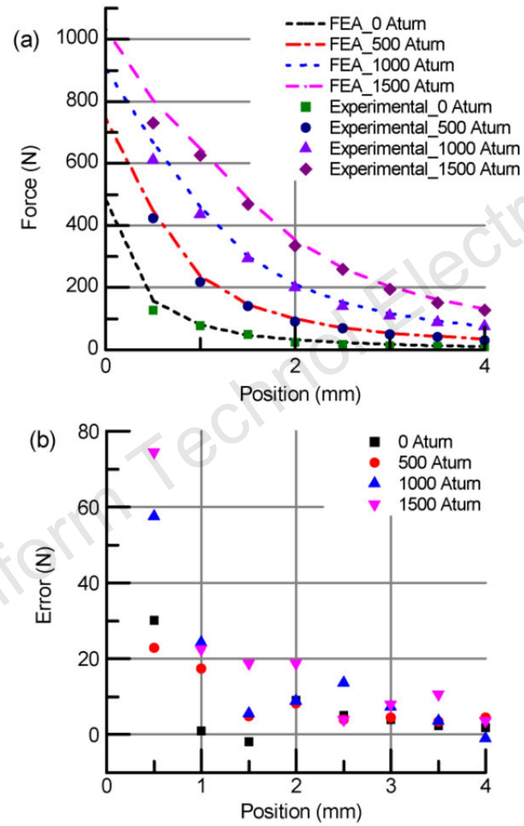

Fig. 11 Static test results for MHVA: (a) force variation with position; (b) force error variation with position

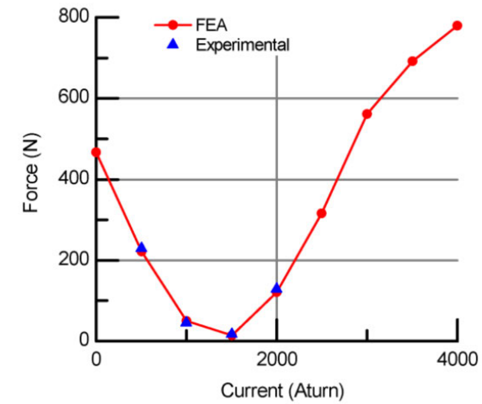

Fig. 12 Inverse current excitation effects on the F_H of MHVA

Conclusions

- A novel modified hybrid valve actuator is proposed.
- The valve actuator uses PM/EM reluctance to achieve reduced energy dissipation and generation of a large holding force.
- MHVA has an improved volume-to-force ratio with low energy consumption compared to a DSVA of the same constructional parameters.
- FEM simulations were validated by experimental results. The results can be used to formulate a mathematical model for use in control design to reduce the impact velocity of the armature.