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Approach control of an Electromechanical Valve Actuator Using Closed-loop Iterative Learning Control

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Abstract— **Electromechanical valves (EMV) are a promising alternative to camshafts in internal combustion (IC) engines. This paper is mainly concerned with the control of EMVs to achieve a soft landing. Due to the nature of the process, control of the valve is normally accomplished in two phase. This paper addresses the control problem over the first phase, namely "the approach control", where the control authority over the system is very low. Repetitiveness of the process and low control authority suggest iterative learning control (ILC) as an appealing solution. An ILC law that exploits the benefits of both feedforward and feedback approaches is proposed for this problem. Also, an iterative method for characterization and generation of the desired trajectory is provided. The effectiveness of the proposed approach controller is demonstrated through simulation studies.**

I. INTRODUCTION

On modern internal combustion engines, mechanical valve trains composed of cams, lifters, and pushrods are being replaced with electromechanical actuators. Flexibility of valve actuation system, in terms of valve lift and valve timing, is a desirable feature for IC engines. The basic motivation for using electromechanical valve control is to achieve further controlled degree of freedom that in turn can provide effective enhancement of engine torque and fuel economy. In this regard, variable valve timing (VVT) systems have come to focus in the past number of years. However, among many proposed VVT systems, the promise of camless valve trains for improved engine performance, emission and fuel efficiency has gained a great deal of interest. A number of alternatives for camshaft replacement including hydraulic [1], rotary motor [2], piezoelectric [3], and electromagnetic solenoid actuators [4] have been proposed. Electormagnetic valve actuators (EMV), however, suggest the most efficient alternative in terms of cost, complexity, control ease, force density, and ruggedness [5].

EMV actuator is basically a spring-magnet system as shown in Figure 1. It consists of two solenoids, two springs and an armature. The armature rest position is in the middle when the spring forces are in balance. Two coils can then be energized alternately to attract the armature to either end to open or close the valve. The coil that attracts the armature is called "catching coil" while the other is called "releasing coil". Gap in this context is referred to the distance between armature and catching coil. The main task of accelerating and decelerating the valve-armature system is performed by springs where the main task of the magnets is to provide energy for landing and holding of the armature by compensating for friction and combustion forces.

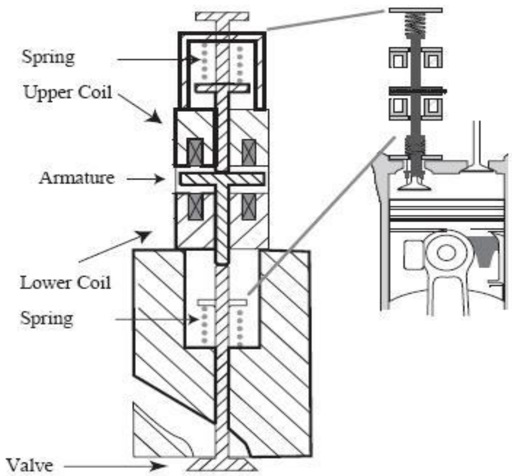

Fig. 1. Cross sectional view of the electromagnetic valve actuator [6].

There are, however, a number of technical issues that needs to be addressed before EMVs can be commercialized. Specifically, though there have been an extensive effort on modeling and control of these valves, still, reliable and robust soft landing control subject to certain practical constraints is a major challenge.

A reliable EMV control scheme should meet certain criteria including the "transition time" and "landing velocity" while satisfying voltage, current and energy constraints. Transition time, i.e. the time required to either open or close a valve, should be short enough to comply with high engine speeds. On the other hand, landing velocity, i.e. valve speed when the valve hits the cylinder head after the valve closing transition, should be kept low to avoid acoustical noise and mechanical wear. The developed control scheme should also be compatible with vehicle supply voltage standards, i.e. 42 volts, and be comparable in terms of consumed energy with existing IC engines. These required conditions along with high nonlinearity, low control authority and rapidly varying disturbances, together present a challenging control problem [7].

Due to the nature of this problem, as will be explained later in Section III, an effective strategy is to break the control problem into two regions i.e. large gap region and

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small gap region. This paper mainly addresses the control problem in large gap region, called the “Approach control”. This work, in fact, completes the work undertaken by [8] for control over small gaps and jointly presents a thorough control scheme over the whole valve transition. The present work addresses a number of shortcomings found in the previous studies: 1) Designing a trajectory that can satisfy performance criteria as well as being realizable has been an issue in the previous works. This paper presents a framework for this purpose in which the trajectory is updated iteratively while the desired points are kept fixed in the trajectory. 2) The current limit has been overlooked in previous works whereas this work addresses this issue in implementation of its proposed control scheme. 3) Disturbance variation is another issue that was considered in simulation studies 4) Finally, the proposed approach give explicit consideration to constraints in an iterative learning-based control law which is another merit of the current study.

The paper is organized as follows. Section II presents the state-space model of the system utilized for simulation studies. The main contribution of the paper is developed in Section III. This section poses the approach control problem, proceeds with proposing an algorithm for desired trajectory design and update, and finally presents an iterative learning control solution for the problem. Simulation experiments will be conducted in Section IV to demonstrate the performance and effectiveness of the proposed controller. Finally, Section V summarizes the results with some concluding remarks.

II. Model description for the EMV actuator

The following lumped-parameter model adopted from [8] is utilized for simulation studies in this paper. The model could be written in state space format as

$$\begin{cases} \dot{X} = F(X,t) + G(X,t)U \\ Y = H(X,t) \end{cases} \qquad (1)$$

where states of the system are armature position, velocity, and coil current, respectively, i.e. $X = [x, v, i]^T$. The input of the system (U) is the applied voltage. The vector fields F and G are given in Equation (2). The output of the system is considered as the armature velocity, i.e. $H(X,t) = X_2$. $f(X_1)$ describes the flux saturation and is parameterized as follows:

$$f(X_1) = \frac{2c_1}{c_2 - X_1} + c_3$$

where c_1, c_2 and c_3 are obtained through curve-fitting. The magnetic flux is thus characterized by $\lambda(x,i) = \lambda_s\left(1 - e^{-if(x)}\right)$ for $i \geq 0$. The nomenclature of the model is given in Table I.

TABLE I
MODEL NOMENCLATURE

symbol	name	symbol	name
x	position	m	mass
v	velocity	K_s	spring constant
i	coil current	B	damping constant
U	voltage	R_c	coil resistance
λ_s	maximum saturated flux	$f(X_1)$	flux saturation

The disturbances and uncertainties of the system are all lumped in F_{dist} as an additive external force term. The major source of disturbance is however due to pressure difference between the cylinder and intake/exhaust runners. As mentioned in [9] and modelled by [10], excessive pressure loads appear when the armature is far away from the catching coil. This fact is considered in system simulations. Another concern about disturbance is its variations between different cycles that should be taken into account in simulations. Variations could be due to varying engine load, gas forces, exhaust pressure variations, etc.

III. Iterative Learning Control

A. Control Problem

Typically, the desired performance includes some indices such as time, current, and velocity-position profile while the hard constraints on input should be satisfied. The inherent nature of the system, however, imposes limits on the selection of an effective control strategy. This system suffers from low control authority over the trajectory path. Specifically, when the armature is far away from catching coil, magnetic force is not strong enough to balance the spring force. On the other hand, in small gaps between armature and catching coil, decreased inductance along with increased back-emf drives the current to zero exceedingly fast and restricts the control authority [11]. Due to this physical limitation, the control over one valve cycle is divided into two different phases namely approach control and landing control.

Approach control attempts to bring the armature to a window of desired state at which time, landing control can take over and lands the valve softly within an admissible time. As mentioned, the possibility of adjusting the coil current during the landing control is limited [12]. Thus, the major task of approach control is to provide sufficient energy for the system to reach required conditions for soft landing. In effect, approach control phase increases robustness against varying disturbances. It is also noticeable that disturbances, as modelled by [10], are more significant in larger gaps.

$$F(X,t) = \begin{bmatrix} X_2 \\ \frac{1}{m}\left[\frac{\lambda_s \dot{f}(X_1)}{f^2(X_1)}\left(1-(1+X_3 f(X_1))e^{-X_3 f(X_1)}\right) - K_s X_1 - B X_2\right] + F_{dist} \\ -R_c \frac{e^{X_3 f(X_1)}}{\lambda_s f(X_1)} X_3 - \frac{\dot{f}(X_1)}{f(X_1)} X_3 X_2 \end{bmatrix}, G(X,t) = \begin{bmatrix} 0 \\ 0 \\ \frac{e^{X_3}}{\lambda_s f(X_1)} \end{bmatrix} \qquad (2)$$

Landing control, for which the control authority is enough to track a smooth landing trajectory, is addressed adequately in the literature [10 and references therein]. The problem of concern in this paper is, however, approach control problem. There are a few solutions proposed for this problem in the literature. There are generally two popular approaches taken for this problem: feedforward control approach and energy–based compensation. To tackle this problem, [13] and [11] break the system model into two linearized models corresponding to large gaps and small gaps, namely near model and far model. Accordingly, an observer-based output feedback controller (LQR) is applied. The applied method is essentially linear and moreover, the effect of disturbances is not considered. Reference [6] suggests a nonlinear feedback controller as a solution. However, in all of the above works, simulations are carried out with source voltage as high as 200 V. Reference [9] presents a closed-loop approach for the whole cycle where a feedforward term is considered to compensate for pressure disturbances in large gaps. This term is updated such that the energy of the mechanical system will maintain. There is however no report about the constraints on source voltage, current, etc. References [10] and [14] present a somewhat similar energy-based solution to approach control problem. Reference [10] estimates the gas force and then compensates for the work done by this force. This approach needs a disturbance observer. Reference [14], in a similar approach, develops a heuristic model for gas force and compensates it where it just needs the values of position and velocity. They both consider only one source of disturbance and in a feedforward configuration have no compensation against other varying disturbance sources. Reference [15] has employed a nonlinear programming algorithm to present a cycle feeforward control for solving this problem. The complexity of the presented approach is rather high and the proposed algorithm is intensive in terms of computation.

This paper, however, attempts to develop an algorithm with low-computational load capable of addressing some of the mentioned challenges. Specifically, the proposed algorithm combines the benefits of feedback and feedforward controllers in an iterative-learning based configuration to both overcome the low control authority problem and also, be able to regulate the system in face of varying disturbances. In particular, we are trying to bring the system to conditions for which the flatness-based landing control proposed in [8] can be applied. Therefore, the desired end conditions for approach control phase can be denoted as follows:

$$\begin{cases} {x_{end}}^{appr} = 2.55\,mm \\ {v_{end}}^{appr} = 2.6\,m/sec \\ {i_{end}}^{appr} = 8.9\,A \end{cases} \qquad (3)$$

Current has not been generally considered in proposed approach control schemes. However, considering restricted input voltage from one side and restricted functionality of magnet in slowing down the armature on the other side, current level at the beginning of landing control should be within a certain range. Keeping the end current fixed on an exact desired value while marinating velocity at the desired end-condition is however somewhat intractable due to varying disturbances and low control authority in large gaps. Hence, we try to maintain the end current in the reasonable range of ${i_{end}}^{appr} \in (7.5\,A, 9.5\,A)$. Moreover, the following constraints should also be taken into account while determining the control efforts.

$$|U(t)| \le 42, \;\; 0 < i(t) \le 35$$

To deal with a well defined control problem, the constraint on current (i.e. X_3) is translated to a dynamic constraint on input voltage as follows. From the state equations we have:

$$\Delta i(t) \cong \Delta t \left[\frac{e^{i(t-\Delta t) f(X_1)}}{\lambda_s f(X_1)} \big(U(t) - R_c i(t-\Delta t)\big) - \frac{\dot f(X_1)}{f(X_1)} i(t-\Delta t) X_2 \right]$$

Considering $i(t) = i(t-\Delta t) + \Delta i(t)$, after some calculations, the inequality $0 < i(t) \le 35$ can be translated into ${U_{limit}}^{d} < U(t) \le {U_{limit}}^{u}$, where

$${U_{limit}}^{u} = \frac{1}{\Delta t} \frac{\lambda_s f(X_1)}{e^{X_3 f(X_1)}} \left[35 - X_3 + \Delta t \frac{e^{X_3 f(X_1)}}{\lambda_s f(X_1)} R_c X_3 + \Delta t \frac{\dot f(X_1)}{f(X_1)} X_3 X_2 \right]$$

$${U_{limit}}^{d} = \frac{1}{\Delta t} \frac{\lambda_s f(X_1)}{e^{X_3 f(X_1)}} \left[-X_3 + \Delta t \frac{e^{X_3 f(X_1)}}{\lambda_s f(X_1)} R_c X_3 + \Delta t \frac{\dot f(X_1)}{f(X_1)} X_3 X_2 \right]$$

This means that generally, we exert the following constraints on the input voltage:

$U(t) < \min(U^{u}_{limit}, 42)$ and $U(t) > \max\big(U^{d}_{limit}, -42\big)$

B. Trajectory Generation

In terms of the desired output performance, the only matter of concern in this problem is values of interest in the end points rather than middle points. It is, however, also desirable to consume less energy to get into the desired end points. It should also be noted that the chosen reference trajectory should be realizable considering the given strict constraints on the input. To acquire a realizable trajectory satisfying the end-point conditions, we resort to an iterative learning algorithm for trajectory generation. The basic idea is adopted from [16]. For this purpose, the desired trajectory is parameterized with B-Spline functions as follows [17]

$${Y_{ref}}^{j} = G \times P^{j}$$

where P is the vector of controlled points, G is the blending matrix containing the basis functions correspondent to knot spots, and j is the iteration index.

B-Splines provide us with an appropriate basis structure to solve the trajectory generation problem in an iterative manner by just updating the coefficients (P^j). Another prominent feature of Splines is the relative ease of their continuous derivative operations using Spline coefficients.

For a p^{th} degree B-Spline, the knot vector is selected as follows

$$R = \left\{ \underbrace{a, \dots, a}_{p+1}, r_{p+1}, \dots, r_{m-p-1}, \underbrace{b, \dots, b}_{p+1} \right\}$$

where the knot vector is spanned between $a = 0$ and $b = 1$. The multiplicity of a, b ensures passing through the two end control points. Thus, for generating new trajectories while maintaining the desired end conditions, the two end control points can be kept fixed while updating the rest. In this manner, P is re-parametrised as follows

$$P^j = P^{j-1} + \rho \tilde{P}^j$$

where $\rho = [0\ I\ 0]^T$, and $\tilde{P}^j$ is the component which is updated at each iteration. In the sequel, we shall explain how P^1 is selected. Obviously, P^1 should be chosen such that the end conditions (3) and start conditions (i.e. ${x_{start}}^{appr} = -4\ mm, {v_{start}}^{appr} = 0$) be satisfied. In this regard, the desired trajectory is expressed as

$$x(t) = \theta_0 + \theta_1 \cos\omega t$$

where θ_0, θ_1, ω, and t_{end} to be determined based on the given conditions. In order to incorporate the current condition in the considered trajectory, i_{end}^{appr} is transformed to a condition on second derivative of x according to state equations, i.e. $\ddot{x}(t) = dv/dt = -2.2169 \times 10^3$. Thus, the mentioned end conditions give the following set of equations

$$\begin{cases} x(0) = \theta_0 + \theta_1 = -4 \times 10^{-3} \\ x(t_{end}) = \theta_0 + \theta_1 \cos\omega t_{end} = 2.55 \times 10^{-3} \\ \dot{x}(t_{end}) = -\theta_1 \omega \sin\omega t_{end} = 2.6 \\ \ddot{x}(t_{end}) = -\theta_1 \omega^2 \cos\omega t_{end} = -2.2169 \times 10^3 \end{cases}$$

from which the unknowns can be determined. From this trajectory, N control points can be selected as

$$P^1 = \begin{bmatrix} x(0) & v(0) \\ \vdots & \vdots \\ x(t_{end}) & v(t_{end}) \end{bmatrix}_{N \times 2}$$

It should be noted that not only $x(t_{end})$, $v(t_{end})$ should be kept fixed in all generated trajectories but also $\ddot{x}(t_{end})$ should be preserved. For this purpose, a B-Spline of order 3 is utilized where the two last rows of P^1 along with the first row is kept fixed. This could be done by appropriate selection of dimensions of zeros in $\rho = [0_{(N-3)\times 1}\ I_{(N-3)\times(N-3)}\ 0_{(N-3)\times 2}]^T$. The trajectory update algorithm is summarized in Table II.

TABLE II
TRAJECTORY UPDATE ALGORITHM

1. Initialization
   Find a set of control points such that the end conditions are satisfied and the trajectory between them is smooth. Set $j = 1$.
2. Compute the reference points ${Y_{ref}}^j = G \times P^j$.
3. Compute ${Y_{out}}^j$ applying the control law for one valve cycle.
4. Given ${Y_{out}}^j$, update the control points such that the reference trajectory is closest in a least-square sense to ${Y_{out}}^j$. Namely,
   $$\tilde{P}^{j+1} = ((G\rho)^T G\rho)^{-1} (G\rho)^T ({Y_{out}}^j - {Y_{ref}}^j)$$
   $$P^{j+1} = P^j + \rho \tilde{P}^{j+1}$$
5. Set $j = j + 1$ and go to step 2.

C. Closed-loop Iterative Learning law for approach control

Breaking the main problem into two phases, i.e. landing and approach control problems is mainly due to the fact that there is not enough control authority over the majority of the valve flight transition. In the approach control problem we are indeed dealing with that interval of low control authority. This characteristic of the system leads us to employ a feedforward control approach. Moreover, the disturbances due to eddy current and uncertainties are mostly repetitive from one cycle to the next. Therefore, an iterative learning control approach could be very appealing. There are however a few factors that should be considered in choosing the applied ILC algorithm. First, the considered system is a nonlinear system with a relative degree $\gamma > 1$. Second, the reference trajectory is not fixed and will be updated for some iterations, thereby calls for some involvement of current cycle feedback in the control law. More importantly, the varying nature of disturbances requires the incorporation of current cycle feedback in control law to achieve a repeatable performance. Third, the constraints on the control action should also be taken into account. The first and second factors have been considered in extended D-type ILC proposed by [18] where the higher order feedback error terms are incorporated in construction of the control law as follows:

$$\Theta_1: \ u_{j+1}(k) = u_j(k) + \Gamma\left(y_{j+1}(k)\right)\left({y_{ref}}^{(\gamma)}(k) - {y_{j+1}}^{(\gamma)}(k)\right)$$

where $\Gamma\left(y_{j+1}(k)\right)$ is the learning gain, γ is the relative degree of the process, and j is the iteration index. The relative degree (γ) in a nonlinear system (1) is defined as the number of times for which the output Y should be differentiated with respect to time before the input U appears explicitly.

Definition [19]. The SISO nonlinear system (1) is said to have strict relative degree γ at $X_0 \in \Pi \subseteq \mathbb{R}^n$ if

$$L_G L_F^i H(X) \equiv 0 \quad \forall X \in \Pi, \mathrm{i} = 0, \dots, \gamma - 2,$$
$$L_G L_F^{\gamma-1} H(X_0) \neq 0.$$

where the Lie derivatives are defined as follows

$$L_g h(x) = \frac{\partial h(x)}{\partial x} g(x), \qquad L_g^i h(x) = L_g\left(L_g^{i-1} h(x)\right).$$

The control law (Θ_1) renders the system (1) stable if $\left\| \left(I + \Gamma(H(x))D(x)\right)^{-1} \right\| \leq 1$, where $D(x) = L_G L_F^{\gamma-1} H(x)$ [18].

This proposed ILC law is modified by introducing a barrier function to count for constraints on the control action. A similar idea is developed in [20] for another iterative learning control algorithm. Suppose there exists some cost function $J(u)$ corresponding to the control problem where $\partial J/\partial u = \left(y_{ref}{}^{(\gamma)}(k) - y_{j+1}{}^{(\gamma)}(k)\right)$ and thus we ended up to Θ_1 by some optimization algorithm (e.g. gradient descent method). Hence, considering the constraint on u (i.e. $u \leq \bar{u}$), we are generally dealing with the following problem:

$$\min\ J(u), \quad subject\ to\ \ u \leq \bar{u}$$

Now, a barrier function $\psi(.)$ is introduced into this constrained minimization problem to change it to an unconstrained problem. Let $z \triangleq u - \bar{u}$, a convex, non-decreasing barrier function $\psi: (-\infty, 0) \to \mathbb{R}$ is chosen such that

$$\lim_{z \to 0^-} \frac{\partial \psi}{\partial z} = \infty$$

Consequently, the minimization problem is transformed to

$$\min \quad J_b(u, \sigma) := J(u) + \sigma\, \psi(u)$$

Hence, the control law can be written as (Θ_2), shown at the bottom of the page, where $\beta \in (0,1)$. Update rule for σ is a general technique being widely used in nonlinear programming. However, $J(u)$ is not known and therefore studying the optimality of the above solution needs more scrutiny which is beyond the scope of this paper. Nevertheless, it is a feasible solution that helps to keep u as far as possible from the limits ($\bar{u}$). Regarding the stability, it should be noted that since this is an iterative learning law and the effect of barrier function is decreasing at each iteration, the stability criteria of Θ_1 holds for Θ_2.

This proposed learning law is tailored according to the properties of the considered problem. Specifically, in terms of the desired performance, time is not as rigorous as velocity-position profile. Accordingly, the control law is modified to (Θ_3), shown at the bottom of the page, for which $sat(.)$ is defined in (4). It is however remarkable that with considered desired trajectory, the time will remain in an acceptable range. In order to choose the barrier function, suppose that the hard limit on U, i.e. $|U(t)| \leq \bar{U}$, can be considered as $U(t)^2 \leq \bar{U}^2$. Thus, barrier function is chosen as $\psi(U) = -Ln\left(-(U^2 - \bar{U}^2)\right)$ where $\bar{U} = 42$.

It can easily be calculated that for system (2) with $Y = H(X) = X_2$ the relative degree is well defined and $\gamma = 2$. Finally, we shall explain that for the first iteration, a feedback linearization control law is applied to the system as $U_F = \frac{1}{L_G L_F H}\left(-L_F^{(2)} H + \widehat{U}\right)$, where $\widehat{U} = Y_{ref}^{(2)} + \alpha_1\left(Y_{ref}^{(1)} - Y^{(1)}\right) + \alpha_2\left(Y_{ref} - Y\right)$. $U = sat(U_F)$, where $sat(.)$ is defined as (4), and α_1 and α_2 are selected such that $s^2 + \alpha_1 s + \alpha_2 = 0$ is Hurwitz.

IV. Simulation Studies

The proposed ILC law (Θ_3) is simulated on the system described by (2) with varying disturbances (F_{dist}) exerted on the system. The parameter values of the model are shown in Table III. The results are presented in Figs. 2 and 3. Fig. 2. illustrates a sample desired trajectory and the tracked path. Fig. 3. shows that end velocity and end current have approached an acceptable range after a number of iterations. The energy loss for a single intake valve, including approach and landing control travel, should be between 2.1 and 3.35 $J/cycle$ [21]. Generally, approach control phase has a higher proportion of energy consumption in one cycle since it covers a longer part of valve travel and also the current is higher in this phase. Results show that energy loss (i.e. $E_j = \sum_k\left(T_s.\left|i_j(k).U_j(k)\right|\right)$), after a few first iterations, remains less than 1.5 $J/cycle$ which shows an acceptable range for energy loss in the approach control phase. The transition time remains between 2.46 ms and 2.5 ms.

TABLE III
MODEL PARAMETERS

parameter	value	parameter	value
x_0	$-4\ mm$	c_1	$0.0232\ mm/A$
m	$0.28\ Kg$	c_2	$4.04\ mm$
K_s	$250.98\ N/mm$	c_3	$4.18 \times 10^{-4}\ A^{-1}$
B	$12.75\ Ns/m$	R_c	$0.52\ \Omega$
λ_s	$0.076\ Wb$	T_s	$2 \times 10^{-5}\ s$

$$\Theta_2: \ u_{j+1}(k) = u_j(k) + \Gamma\left(y_{j+1}(k)\right)\left(y_{ref}{}^{(\gamma)}(k) - y_{j+1}{}^{(\gamma)}(k)\right) + \sigma_i \frac{\partial \psi}{\partial u}\left(u_j(k)\right), \qquad \sigma_{i+1} = \beta\sigma_i.$$

$$\Theta_3: \begin{cases} U_{j+1}^*(x) = U(x) + \Gamma\left(Y_{j+1}(x)\right)\left(Y_{ref}{}^{(\gamma)}(x) - Y_{j+1}{}^{(\gamma)}(x)\right) + \sigma_i \dfrac{\partial \psi}{\partial U}\left(U_j(x)\right) \\ \sigma_{i+1} = \beta\sigma_i \\ U_{j+1} = sat(U_{j+1}^*) \end{cases}$$

$$sat\left(U_{j+1}^*\right) = \begin{cases} \min(U_{limit}{}^u, 42), & if\ U^*(t) > \min(U_{limit}{}^u, 42) \\ \max\left(U_{limit}{}^d, -42\right), & if\ U^*(t) < \max\left(U_{limit}{}^d, -42\right) \\ U_{j+1}^*, & otherwise \end{cases} \qquad (4)$$

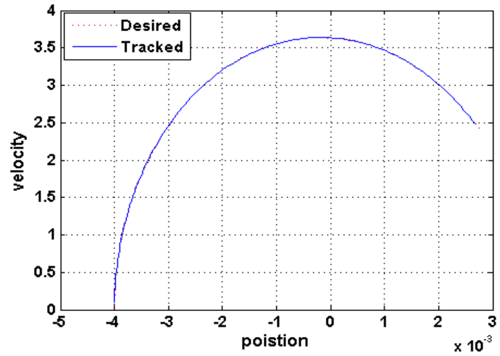

Fig. 2. Desired (dotted line) and tracked (solid line) trajectory.

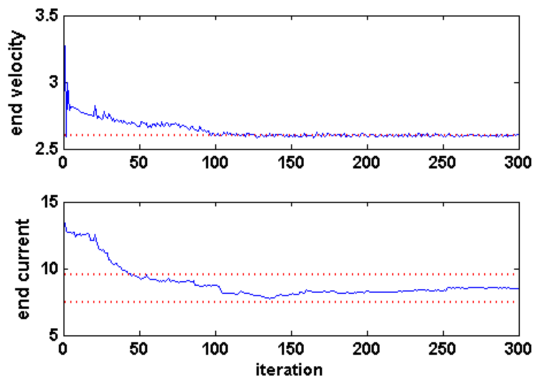

Fig. 3. End velocity and end current at $x = 2.55\ mm$.

V. Concluding Remarks

This paper presented an iterative learning-based control law for approach control of an electromechanical valve. The control objective is to reach the predefined desired conditions for a landing controller that can take over in the second phase of the overall control task, and land the valve softly. These conditions define certain velocity and current conditions which are desirable as an initial condition for the landing controller. The problem of desired trajectory update is addressed by introducing an iterative update law where the trajectory is characterized with B-Splines. Simulation results show that the proposed method is effective while it is also robust to varying disturbances which inherently exist in the process.

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