tial condition an It atif a ning Cont oll (I C) i ll it d fo thi application. Vlthough p titif cont ol approach i appli d in 6] th uting cont oll o 7 ll h n th f nc ignal i p iodic. Thi i not th ca in ngin fa ia; l faf tiing application: cau a n op ning p oc d p nd on th d if ignal and th ngin anag mn t cont oll . Th I C, u th p ition o f om th p fiou t an ition to odify th input of th n xt t ansition in o d to impo f th t ac7ing of a gif n t aj cto y. u y choo ing a uffici ntly oth t aj cto y , a th t ac7ing o go to z o, ould th impact f locity.

Th yt mod l and con t ol difficulti a uan iz d in S ction 2. S ction p nt an of fi of I C th o y. Modig cation du to impl m tation i a p nt d in S ction 4. Exp im tal ut a found in ction 5.

2 Model and control Difficulties

2.1 System model

V nonlin a yt m mod l i d f lop d in 7] and lat xt nd d to includ impact dynain in 5]. Th mod l consi t of fou tat th a atu di tanc f om th catc hing coil, z, th a atu f locity, v, th cu nt in th lo coil, i_l, and th cu nt in th upp coil, i_u. To achi f fa l a, a f puling t chniqu i d f lop d in 7] to d if th holding cu nt to z o f y quic7ly. Thu, th holding cu nt ha ittl in nc on th otion of th a atu . u y a uming that f alf op ning and clog a id ntical, th fou tat yt i d g n d a th follo ing th at yt m

i Catching coil cu nt V]

z Di tanc f om th catc hing coil m]

f V atu f locity m/]

Th uting quation of otion a

$$\frac{di}{dt} = \frac{V_c - ri + \chi_1(i,z)\,v}{\chi_2(z)} \quad (1)$$

$$\frac{dz}{dt} = 1000v \quad (2)$$

$$\frac{dv}{dt} = \frac{1}{m}\left(-F_{mag}(i,z) + k_s(4-z) - bv\right) \quad (3)$$

h

$$\chi_1(i,z) = \frac{2k_a i}{(k_b+z)^2} \quad (4)$$

$$\chi_2(z) = \frac{2k_a}{1000\,(k_b+z)} \quad (5)$$

$$F_{mag}(i,z) = \frac{k_a i^2}{(k_b+z)^2} \quad (6)$$

itt n compactly a

$$\frac{dx}{dt} = f(x, V_c) \quad (7)$$

$$x = \begin{bmatrix} i & z & v \end{bmatrix}^T \quad (8)$$

$$y = \begin{bmatrix} 0 & 1 & 0 \end{bmatrix} x \quad (9)$$

h V_c i th catching coil oltag V], i th i tanc Ω], mi th yt m 7g], k_s i th ping tiffn / m : i th damping / in F_{mag} i th agn tic fo c du to th catching coil], $\chi_1 v$ i th : ac7 EM V], and χ_2 i th inductanc 2], and y i th output.

2.2 Control difficulties

Th ain difficulti m f om a lac7 of cont ol autho ity of th a atu otion a ay f om th catching coil and th cu nt n a th catching coil. o la g di tanc f om th catching coil th agn tic fo c i much l th ping fo c , a ho n in igu 2. Th fo th yt m p n i doinat d : y th ping fo c and th cont oll ha no autho ity of th a atu otion at la g di tanc a th catching coil th agn tic fo c do a f in nc of th a atu otion, : ut anipulation of quation ( ) f al that th input f oltag ha ittl in nc on th cu nt dynain To d onst at thi con id th cu nt dynain

$$\frac{di}{dt} = 1000\left(\frac{(V_c - ri)(k_b+z)}{2k_a} + \frac{iv}{(k_b+z)}\right). \quad (\ )$$

ot that $k_b \ll 1$ and z i approaching z o. Th n placing th t m $k_b + z$ ith th fanifting pa ant $\varepsilon = k_b + z$, ut in

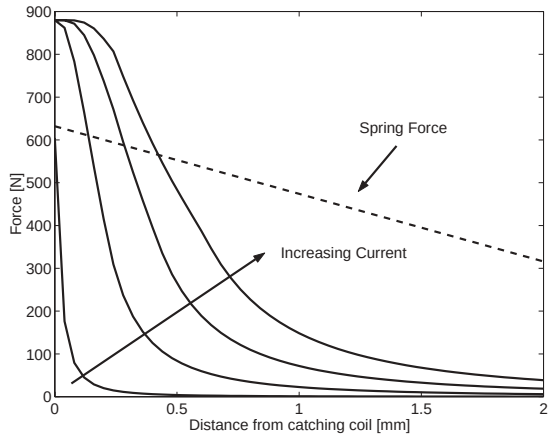
$$\frac{di}{dt} = 1000\left(\frac{(V_c - ri)\,\varepsilon}{2k_a} + \frac{iv}{\varepsilon}\right). \quad (\ )$$

Th fo f y n a th catching coil th input, V_c ha ittl ff ct on th cu nt dynain Phy ically, thi i au d : y th : ac7 EM and th changing inductanc .

To uan iz , a ll d ign d f d: ac7 cont oll ould

- Initially ai th cu nt hil th input can in nc th cu nt dynain n p pa ation fo h n th a atu n a th catching coil.
- Vpply high f oltag at th nd of th t anition to count act th changing : ac7 EM and inductanc .

In 4, 5] thi accomi h d th ough th u of lin a and nonlin a cont oll , p ctif ly.



igu 2 Magn tic fo c f u po ition fo f alf alu f cu nt

V lin a f d: ac7 cont ol analy i and d ign i n t d in 4]. V t o tag R f d: ac7 cont oll i d ign d and im pl m nt d to account fo th changing cont ol autho ity. Th g t tag of th f d: ac7 (hich act fo di tanc g at than m a ay f om th catching coil) p naliz cu nt much m than po ition o f locity in th R optimization. V th f d: ac7 ha cont ol autho ity of cu nt du ing thi im it i a: l to ai th cu n t to om nominal catching f alu , hil adju ting ligh tly fo d f iation in p i tion and f locity. a th catching coil (di tanc than m a ay) th cont oll itch to th cond tag . In th cond tag th f d: ac7 p naliz po ition and f locity h af ily in th R optimization, to n u that th a m tu i ought into contact ith th catching coil. Cu nt i not p naliz d in th cond tag a it : com ingula p tu : d n a th catching coil, quation ( ), and ha n m f d f ia and l duction 4]. Thi cont oll ac hi f imp act f locit i ith a man of . 6 m/

Th lin a cont ol la fo V_c xac : at th lo of cont ol autho ity : y : ing p opo tional to th d c a ing a m tu di tanc (cond tat). It qui a g gain to ta: ili th y t m and thi ad to f qu n t actuato atu ation n a th catching coil. V m app opiat olution i th nonlin a f d: ac7 la

$$V_c = \frac{K_1}{\gamma + z} v + \frac{K_2}{\beta + z} \qquad (2)$$

d ign d in 5]. S h K_1, K_2, γ, and β a adju ta: l gain Th input V_c i inf y p opo tional to th d c a ing di tanc th : y all fiating th ff ct of th : ac7 EM and changing inductanc n a th catching coil. V ay f om th catching coil th input f ol tag i uffici nt to ai th cu nt in p pa ation fo catc hing th a m tu . Thi f d: ac7 al achi f imp act f locit i ith a man of . 6 m/

In 4, 5] an ddy cu nt n i u d to ma th a - m tu di tanc , and a nonlin a o: f i mpli m t d to ma th unma u d tat and g lt th noi y po ition ma u m t. Th nonlin a o: f i gif n : y

$$\frac{d\hat{x}}{dt} = f(\hat{x}, V_c) + L(y - \hat{y}) \qquad (\ )$$

h $\hat{x}$ i th ti ma d tat f cto $[\ \hat{i}\ \ \hat{z}\ \ \hat{v}\ ]^T$ th gain ma ix i cho n : y u ing a alman g lt , y i th ma u d po ition, $\hat{y}$ i th ti ma d po ition, and th function $f(\hat{x}, V_c)$ i th a ma quation (7).

To imp o f th t an nt p on th u of f d-fo a d comp n a ion f om cycl to cycl u ing an It ati f a ning Cont oll i inf tigat d in]. Manufactu ing f a iation, di tu : anc , and a m it impractical to o: u ty achi f th ting nt t an nt p on qui m t ith a f d: ac7 loop V th f alf ution i p at d m y tim p cond (i. .5 tim p cond, h n th ngin i un- ning at p m th f d: 7cin] i augm nt d ith an I C. U ing th t ac7ing o f om th p fiou f alf t an- ition th I C modi th input of th n xt t an ition to d c a th t ac7ing o . 2 , imp m tation i a- ociat d ith applying an I C to th EMV actuato a in- tigat d, and xp im nt al ult a p n t d.

3 Iterative Learning Controller

3.1 ILC by singular value decomposition

It ati a ning Cont ol xploit th p titif natu of a y t mo imp o f th t ac7ing of a d i d t aj cto y, y_d, f om cycl to cycl .

t th input and th output of th y t m gif n : y $u[k]$ and $y[k]$. S h $u[k]$ and $y[k]$ a th k^{th} input and output t aj cto y p ctif ly. t u d g n th mapping $\Gamma : R^n \to R^n$ a $y[k] = \Gamma(u[k])$. U ing th impul p on qu nc $\{h[n]\}$ of th clo d loop di t lin a iz d y t m to fo m th conf olution-ma ix

$$P = \begin{bmatrix} h[1] & 0 & 0 & \cdots & 0 \\ h[2] & h[1] & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & & \vdots \\ h[N-1] & h[N-2] & \cdots & h[1] & 0 \\ h[N] & h[N-1] & \cdots & h[2] & h[1] \end{bmatrix} \qquad (4)$$

that p of id a lin a app o ximation of th y t m a th quili: ium $\Gamma(u[k]) \cong Pu[k]$.

Th pu po of th I C i to g nd th input, u^*, uch that $y_d \cong Pu^*$. V lin a I C i gif n : y

$$u[k+1] = Su[k] + E(y_d - y[k]) \qquad (5)$$

h th mat ix S i th ight on th p fiou input and th mat ix E i th ight on th p fiou o . S and E n d to : ct d uch that

$$u^* = \lim_{k\to\infty} u[k]. \quad (6)$$

V ugg td in ,], l t S and E : gif n : y

$$S = I, \text{ and } E = \frac{1}{\sigma_o} R L^T \quad (7)$$

h R and L contain th ight and l ft ingula f cto of th ingula falu d compotion, $P = L\Lambda R^T$. Λ i a diagonal mat ix ho l mn t a th ingula falu of th conf olution-mat ix, σ_i, a ang d in d c ang o d , $\sigma_o \geq \sigma_1 \geq \cdots \geq \sigma_i \geq \cdots \sigma_{N-2} \geq \sigma_{N-1}$.

V uming $y[k] \cong Pu[k]$, quation (5) i itt n a

$$u[k+1] = Su[k] + E(y_d - Pu[k]) \quad (8)$$

$$\Rightarrow R^T u[k+1] = \left(I - \frac{1}{\sigma_o}\Lambda\right) R^T u[k] + \frac{1}{\sigma_o} L^T y_d \quad (9)$$

Vplying th lin a t an fo mation $v[k] = R^T u[k]$, and $\mu = L^T y_d$ ult in

$$v[k+1] = \left(I - \frac{1}{\sigma_o}\Lambda\right) v[k] + \frac{1}{\sigma_o}\mu \quad (2 \ )$$

hich can : itt n into pa at quation

$$v_i[k+1] = \left(1 - \frac{\sigma_i}{\sigma_o}\right) v_i[k] + \frac{1}{\sigma_o}\mu_i \ \forall \ i \in [0,\ N-1]. \quad (2 \ )$$

Thu u choic of S and E yi ld a d -coupl d l a ning algo- ithm Th conf g nc of th I C i gof n d : y th ig n- falu of th N cala quation in (2). Each ig nfalu i gif n : y $\lambda_i = \left(1 - \frac{\sigma_i}{\sigma_o}\right)$. Conf g nc i gua ant d fo ach cala quation if $|\lambda_i| < 1$. V $\sigma_o \geq \sigma_i > 0$, $|\lambda_i| < 1$ i n d. Solf ing quation (2) cu f ly yi ld

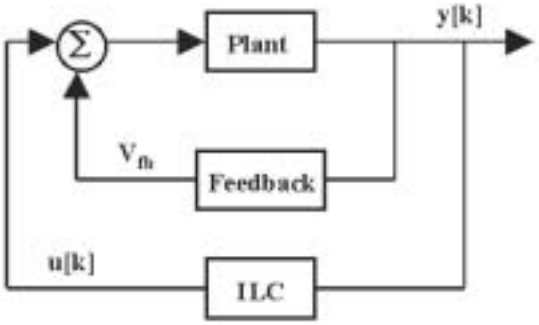
$$v_i[k] = \left(1 - \frac{\sigma_i}{\sigma_o}\right)^k v_i[0] + \frac{1 - \left(1 - \frac{\sigma_i}{\sigma_o}\right)^k}{\sigma_i}\mu_i \quad (22)$$

hich conf g to

$$\lim_{k\to\infty} v_i[k] = v_i^* = \frac{1}{\sigma_i}\mu_i. \quad (2 \ )$$

Sinc th conf g nc at i d t im d : y $1 - \frac{\sigma_i}{\sigma_o}$ and v_i^* i p opo tional to σ_i^{-1}, output compon n t that qui al input a l a n d fa t than output compon n t qui ing la g input hic h i ul in h ling to a foid actuato u ation.

T an fo ing quation (2) : ac 7 into y_d and u g nd



igu Th it atif l a ning cont oll a pli d to th EMV actuato

$$R^T u^* = \Lambda^{-1} L^T y_d$$

hich aft noting that $R^T = R^{-1}$ and $L^T = L^{-1}$ yi ld

$$u^* = R\Lambda^{-1} L^T y_d. \quad (24)$$

Vft conf g nc th plan t output i qual to th d d t aj cto y

$$\begin{aligned} y &= Pu^* \\ \Rightarrow y &= L\Lambda R^T u^* \\ \Rightarrow y &= L\Lambda R^T R\Lambda^{-1} L^T y_d \\ \Rightarrow y &= y_d. \end{aligned}$$

So in nc th it atif l a ning cont oll i nding th plan t inf f om cycl to cycl to achi f t ac7ing of th d d t aj cto y.

3.2 ILC as applied to the EMV actuator

In thi pap , th I C i pli d to th EMV Vctuato a ho n in igu . S h th output, y, i th a atu di anc f om th catching coil, and th input, u, i a pu f d-fo a d fo tag .

To pop ly d if th lin a mod l f om th nonlin a y t m (7), l t

$$V_c = V_{fb} + V_{ff} \quad (25)$$

h V_{fb} i th f d: ac7 fo tag f om th nonlin a con- t oll (2), and V_{ff} i th f d-fo a d fo tag , u, f om th I C a xplain d in ction . .Su tituting into quation ( ), th clo d loop cu n t dynami a

$$\frac{di_{cl}}{dt} = \frac{V_{fb} + V_{ff} - ri + \chi_1 v}{\chi_2} \quad (26)$$

$$\frac{di_{cl}}{dt} = \frac{\frac{K_1}{\gamma+z}v + \frac{K_2}{\beta+z} + V_{ff} - ri + \chi_1 v}{\chi_2} \quad (27)$$

Th A_{cl} and B_{cl} matric of th closd loop lin a ytm

$$\frac{dx}{dt} = A_{cl}x + B_{cl}V_{ff} \quad (28)$$

$$y = \begin{bmatrix} 0 & 1 & 0 \end{bmatrix} x \quad (29)$$

a gif n : y

$$A_{cl} = \begin{bmatrix} \frac{\partial}{\partial i}\left(\frac{di_{cl}}{dt}\right)\Big|_{x=x_{eq}} & \frac{\partial}{\partial z}\left(\frac{di_{cl}}{dt}\right)\Big|_{x=x_{eq}} & \frac{\partial}{\partial v}\left(\frac{di_{cl}}{dt}\right)\Big|_{x=x_{eq}} \\ 0 & 0 & \frac{\partial}{\partial v}\left(\frac{dz}{dt}\right)\Big|_{x=x_{eq}} \\ \frac{\partial}{\partial i}\left(\frac{dv}{dt}\right)\Big|_{x=x_{eq}} & \frac{\partial}{\partial z}\left(\frac{dv}{dt}\right)\Big|_{x=x_{eq}} & \frac{\partial}{\partial v}\left(\frac{dv}{dt}\right)\Big|_{x=x_{eq}} \end{bmatrix} \quad (\ )$$

and

$$B_{cl} = \begin{bmatrix} \frac{\partial}{\partial V_{ff}}\left(\frac{di}{dt}\right)\Big|_{x=x_{eq}} \\ 0 \\ 0 \end{bmatrix} \quad (\ )$$

h $x_{eq} = [\ i_e \quad 0 \quad 0\ ]$ ith quili: iumat , and i_e i th falu of cu nt uch that $F_{mag}(i_e, 0) = 4k_s$.

Th fo th input f oltag d p nd n th f d-fo a d and f d: ac7 a ho n in th : loc7 diag am in igu . Th conf olution at ix, P fo th I C, i fo md : y th input pon of th dic t f ion (ith a apping at 2 72 z) of quation (28), (29), ( ), and ( ).

4 Implementation issues

Thi ction p nt odi ication to th I C to compn fo nonlin a iti noi , and computational load.

4.1 Computational limitations

Th it atif l a ning cont oll n d to un altim ithin an f nt (con utif f alf op ning o clo ing) th com putational load i con ain d : y ou p oc g capa: iliti In thi ction p nt ho th computational load can : duc d : y ca ful con id ation of th p fo anc o: j ctif and actuato autho ity.

Th ain pu po of th I C i to ac hi f t landing of th a atu again th catching coil. Y uch, it only n d to achi f t ac7ing of th d i d po ition at th f y nd of th a atu t an ition. t u pa tition th output pac , $y[k] = Pu[k]$, into

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} P_1 \\ P_2 \end{bmatrix} u \quad (2)$$

h y_1 and y_2 a th initial and g nal po tion of th po tion t aj cto y output p ctif ly. Th dinction : t n th t o po tion id g n d : y th dianc that co pond to agn tic fo c high than th ping fo c . Th agn tic g ld : com t ong f n fo th quili: ium (lo) cu nt falu fo dianc than . m Th output pac pa - tition in th n d g n d a

- y_1 : th po tion of th po tion t aj cto y output fo dianc g at than . m a ay f om th catching coil.
- y_2 : th po tion of th po tion t aj cto y output fo dianc than . m a ay f om th catching coil.

Th fo to achi f t ac7ing of only y_2 th apping n po y d : y th I C i duc d to $y_2 = P_2 u$. Th computational load i u th d c a d : y ta7ing into account th cont ol autho ity i ai d in S ction 2. 2.

Th input pac $y_2 = P_2 u$ can no : pa at d a

$$y_2 = \begin{bmatrix} P_{21} & P_{22} & P_{23} \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix} \quad (\ )$$

h u_1 contain th input ignal appli d hil th a atu i g at than . 5 m a ay f om th catching coil, u_2 contain th input ignal appli d hil th a atu i - t n . 5 m and . m a ay f om th catching coil, and u_3 contain th input ignal appli d hil th a atu i l than . m a ay f om th catching coil. Sili ly , P_{21} an th ff ct of input appli d hil th a atu dianc i g at than . 5 m a ay f om th catching coil to y_2, P_{22} an th ff ct of input appli d hil th a atu dianc i t n . 5 m and . m a ay f om th catching coil to y_2, and P_{23} an th ff ct of input appli d hil th a - atu dianc i than . m a ay f om th catching coil.

Th ignig canc of th gion in th input pac can : d i: d a follo i t, inc th input ha ittl ff ct on th cu nt dynaic fo dianc quation ( ), th ion d fo th it atif l a ning cont oll to odify th input f oltag at dianc f om th catching coil, $y \leq 0.3$ m . S cond, a th agn tic fo c im uch l than ping fo c at la g dianc th i al o no a on h y th it atif l a ning cont oll hould odify th input f oltag h n th a atu i f y fa a ay f om th catching coil, $y > 3.5$ m .

om th union of th y, th it atif l a ning cont oll only adju th f d-fo a d f oltag : t n . 5 m and

. m ay f om th catc hing coil. Vt a ding at of 2 72 z thi o ond o app o xim t ly p hich i th ax im um z that ou p oc g : oa d can imp m t in al tim To 7 pth m ic qua , th z of y_2 i t o : p

Th g nal app ing p o y d : y th I C i thu $y_2 = P_{22} u_2$. Th ighting m ic S and E of quation (5) a d t - im d : y th ingula f alu d comp ition of P_{22}.

Du to ding and ma m t noi , it i not po l to haf u_2 ta t and nd xactly at . 5 m and . m a ay f om th catc hing coil. o i t po l to haf y_2 ta t x- actly at . m ay f om th catc hing coil. To cla ify, thu , th comp tation int oduc additional notation : a d on th di t p d f nt t und x th k^{th} it ation of th input f oltag , u_2, hich ha ngth a

$$u_2[k][j_u] \text{ fo } j_u \in (0, 30), \qquad (4)$$

and d g n $u_2[k][0] = 0$. o di anc g at than . 5 m a ay f om th catching coil j_u i ld at z o. Vft th cont oll d t ct a po ition l than . 5 m ay f om th catching coil, j_u inc a nc m tally ith th ding at .

Sim ly , l t u und x th k^{th} it ation of th output, y_2, hich ha ngth a

$$y_2[k][j_y] \text{ fo } j_y \in (1, 30) \qquad (5)$$

h $y_2[k][j_y]$ to th m u d output at th cu nt tim p o di anc g at than . m a ay f om th catching coil j_y i ld at . Thu , th cont oll 7 p iting th f alu of $y_2[k][1]$ at ach tim p Vft th cont oll d t ct a po ition l than . m ay f om th catching coil, j_y inc a nc m tally ith th ding at . Th fo th cont ol cap tu app o xim t ly th la t . m of th t an ition.

Th xi to m f a iation in h xactly u_2 and y_2 : gin and nd du to th ding at and noi 2 o f , j_u i al ay allo d to ach , fn if thi man that th I C ill m dify th f oltag fo di anc than . m ay f om th catc hing coil.

4.2 Selection of desired trajectory

u y t uncating th po tion of th t aj cto y i to t ac7, haf inadf t ntly int oduc d anoth cation. Th d i d t aj cto y, y_d, mu t: a oth xt n on of y_1 fo it to : f a ily t ac7 d : y y_2. Sp ci g cally , th po ition and f locity at th ta t of y_d mu atc h th po ition and f locity at th nd of y_1.

To a ify thi con aint l t

$$y_d[k][j_y] = y_2[k][1]\, e^{\frac{v[k][1]}{y_2[k][1]}(j_y - 1)TS} \qquad (6)$$

h $v[k][1]$ i th f locity of th a tu h n th ap $y_2[k][1]$ i co d d and TS i th ding tim

V m n gatif falu i cho n fo $v[k][1]$ that ill nu that y_d i d caying xpon n tially and th u a h t ac7ing o d c a o hould th impact f locity. Th g x d $v[k][1]$ falu do not gua ant a oth t aj cto y ; ut it i a p olution fo th ca of z o ai di u : anc Id ally, could u a f locity o fo an accu at falu of th initial f locity o could u th tan d f locity f om th o: f in ( ).

4.3 Noise compensation

To p f nt th I C f om att m ing to comp n at fo no noi , th ma u d t aj cto y n d o : g lt d. S hil th o: f do g lt th output, it do not comp t ly lim at th noi Vgain, th p titif natu of th y m i xploit d to imp o f th g lt ing.

In ad of upd ating f y cycl , th I C i odi d to upd at f y thi d cycl . Th t ac7ing o i thu d t im d : y th diff nc : t n th d i d t aj cto y and th af ag of th p fiou th ma u d t aj cto i Equation (5) i no gif n : y

$$u[n+1] = Su[n] + Ey_{error} \text{ fo } n = 3k \qquad (7)$$
$$u[n+1] = u[n] \text{ fo } n \neq 3k \qquad (8)$$

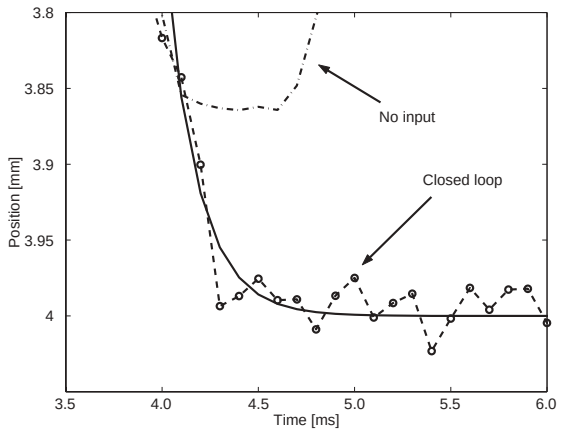
h

$$y_{error} = y_d - \frac{1}{3}\sum_{j=0}^{2} y[n-j]. \qquad (9)$$

5 Experimental results

Th follo ing xp im t conduct d to gaug th ff c- tif n of th I C. If ll tun d, th nonlin a f d: ac7 gif n : y quation (2) achi f p act f lociti ith a man of . 6 m Th output of th ll tun d nonlin a f d: ac7 atc h th d i d t aj cto y clo y, a o n in igu 4. Th f p n al o includ d in igu 4 fo comp i on.

In ach xp im t th f d: ac7 i p tu : d igh tly, and th I C i d to t ac7 th d i d t aj cto y. o con ncy ith ou p fiou o 7 4, 5, 7] th po ition plott d in th follo ing gu i th d fiation f om th idl po ition (4 m li anc f om th coil).



igu 4 Compa i on of th d i d t aj cto y and th output ac hi f d : y a ll tun d f d: ac 7

5.1 Matched perturbation

o th g t xp imn t th f d: ac7 i ondi g d : t n . 5 mm and . mm uc h that th input i ld con an t du ing thi p iod. V th I C op at f th am ang , thi p nt an a y na io fo it to handl .

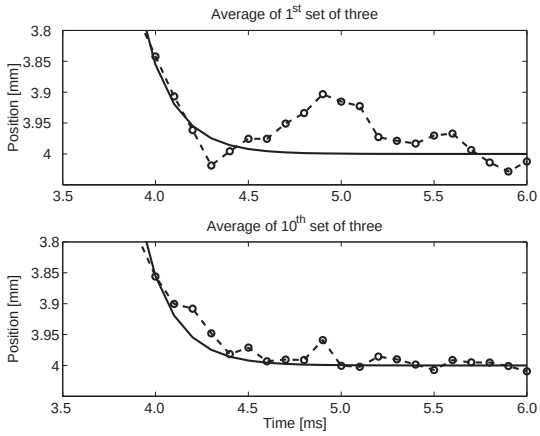
Th af ag of th 1^{st} of th t aj cto i th af ag of th 10^{th} of th t aj cto i , and th d i d t aj cto y a plott d tog th fo compa i on in igu 5. Initially th t ac7ing o i quit la g and th a atu : ounc again th catching coil. T n it ation at , th output i much oth and th o ha d c a d igni g can tly.

Th chang in th input fo ltag : t n th 1^{st} and 10^{th} it ation i sho n in igu 6. Th dott d lin p nt th fo ltag that ould haf : n gif n : y th non-mdi g d f d: ac7.

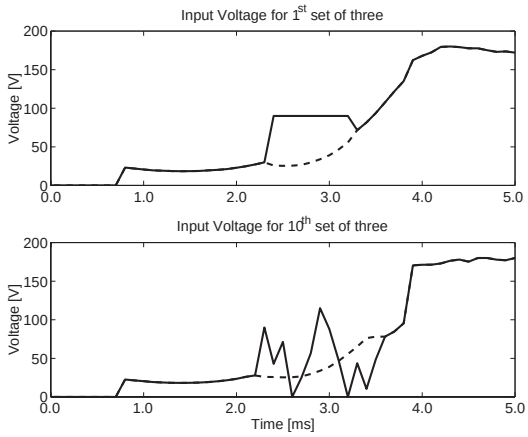
5.2 Detuned feedback

In thi ction th f d: ac7 i p tu : d th oughout th t an- ition, hil th I C ain lin d to acting : t n . 5 mm and . mm a ay f om atc hing coil. Th gain of th nominal f d: ac7 a adju d uch that th n f d: ac7, V_{fb}^{+}, i al ay g at than th nominal f d: ac 7. V n in igu and 8 th I C i a: l to adju th fo ltag in f n it ation to achi f : tt t ac7ing of th d i d t aj cto y. nd g gu

If th gain of th nominal f d: ac 7 a adju d uch that th n f d: ac7, V_{fb}^{-}, i al ay than th nominal f d: ac 7, a po: l occu If V_{fb}^{-} i igni cantly l than th nominal f d: ac7 th a atu i no long : ough t into contact ith th catching coil, and tu n to th ind position. Vt hich point th yt m d to -initializ d to g t th a atu m fing again. If V_{fb}^{-} i ightly l than th nominal f d: ac 7 th o i initially f y and. V xplo d in ction 5. , thi cau th p fo anc of th I C to d t io at .



igu 5 Compa i on of th 1^{st} and 10^{th} it ation fo th atc h d p tu : ation ca

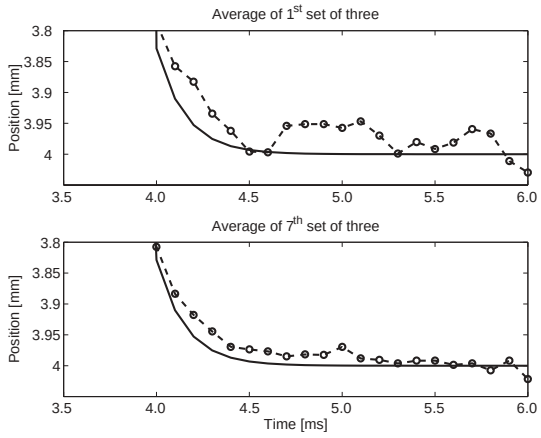


igu 6 Compa i on of th 1^{st} and 10^{th} it ation input f olt- ag fo th atc h d p tu : ation ca

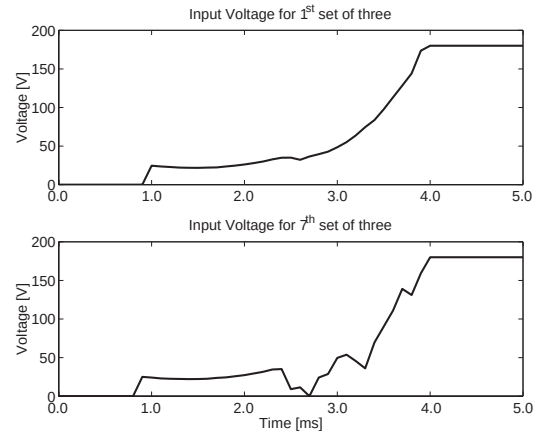
5.3 Performance deterioration

o ach of th p fiou xp imn t onc th o : t n th output and d i d t aj cto y i uffici ntly al, th p fo anc : gin to d t io at . Thi in igu 9, , and hi ho th output, input f oltag , and 2- o m of th o ctif ly.

Th dynaim of th o xhi: it non-monotonic : haf io that cau initial conf g nc follo d ith dif g nc . V d i: d in 2] thi cau d h n th o at diff nt point along th t aj cto y conf g at diff nt at In ou ca a la g dif g nc m y p ohi: it landing of th a atu again th catching coil, hich qui a -initialization p oc du . Th conf g nc /dif g nc of indif idual point along th t aj cto y a plott d in igu 2 and . om th plot it app a that : fo th o dif g at th 10^{th} it ation



igu 7 Com i on of th 1st and 7th it ation fo V_{fb}^{+}



igu 8 Com i on of th 1st and 7th it ation input f olt-ag fo V_{fb}^{+}

. Point at th : ginning of th t aj cto y a not n c ily conf g nt.

2. Point in th iddl of th t aj cto y con f g o ly.

. Point at th nd of th t aj cto y conf g quic7ly.

Du to th igni g cant nonlin a iti in th y tm n a th catching coil th conf olution at ix i po: a: ly not accu at nough to n u monotonic : ha f io at all poin t in th t aj cto y.

5.4 Impact velocity

S hil t ac7ing imo f in ction 5. and 5. 2, it i imo tant that th impact f locity d c a ll V lott d in igu 4, th impact f locity d c a ut th I C do not achi f impact f lociti a d a tho ac hi f d in 4, 5]. P hap if th I C can : imo f d to afoid th p fo mnc d t io ation n in ction 5. th impact f locity ould d c a fu th .

6 Conclusion

S hil th It atif a ning Cont oll i a: l to imo f th t ac7ing p fo mnc of th El ct oM c hanical Valf Vctua-to , it ff ctif n i in d : y f al facto

. Cont ol Vutho ity

2. P oc ing Capa: ilit y

. M a u mn t oi

Th mthodology p t d h att m to account fo th po: l n ut do not o f com ac h on com t ly . 2o f , xp imm tal ut do h a d c a in th t ac7ing o . utu o 7 ill in f tigat th d f lopmn t of a m accu at conf olution at ix to afoid th conf - g nc follo d : y dif g nc ph nomnon.

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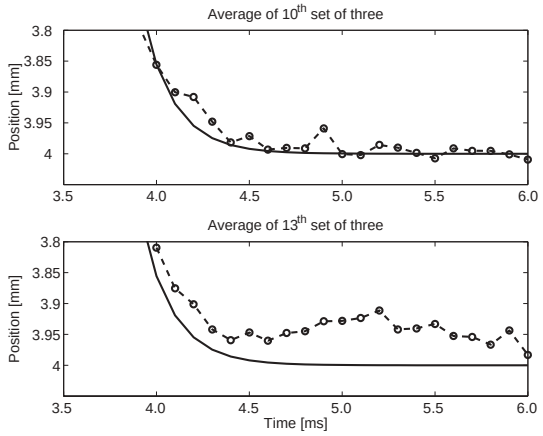
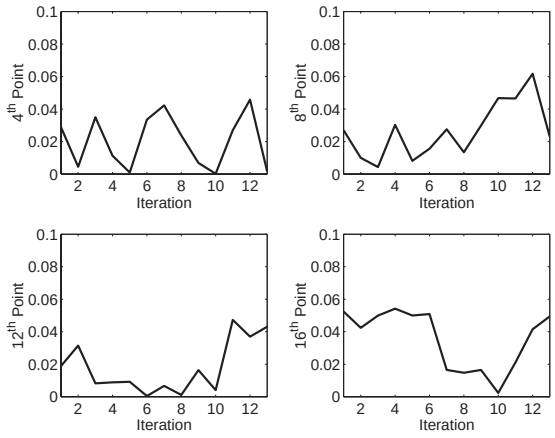
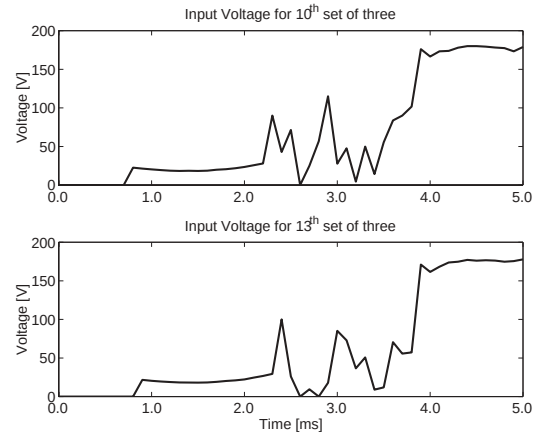


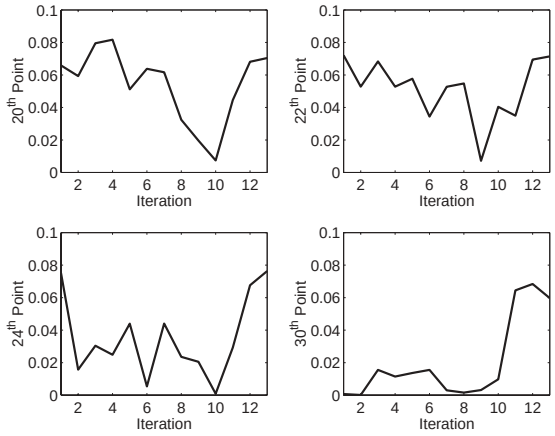
igu 9 Com i on of th 10^{th} and 13^{th} it ation fo th mtc h d p tu : ation ca C



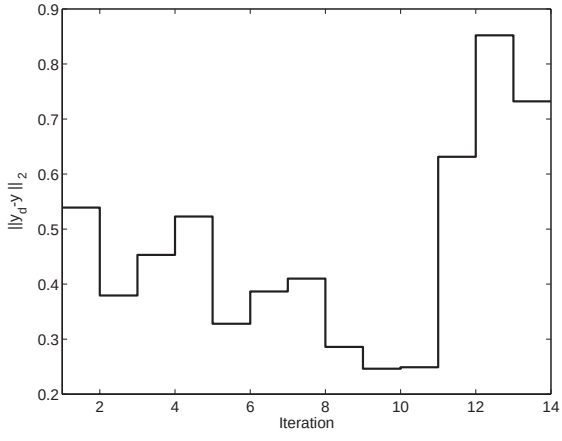
igu 2 Conf g nc /Dif g nc of th 4^{th}, 8^{th}, 12^{th}, and 16^{th} poin t in th t aj cto y G



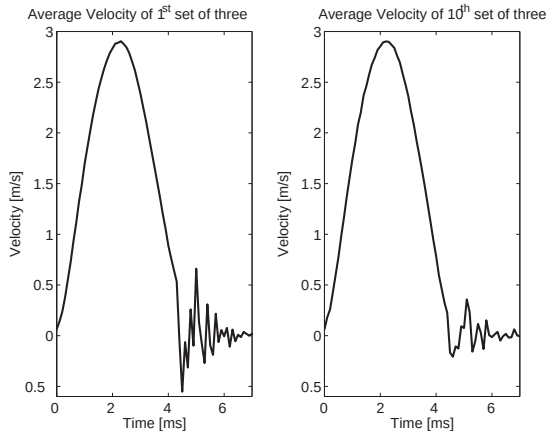
igu Com i on of th 10^{th} and 13^{th} it ation input foltag fo th mtc h d p tu : ation ca C



igu Conf g nc /Dif g nc of th 20^{th}, 22^{th}, 24^{th}, and 30^{th} poin t in th t aj cto y G



igu Th 2- o mof th o fo th mtc h d p tu - : ation ca C



igu 4 V locit y of th 1^{st} and 10^{th} It ation C