Proceedings of the 6th WSEAS International Conference on Robotics, Control and Manufacturing Technology, Hangzhou, China, April 16-18, 2006 (pp125-129)

Research of the Deadbeat Predictive Control Algorithm for the EMC Measuring

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Abstract: - This paper presents a new predictive control algorithm for the EMC measuring system. It proposed the control signal set and the time-optimal Bang-Bang control based on the new minimum step predictive algorithm. The system decreased monotonically during the interim within satisfied accuracy rate and eliminated system steady error. Simulation results show the advantages and adaptabilities in the repetition of the master signal (reference signal). Moreover, it is robust to counteract the model mismatch and the exterior interference.

Key-Words: - Radiant disturbance, predictive control, Bang-Bang control, EMC

1 Introduction

Electromagnetic disturbance[1][2] is the phenomenon of degrading the device, equipment or system's function and doing harm to life or lifeless matter. It can transmit by radiating and conducting, and the measurement of radiated disturbances must consider it's repeatability, economy, accuracy, anti-disturbing capacity and rapid determination.Fig.1 and Fig.2 show the concept of measurements made on an open area test site with the direct and ground reflected rays arriving at the receiving antenna. The electric field-strength can be expressed as follows:

$$\vec{E} = \vec{E}_A + \vec{E}_B$$

For electric field-strength measurements the antenna height above the ground plane shall be varied with a specified range to obtain the maximum reading which will occur when the direct ($\vec{E}_A$)and reflected rays($\vec{E}_B$) are in phase. As a general rule, for measurement distance up to and including 10 m, the antenna height for electric field strength measurements shall be raised between 1 m and 4 m for measurement distances of 10 m and less, and between 1m and 4 meters ,or between 2 m and 6 m for distances greater than 10 m . But it is an important question how to control the receiving antenna to measure the maximum emission with high precision, strong robust and the minimum scan times.

2 Algorithm Studying of the Deadbeat Predictive Control

Supported by the National Science Foundation of China under Grant No.69684001.

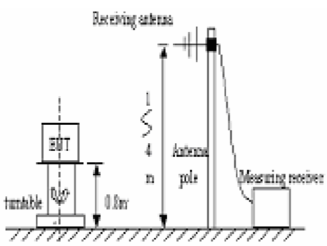

Fig.1 Measurement of radiant disturbance

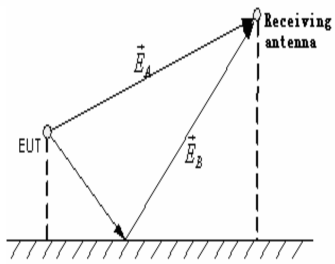

Fig.2 The direct and reflected waves of radiant disturbance

Predictive control[3][4][5]is a new control method, it rose at the end of 1970s,developed to the application of industrial process in 1980s,and gradually extends its applications to a large areas in 1990s.Meanwhile the special features of the deadbeat prediction control based on the composition of the deadbeat signal sets are the non-parameter model being utilized, monotonously steady state of system's transient process being ensured and the degree of error-free and precision being afforded at steady state.Please, leave two blank lines between successive sections as here.

2.1 Description of system's Output and Control

Fig.3 shows the basic structure of a sampling control system, where $G(S)$ is the transfer function of discrete controlled object. If D/A is zero-order hold , the impulse response of the discrete system $g(0)$ equals to 0, then the system's output at sampling point I can be expressed as follows:

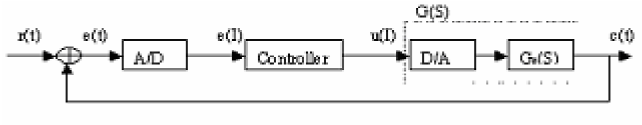

Fig.3 Sampling control system

$$C(I)=C_0+\sum_{k=0}^{I-1}g(I-k)U(k)=C_o+C_0(I) \quad (1)$$

$$C_0(I)=\sum_{k=0}^{I-1}g(I-k)U(k)=C_b(I)+g(1)U(I-1) \quad (2)$$

$$C_b(I)=\sum_{k=0}^{I-2}g(I-k)U(k) \quad (3)$$

where the $C_0(I)$ is defined as the position-control-signal, marked as $U_s(I-1)$. According to discrete convolution principle, we can get:

$$C'(I)=[C_b(I)+g(1)U(I-1)-C_o(I-1)]/T \quad (4)$$

$$C''(I)=[C_b(I)+g(1)U(I-1)-C_o(I-1)-C'_o(I-1)T]/T^2 \quad (5)$$

In the formula (4), $U(I-1)$ can control the system output's velocity, named $U_v(I-1)$, and in the formula (5), $U(I-1)$ can control the system output's acceleration, named $U_a(I-1)$. Then, the control signals needed are :

$$U_s(I-1)=\left[C(I)-C_0-C_b(I)\right]/g(1) \quad (6)$$

$$U_v(I-1)=\left[C'(I)T-C_b(I)+C_0(I-1)\right]/g(1) \quad (7)$$

$$U_a(I-1)=\left[C''(I)T^2-C_b(I)+C_0(I-1)+C'_0(I-1)T\right]/g(1) \quad (8)$$

From formulas (6)(7)(8), unrestricted deabeat control signals can be constructed:

$$U_{sm}(I-1)=U_s(I-1)\big|_{C(I)=r(I)} =\left[r(I)-C_0-C_b(I)\right]/g(1) \quad (9)$$

$$U_{vm}(I-1)=U_v(I-1)\big|_{C'(I)=r'(I)} =\left[r'(I)T+C_0(I-1)-C_b(I)\right]/g(1) \quad (10)$$

$$U_{am}(I-1)=U_a(I-1)\big|_{C''(I)=r''(I)} =\left[r''(I)T^2+C_0(I-1)+C'_0(I-1)T-C_b(I)\right]/g(1) \quad (11)$$

where $r(I)$ is the system input's value at sampling point I. When $\Delta U(I-1)$ controls $C''(I)$, the deadbeat control signal above can be expressed as the increment form based on U_{a0}:

$$\Delta U_{sm}(I-1)=U_{sm}(I-1)-U_{ao}(I-1)=\left[r(I)-C(I)\right]/g(1) \quad (12)$$

$$\Delta u_{vm}(I-1)=u_{vm}(I-1)-u_{ao}(I-1)=\left[r'(I)-C'_0(I-1)\right]T/g(1) \quad (13)$$

$$\Delta u_{am}(I-1)=u_{am}(I-1)-u_{ao}(I-1)=\left[r''(I)T^2\right]/g(1) \quad (14)$$

where

$$U_{a0}(I-1)=U_a(I-1)\big|_{C''(I)=0} =\left[-C_b(I)+C_0(I-1)+C'_0(I-1)T\right]/g(1) \quad (15)$$

In order to limit $U(I-1)$, we definite a group of valve-value signals reflecting valve of input signals as well as their derivatives at the point $U(I-1)$. Let the specified values of $C(I)$, $C'(I)$ and $C''(I)$ be S_r, V_r and A_r respectively. From formulas (6)(7)(8) a set of valve-value control signals can be constructed:

$$U_{sr}(I-1)=\left[S_r-C_0-C_b(I)\right]/g(1) \quad (16)$$

$$U_{vr}(I-1)=\left[V_rT+C_0(I-1)-C_b(I)\right]/g(1) \quad (17)$$

$$U_{ar}(I-1)=\left[A_rT^2+C_0(I-1)+C'_0(I-1)T-C_b(I)\right]/g(1) \quad (18)$$

They make $C(I)=S_r$, $C'(I)=V_r$, $C''(I)=A_r$.

The valve-value signals above can be expressed as increment form based on U_{a0}:

$$\Delta u_{sr}(I-1)=u_{sr}(I-1)-u_{ao}(I-1) =\left[S_r-C_0-C_0(I-1)-C'_0(I-1)T\right]/g(1) \quad (19)$$

$$\Delta u_{vr}(I-1)=u_{vr}(I-1)-u_{ao}(I-1) =\left[V_r-C'_0(I-1)\right]T/g(1) \quad (20)$$

$$\Delta u_{ar}(I-1)=u_{ar}(I-1)-u_{ao}(I-1) =A_rT^2/g(1) \quad (21)$$

Therefore, the deadbeat predictive control signal can be constructed as:

$$\Delta U(I-1)=C_s\Delta U_{sm}(I-1)+C_v\Delta U_{vm}(I-1)+C_a\Delta U_{am}(I-1) \quad (22)$$

Where the weighted coefficients C_s, C_v, C_a can be defined with the selected control policy.

2.2 Control Policy Design

The basic control policy is applying the time optimal Bang-Bang control base on the deadbeat control signals and optimizing the control process piecewise. Fig.4 shows the time optimal speed trace based on desired state.

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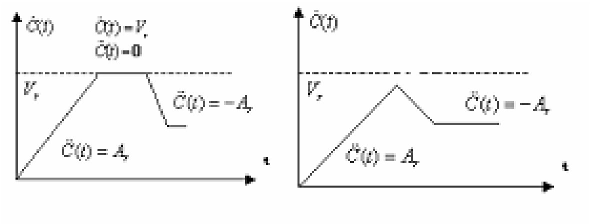


a. Large error b. small error

Fig. 4 The deadbeat predictive control trace

Considering the relation between acceleration directions of Bang-Bang control and initial states of the system, we define:

$$\Delta U_{ap}=S_{gn}(e(I))\Delta U_{ar}, \Delta U_{an}=-\Delta U_{ap} \quad (23)$$

when $e(I)>=0, Sgn=1, e(I)<0, Sgn=-1$. ΔU_{ap} is acceleration valve-value signal and ΔU_{an} is deceleration valve-value signal.

The special features of control process are as follows:

$\Delta U(I)=\Delta U_{ap}$ is chosen at the acceleration stage to obtain the least acceleration time; at the constant speed stage, if it exists, let $\Delta U(I)=0$, so that the derivation is reduced as quickly as possible; In the deceleration stage, to ensure the transient process to tend towards the steady stage monotonically as quickly as possible, the new control policy based on the deadbeat increment control signals are adopted :constructing a new switching equation and getting the switching point of rolling optimization, which can ensure the control switch to the deceleration stage in time and preciously. After entering into the deceleration stage ,the combination control of the deadbeat increment control signal is adopted in stead of $\Delta U(I)=\Delta U_{an}$, which ensure the deceleration be maximum, where the weighted coefficients C_s, C_v, C_a can be obtained through rolling optimization. at tracing stage, let $\Delta U(I)=\Delta U_{sm}(I)$, adopting the deadbeat position prediction control.

Single step prediction of the deadbeat increment signals:

$$\Delta U_{vm}(I\text{-}1)=\left[r'(I)-C'(I\text{-}1)\right]T/g(1)$$

$$\Delta U_{vm}(I)=\left[r'(I+1)-C'(I)\right]T/g(1)$$

$$\Delta U_{vm}(I\text{-}1)-\Delta U_{vm}(I)=\left[r'(I)-r'(I+1)+C'(I)-C'(I\text{-}1)\right]T/g(1)$$

$$=\left[C'(I)-C'(I\text{-}1)\right]T/g(1)=\frac{C'(I)-C'(I\text{-}1)}{T}T^2/g(1)$$

$$=C''(I)T^2/g(1)=\Delta U(I\text{-}1)$$

$$\Delta U_{vm}(I)=\Delta U_{vm}(I\text{-}1)-\Delta U(I\text{-}1)$$

$$\Delta U_{sm}(I\text{-}1)=\left[r(I)-C_0-C_0(I\text{-}1)-C'(I\text{-}1)T\right]/g(1)$$

$$\Delta U_{sm}(I)=\left[r(I+1)-C_0-C_0(I)-C'(I)T\right]/g(1)$$

$$\Delta U_{sm}(I)-\Delta U_{sm}(I\text{-}1)$$

$$=\left[r(I+1)-r(I)-C_0(I)+C_0(I\text{-}1)-C_0'(I)T+C_0'(I\text{-}1)T\right]/g(1)$$

$$=\left[\frac{r(I+1)-r(I)}{T}T-\frac{C_0(I)-C_0(I\text{-}1)}{T}T-\left(C_0'(I)-C_0'(I\text{-}1)\right)T\right]/g(1)$$

$$=\Delta U_{vm}(I)-\Delta U(I\text{-}1)=\Delta U_{vm}(I\text{-}1)-2\Delta U(I\text{-}1)$$

thus

$$\Delta U_{sm}(I)=\Delta U_{sm}(I\text{-}1)+\Delta U_{vm}(I\text{-}1)-2\Delta U(I\text{-}1) \quad (24)$$

Multi-steps prediction of the deadbeat increment signals:

$$\Delta U_{vm}(I+I_r)=\Delta U_{vm}(I)-I_r\Delta U(I)$$

$$\Delta U_{sm}(I+I_r)=\Delta U_{sm}(I)+I_r\Delta U_{vm}(I)-C_{Ir}\Delta U(I) \quad (25)$$

where $C_{Ir}=0.5I_r(I_r+3)$

2.3 The Optimal Control Law of the Tracking-Stage

When using $\Delta U(I\text{-}1)$ to control the system output acceleration $C''(I), C''(I)$ must be less than A_r. Therefore , $\Delta U(I\text{-}1)=\Delta U_{sm}(I-1)$ can be adopted if and only

$$if\ |\Delta U_{sm}(I_s)|<=|\Delta U_{an}| \quad (26)$$

Then

$$\Delta U_{vm}(I_s+1)=\Delta U_{sm}(I_s+1)$$
$$=\Delta U_{vm}(I_s)+\Delta U_{am}(I_s)-\Delta U_{sm}(I_s) \quad (27)$$

thus the condition and the result of choosing $\Delta U(I_s+1)=\Delta U_{sm}(I_s+1)$ at sampling point I_s+1 are condition:

$$\left|\Delta U_{vm}(I_s+1)\right|=\left|\Delta U_{sm}(I_s+1)\right|<=\left|\Delta U_{an}\right| \quad (28)$$

result:

$$\Delta U_{vm}(I_s+2)=\Delta U_{sm}(I_s+2)=\Delta U_{am}(I_s+1) \quad (29)$$

formula (28) can be rewritten as:

$$\left|\Delta U_{vm}(I_s)+\Delta U_{am}(I_s)-\left|\Delta U_{sm}(I_s)\right|\right|<=\left|\Delta U_{an}\right| \quad (30)$$

$$\left[\Delta U_{vm}(I_s)+\Delta U_{am}(I_s)\right]*\Delta U_{sm}(I_s)>=0 \quad (31)$$

from formula (29),at the sampling points $I>=I_s+2$ the condition and the result of choosing continuously $\Delta U(I\text{-}1)=\Delta U_{sm}(I\text{-}1)$ condition are :

$$\left|\Delta U_{am}(I\text{-}1)\right|<=\left|\Delta U_{an}\right| \quad (32)$$

result: $\Delta U_{vm}(I)=\Delta U_{sm}(I)=\Delta U_{am}(I-1)$ (33)

2.4 The Optimal Control law of the Deceleration-stage

2.4.1 Switching equations

The switching equation is used to select the switching point I_b at which deceleration-stage begins. The optimal standard used here is: if I_b is the switching point, then from I_b, select $\Delta U(I)=\Delta U_{an}(I)\ (I>=I_b)$ to begin the deceleration-stage, and make $\Delta U_{sm}(I)=0, \Delta U_{vm}(I)=0$ be satisfied at the same sampling point I_b+I_{r1} to ensure the transient process to tend towards steady stage monotonically as quickly as possible. And from the prediction formulas of $\Delta U_{vm}(I)$ and $\Delta U_{sm}(I)$, the switching equation can be obtained:

$$\Delta U_{vm}(I_b+I_{r1})=\Delta U_{vm}(I_b)+I_{r1}\Delta U_{am}(I_b)-k_{r1}\Delta U_{an}(I_b)=0 \quad (34)$$

$$\Delta U_{sm}(I_b+I_{r1})=\Delta U_{sm}(I_b)+I_{r1}\Delta U_{vm}(I_b)+D_{kra}\Delta U_{am}(I_b)-D_{kr}\Delta U_{an}=0 \quad (35)$$

where:

$$D_{kra}=C_{kra}+\Delta I^3,\ D_{kr}=C_{kr}+\Delta I^2(1+\Delta I)$$

$$I_r=INT(I_{r1}),\ \ \Delta I=I_{r1}-I_r \quad (36)$$

As follows are adopted: from $I=0$,the needed deceleration steps I_{r1} to make $\Delta U_{vm}(I+I_{r1})=0$ are predicted point by point, if $|F_u(I-1)-F_u(I)|>=1.2|F_u(I)|$ or $F_u(I)*F_u(I-1)<=0$ then predict the value of switching function $F_u(I)=|\Delta U_{sm}(I+I_{r1})|$,and switch to the deceleration sage at I , otherwise continue the process above at point $I+1$.

2.4.2 Optimization of Deceleration Law

The optimization of deceleration stage control law is that under the limitation of $|U(I)|<=|\Delta U_{an}(I)|$, optimize $\Delta U(I)$ at each sampling point in order to satisfy the condition of switching to the deceleration-stage at sampling point $I_s=I+I_r$,that is :

$$\Delta U_{sm}(I+I_r)=I_e\Delta U_{an}$$
$$=\Delta U_{sm}(I)+I_r\Delta U_{vm}(I)+C_{kra}\Delta U_{am}(I)-C_{kr}\Delta U(I)$$

(37)

$$\Delta U_{vm}(I+I_r)+\Delta U_{am}(I+I_r)$$
$$=\Delta U_{vm}(I)+I_r\Delta U_{am}(I)-I_r\Delta U(I)+\Delta U_{am}(I)$$

(38)

where $I_e<=1$. $\Delta U_{sm}(I+I_r)$ should equal to a $\Delta U_{vm}(I+I_r)$.So we have

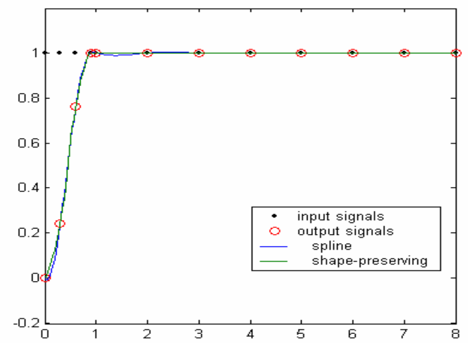
$$\Delta U(I)=\left[\Delta U_{sm}(I)+I_r\Delta U_{vm}(I)+C_{kra}\Delta U_{am}(I)-I_e\Delta U_{an}\right]/C_{kr} \quad (39)$$

$$I_r=\frac{3\Delta U_{vm}(I)+3\Delta U_{am}(I)-2\Delta U_{sm}(I)-4I_e\Delta U_{an}}{\Delta U_{vm}(I)+2I_e\Delta U_{an}} \quad (40)$$

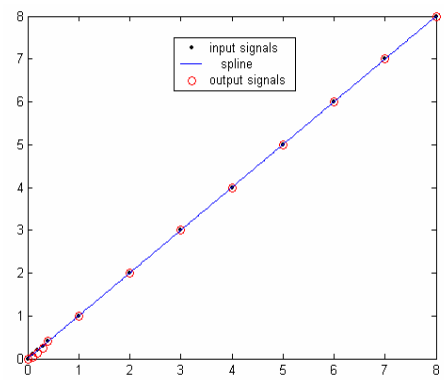
This shows that the bigger is I_e, the less is I_r.Thus, I_e can be selected as 1.Substituting I_r into formula (39) ,we can obtain optimal deceleration law of $\Delta U(I)$.

3 Simulation Examples

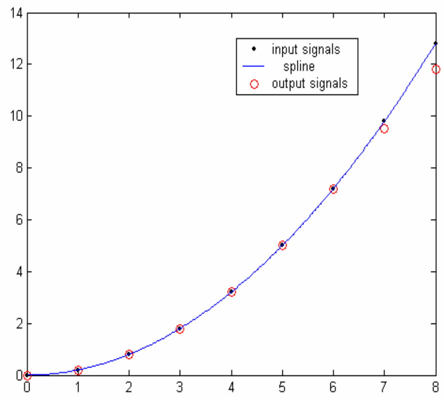
$$G(s)=\frac{40000(s+0.15)}{s(s+0.1)(s+100)}$$



Example 1 R(t)=1(t)



Example 2 R(t)=t



Example 3 $R(t)=0.2t^2$

4 Conclusion

From example 1-3,it is seen that the control method make the transient process tends steady state monotonously, and the error of steady state is less than 10^{-6}.Example shows that the control method can measure the maximum emission with high precision ,strong robust and the minimum scan times.

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