第5卷 第2期　　控制理论与应用　　Vol. 5, No.2
1988年6月　　CONTROL THEORY AND APPLICATIONS　　June, 1988

Modified Dynamic Matrix Control

Zhu Xuefeng, Huang Daoping, Liu Yongqing

(Department of Automation, South China
University of Technology, Guangzhou)

Abstract

Based on the analysis of Dynamic Matrix Control which appeared in seventies, it is found that the algorithm cannot give satisfactory results in regulation case. Therefore, a new modified algorithm with variable predictive coefficients is presented. By theoretical analysis and practical application, it has been proven that the modified algorithm is correct and advantageous. Control experiments which are carried out in a experimental thermal equipment in the process control laboratory have shown that the algorithm is of potential practical value.

Introduction

The Dynamic Matrix Control(DMC) appeared in the end of sixties or the beginning of seventies. It is a multi-step predictive algorithm that combines the discrete convolution model and the least squares method. In the last decade, DMC has attained practical application in America and France, and got satisfatory results. Although it has got fairly good results in some areas of process control, the DMC control still has a serious disadvantage. The DMC algorithm can attain stable and rapid response in servo operation system, but the response in regulation case is often slow. Since regulation operation is most widely used in chemical and related industris, the disadvantage as mentioned has hampered the DMC to become widespread in process control.

Therefore, improvement of the control quality of DMC in regulation case is necessary in the practice of process control.

Manuscript received Feb.25, 1987, revised Oct 27, 1987.

Improvement of Conventional DMC

1) Development of the algorithm with predictive corrective coefficient

It is shown from the derivation of conventional DMC algorithm (see references1, 2) that the predictive output values $\hat{Y}_{k+j}$ are corrected by the term $(Y^C_{k+j-1} - \hat{Y}_{k+j-1})$. In this situation, there exists the following relationship:

$$Y^C_{k+j-1} - \hat{Y}_{k+j-1} = Y^C_{k+j-2} - \hat{Y}_{k+j-2} = \cdots = Y_k - \hat{Y}_k$$

That means that all future R predictive output values are corrected with the same term $(Y_k - \hat{Y}_k)$. As is well known, the predictive errors depend not only on the model errors but on the disturbances. The process disturbances change frequently. Therefore, it is not reasonable to correct all R predictive output values by the same current error $(Y_k - \hat{Y}_k)$. Taking this into consideration, a method adding predictive corrective coefficient μ to the predictive correction term is proposed. Then the predictive output values are corrected in such a manner:

$$Y^C_{k+j} = \hat{Y}_{k+j} + \mu(Y^C_{k+j-1} - \hat{Y}_{k+j-1}) \qquad j = 1, 2, \cdots, R \tag{1}$$

The Eq.(1) can be written in another way:

$$Y^C_{k+j} = \hat{Y}_{k+j} + \mu^j (Y_k - \hat{Y}_k) \qquad j = 1, 2, \cdots, R \tag{2}$$

In the following, the method that will be used to derive the modified DMC algorithm is the same as that in conventional DMC. We finally have got the modified DMC algorithm (MDMC) as follows:

$$\Delta U_k = K^T \hat{E}' \tag{3}$$

Where, K^T is the first row of matrix $(A^T A + Q)^{-1} A^T$. Q is a diagonal matrix. A is a dynamic matrix:

$$A = \begin{pmatrix} a_1 & 0 & 0 \cdots 0 \\ a_2 & a_1 & 0 \cdots 0 \\ \vdots & & \\ a_L & a_1 & \cdots \quad a_1 \\ \vdots & & \\ a_R & a_{R-1} & \cdots \quad a_{R-L+1} \end{pmatrix}, \quad a_j = \sum_{i=1}^{j} h_i \quad j = 1, 2, \cdots, R \tag{4}$$

But here, $\hat{E}'$ is

$$\hat{E}' = \begin{pmatrix} (1-a)r_k + (a-\mu)Y_k - P_1 \\ (1-a^2)r_k + (a^2-\mu^2)Y_k - P_2 \\ \vdots \\ (1-a^R)r_k + (a^R-\mu^R)Y_k - P_R \end{pmatrix} \tag{5}$$

where,

$$P_j = -\mu^j \hat{Y}_k + a_j u_{k-1} + \sum_{i=j+1}^{N} h_i u_{k+j-i} \qquad j = 1, 2, \cdots, R \tag{6}$$

Comparing Eq. (3) with the counterpart of conventional DMC, it can be found that they are equal in the form, but are different as far as the term $\hat{E}'$ is concerned.

2) Analysis of closed-loop control system with MDMC in both servo and regulation cases

For the control law Eq.(3) further analysis can be made. Substituting Eq.(5) into Eq.(3) and then taking Z transformation, the transfer function of MDMC regulator is obtained.

$$U(z) = \frac{g_{01}}{1 + c_1 z^{-1} + c_2 z^{-2} + \cdots c_N z^{-N}} \cdot R(z) + \frac{g_{02}}{1 + c_1 z^{-1} + \cdots c_N z^{-N}} \cdot Y(z)$$
$$= D_1(z) \cdot R(z) + D_2(z) \cdot Y(z) \tag{7}$$

where

$$g_{01} = \sum_{i=1}^{R} K_i (1 - a^i), \qquad g_{02} = \sum_{i=1}^{R} K_i (a^i - \mu^i) \tag{8}$$

It is obvious from Eq.(7) that MDMC has different control laws in servo and regulation cases. This feature is of great advantage for rejecting the disturbances. That is the main merit of modified DMC.

Let us further analyze the closed-loop transfer function of MDMC in both cases. The control system under study is shown in Fig. 1. The closed-loop transfer function can be obtained from Eq. (7) and Fig. 1.

$$\frac{Y(z)}{R(z)} = \frac{g_{01} H G_P(z)}{1 + (q - 1 + d_1 - wh_1) z^{-1} + (d_2 - wh_2) z^{-2} + \cdots (d_{N-1} - wh_{N-1}) z^{-N+1} - wh_N z^{-N}} \tag{9}$$

where

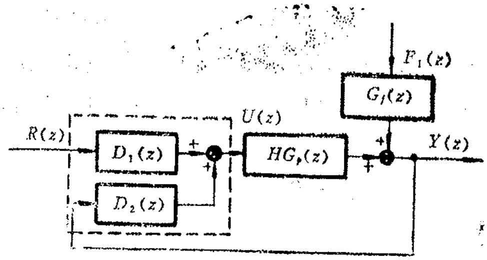

Fig. 1 Block Diagram of the MDMC System

$$q=\sum_{i=1}^{R}K_i a_i, \qquad w=\sum_{i=1}^{R}K_i a^i$$

$$d_j=\begin{cases}\sum_{i=1}^{R}K_i h_{i+j} & 1\leqslant j\leqslant N-R\\[2ex] \sum_{i=1}^{N-j}K_i h_{i+j} & N-R+1\leqslant j\leqslant N-1\end{cases} \tag{10}$$

$HG_P(z)$ is the Z-transfer function of the process with zero hold. It is shown from Eq.(8), (10) that g_{01}, q, w, d_j are not related with correction coefficient μ. Therefore, the closed-loop transfer function in servo cases does not depend upon μ.

Let $Z=1$ in Eq.(9), we finally have (omit the simplifying procedures):

$$Y_{ss}/R_{ss}=1 \tag{11}$$

That means that the servo system is in zero offset no matter what value of μ is taken.

Let us further consider the closed-loop transfer function in regulation case. Similarly, we can get:

$$\frac{Y(z)}{F(z)}=\frac{1+(q-1+d_1-bh_1)z^{-1}+(d_2-bh_2)z^{-2}+\cdots bh_N z^{-N}}{1+(q-1+d_1-wh_1)z^{-1}+(d_2-wh_2)z^{-2}+\cdots wh_N z^{-N}} \tag{12}$$

where $$b=\sum_{i=1}^{R}K_i\mu^i$$

Coefficient b is the only one which will be affected by μ. It can further be seen from Eq. (12) that in regulation case the value of μ would not affect the locations of closed-loop poles, but does affect the locations of closed-loop zeros, so does the transient behavior of the control system. The hope to improve the control performance with correction coefficient is mainly based on that. Similarly, we can study the offset of the closed-loop control system in the case by letting $Z=1$. Then Eq. (12) will become:

$$\frac{Y_{ss}}{F_{ss}}=\frac{\sum_{i=1}^{R}K_i(1-\mu^i)}{\sum_{i=1}^{R}K_i(1-\alpha^i)} \tag{13}$$

The denominator of Eq. (13) is generally not zero because of $0\leqslant\alpha<1$. Then different values of μ would lead to different results. When $\mu=1$, it is obvious from Eq. (13) $Y_{ss}/F_{ss}=0$. That means that there is no offset in this case. But while $\mu\neq1$ there will be offset, the value of which is:

$$Y_{ss}=\frac{\sum_{i=1}^{R}K_i(1-\mu^i)}{\sum_{i=1}^{R}K_i(1-\alpha^i)}\cdot F_{ss} \tag{14}$$

By digital simulation, the experiments of modified DMC with different values of μ for overcoming disturbances have been conducted. The control system simulated is shown in Fig. 1, where, the process has $G_p(s)=e^{-2s}/(2s+1)$, $G_f(s)=1/(2s+1)$. The experimental results and effects of coefficient μ are indicated in Fig. 2. It is known from Fig. 2 that it is difficult to handle the mentioned contradiction between offset and response speed if μ is taken to be a constant. To solve it, a modified DMC with variable correction coefficient is proposed.

3) The way of variation of μ

In order to satisfy the following requirements:

A) powerful capacity for rejecting the disturbance;

B) no offset for any cases;

C) small undershoot.

the MDMC with variable μ should be adopted. The predictive correction coefficient μ will vary in such a way:

$$\mu=1+\Delta\mu$$

and

$$\Delta\mu=\lambda_1|E|+\lambda_2\operatorname{sgn}(E)\frac{dE}{dt} \tag{15}$$

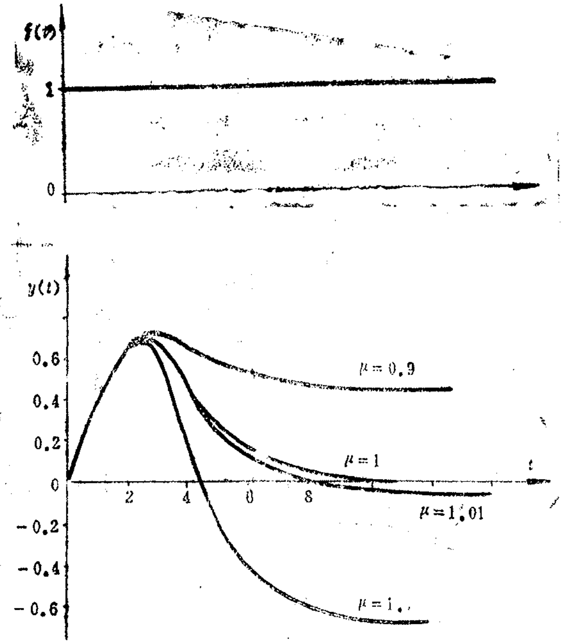

Fig. 2 Effect of the Correction Coefficient μ on the System Response

where $E = Y - Y_{s.p}$

Y — controlled variable, $Y_{s.p}$ — set point

$$\text{sgn}(E) = \begin{cases} 1 & E>0 \\ -1 & E<0 \end{cases}$$

$\lambda_1 > 0$, $\lambda_2 > 0$ are on-line turning parameters

The term $\Delta\mu$ consists of two parts. the first part $\lambda_1|E|$ is the corrective one for absolute error E. The second part is $\lambda_2\ \text{sgn}(E)\dfrac{dE}{dt}$. It will be larger than zero when the controlled variable Y departs from the set point Y_{sp}, so more powerful control action will be implemented. In the contrary case, it becomes negative.

Through digital simulation, the authors have studied the responses of the simulated process by means of MDMC with different values of λ_1, λ_2. The comparison of the modified algorithm with conventional DMC and PI control for the same process has also been done. A typical simulation result is shown in Fig. 3, where, $G_p(s) = e^{-2s}/(2s+1)$, $G_f(s) = 1/(2s+1)$, the input is unit step change in the load. It is apparent from Fig. 3 that MDMC is superior to conven-

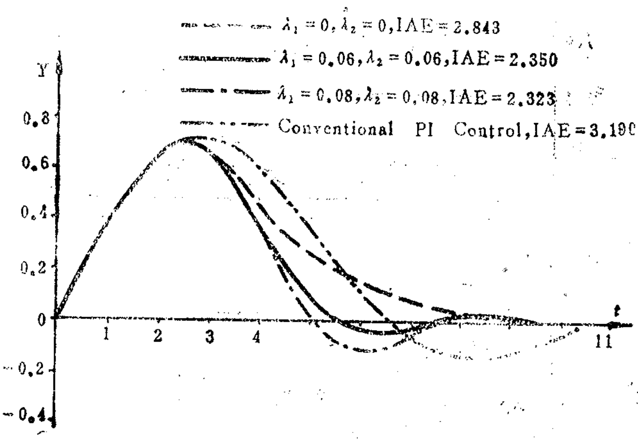

Fig. 3 Effect of the Turning Parameter λ_1, λ_2 on the System Response

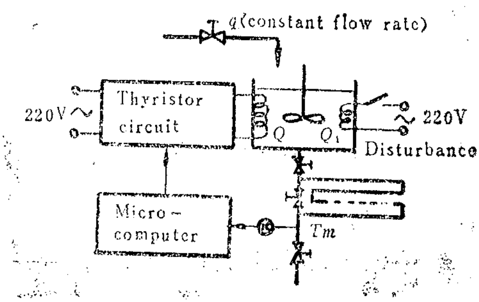

Fig. 4 Flow Diagram of Temperature Control System in an Experimental Equipment

tional DMC and PI control. The values of λ_1, λ_2 must be turned on-line. For the simulated process, $\lambda_1 = 0.06$ and $\lambda_2 = 0.06$ are optimal.

Real Time Control Investigation of the Algorithm(MDMC) in a Temperature Experimental Equipment

The real time control study with MDMC in a temperature experimental equipment has been carried out. (The algorithm is implemented in a microcomputer with 8'bits A/D and D/A converters.) The flow diagram of the control system under study is shown in Fig. 4. The controlled variable is the temperature T_m just at the outlet of a set of bending pipes. The control variable is the heat input to the water in tank 1. All the instruments used are of electronic with standard signal. The experimental results are shown in Fig. 5, 6 respectively. It is obvious from the figures that MDMC can provide much better responses than conventional DMC and PI control, particularly in regulation case. It is also effective for large dead time compensation.

Conclution

The theoretical analysis, digital simulation and real-time control investigation all have proven that modified DMC(MDMC) algorithm with variable predictive correction coefficient μ is of effective value in practical application. It is much superior to conventional DMC and PI control, especially in regulation system. It is also a good algorithm for compensating large dead time. The MDMC is easy to be implemented with microcomputer. Therefore, the algorithm may have potential value in the application of the process control field.

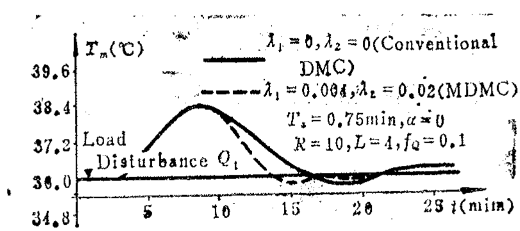

Fig. 5 Comparison of the Conventional DMC with the MDMC (Response in Heating System)

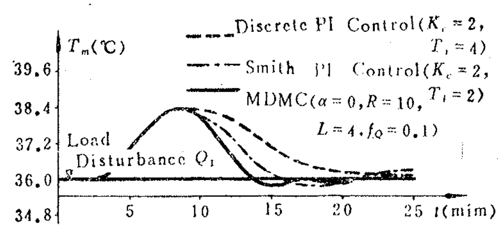

Fig. 6 Comparison of the Various Control Algorithms in the Heating System

References

[1] Marchetti, J.L., Mellichamp, D.A., Seborg, D.E. Predictive Control

Based on Discrete Convolution Models, 74th Annual AICHE Meeting, New Orleans, November,(1981).

〔2〕 Cutler,C.R., Dynamic Matrix Control - A Computer Control Algorithm Proceedings JACC, (1980), Paper WP5 - B.

〔3〕 Bruijn,P.M. and Verbruggen, H.B., Model Algorithmic Control Using Impulse Models, Journal A, 25:2,(1984),69 - 74.

〔4〕 Richalet,J., Rault, A,, Testud,J.L. and Papon,J., Model predictive Heuristic Control: Applications to Industrial Processes, Automatica, 14:5 (1978) ,413 - 428.

〔5〕 Cutler,C.R., Dynamic Matrix Control of Imbalanced Systems, ISA Trans., 21:1, (1982) , 1 - 5.

改进型的动态矩阵控制

朱学峰　黄道平　刘永清

（华南理工大学自动化系，广州）

摘　要

本文在分析了七十年代出现的动态矩阵控制算法的基础上，发现该算法在克服干扰的定值调节方面质量不高，从而提出了变预估修正系数的改进算法。并且通过理论分析和实际应用证实了这种改进的正确性和优越性。在过程控制实验室的温度装置上进行的实时控制试验，表明了这种改进算法有较大的实用价值。