Review of Tuning Methods of DMC and Performance Evaluation with PID Algorithms on a FOPDT Model

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***Abstract*— this paper presents review of easy to use and reliable tuning strategy for SISO Dynamic matrix control (DMC). The tuning strategy achieves set point tracking with minimal overshoot and modest manipulated input move sizes and is applicable to a broad class of open loop stable processes. The simulation of a simple FOPDT model is carried out using advanced control algorithms, specifically these advanced algorithms are the IMC-based PID controller, DMC. And their performance is compared with PID Controller which is tuned using Z-N tuning method.**

***Keywords*—First order with ime Delay(FOPDT), Internal model control(IMC),Dynamic Matrix control (DMC), PID.**

I. INTRODUCTION

To date, the most popular control algorithm used in industry is the PID controller which has been implemented successfully in various technical fields. However, since the evolution of computers during the 1980s a number of modern and advanced control algorithms have been also developed and applied in a wide range of industrial and chemical applications. Some of them are the Internal Model – based PID controller, the Model Predictive controller and, the common characteristic of the above algorithms is the presence in the controller structure an estimation of the process' model. The purpose of this paper is to apply these advanced algorithms to a linear first order plus delay time (FOPDT) process model and compare their step response with the conventional PID controller.

Initially, it will be presented a brief discussion over the theoretical designing aspects of each applied algorithm. The main section of the paper is devoted to the simulation results in terms of type 1 servomechanism performance of a simple FOPDT process, using the above control algorithms in various practical scenarios.

The primary benefit of a FOPDT model approximation is that it permits derivation of a compact analytical expression for computing λ of DMC although a FOPDT model

Approximation does not capture all the features of some higher-order processes, it often reasonably describes the process gain, overall time constant, and effective dead time of such processes [4]. In the past, tuning strategies based on a FOPDT model such as Cohen-Coon, IAE, and ITAE have proved useful for PID implementations. The tuning strategy reviewed here is significant because it offers an analogous approach for DMC.

The theoretical details in this paper are organized as follows: (i)Review of the DMC tuning and its simulation on FOPDT model is carried out.(ii) The PID is tuned using Z-N method.(iii) Then IMC-PID is tuned and (iv) the simulation results are compared with PID.

II. DYNAMIC MATRIX CONTROL

In this paper review of tuning strategy of single-input single-output (SISO), DMC which is applicable to a wide range of open loop stable processes is taken. The DMC control law is given by,

$$u = (A^T A + \lambda I)^{-1} A^T e \quad (1)$$

Where A is the dynamic matrix, e is the vector of predicted errors over the next P sampling instants (prediction horizon), λ is the move suppression coefficient, and u is the manipulated input profile computed for the next M sampling instants, also called the control horizon. The A^TA matrix, to be inverted in the evaluation of the DMC control law, is referred to in this work as the system matrix. Implementation of DMC with a control horizon greater than one manipulated input move necessitates the inclusion of a move suppression coefficient λ. This coefficient serves a dual purpose of conditioning the system matrix before inversion and suppressing otherwise

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aggressive control action occurs. It is often used as the primary adjustable parameter to fine tune DMC to desirable performance.

DMC refers to a class of advanced control algorithms that compute a sequence of manipulated variables in order to optimize the future behavior of the controlled process. Initially, it has been developed to accomplish the specialized control needs in power plants and oil refineries. However because its ability to handle easily constraints and MIMO systems with transport lag, it can be used in various industrial fields [9].

The first predictive control algorithm is referred to the publication of [12]. However, in [5] developed their own MPC algorithm named Dynamic Matrix Control, Since then, a great variety of algorithms based on the MPC principle has been also developed. Their main difference is focused on the use of various plant models which is an important element of the computation of the predictive algorithm (i.e. step model, impulse model, state-space models, etc). The main idea of the predictive control theory is derived from the exploitation of an internal model of the actual plant, which is used to predict the future behavior of the control system over a finite time period called prediction horizon *p* (Fig. 1). This basic control strategy of predictive control is referred to as receding horizon strategy [8].

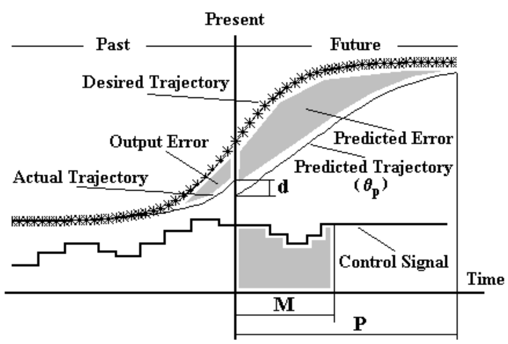

Fig. 1 Receding Horizon Strategy

Its main purpose is the calculation of a controlled output sequence $y(k)$ that tracks optimally a reference trajectory $y^0(k)$ during M present and future control moves ($M \le p$). Though M control moves are calculated at each sampled step, only the first $\Delta\hat{u}(k)=(u^0(k)-u(k))$ is implemented. At the next sampling interval, new values of the measured output are obtained. Then the control horizon is shifted forward by one step and the above computations are repeated over the prediction horizon. In order to calculate the optimal controlled output sequence, it is used a cost function of the following form.

$$J = \sum_{l=1}^{p} \left\| \lambda_1 [\, y(k+l \mid k) - y^0(k+l)] \right\|^2 + \sum_{l=1}^{M} \left\| \lambda_2 \, [\Delta\hat{u}(k+l-1] \right\|^2 \qquad (2)$$

Where ρ1 and ρ_2 are weighting matrices used to penalize particular components of output and input signals respectively, at certain future intervals.

The solution of the LQR control problem is resulted to a feedback proportional controller estimated as the gain matrix k solution of the well-known Riccati equation over the prediction horizon.

$$u(k) = -kx_k \qquad (3)$$

Tuning of unconstrained SISO DMC [11] is challenging because of the number of adjustable parameters that affect closed-loop performance. These include the following: a finite prediction horizon, *P*; a control horizon, *M*; a move suppression coefficient, λ; a model horizon, *N*; and a sample time, *T*. The first problem that needs to be addressed is the selection of an appropriate set of tuning parameters from among those available for DMC. Practical limitations often restrict the availability of sample time, *T*, as a tuning parameter [10]. The model horizon is also not an appropriate tuning parameter since truncation of the model horizon, *N*, misrepresents the effect of past moves in the predicted output and leads to unpredictable closed-loop performance. This review is targeted towards selection of appropriate tuning parameters for developing a DMC tuning strategy's base case process is employed to illustrate the effect of adjustable parameters on DMC response for a step change in set point.

2.1. Implementation of the DMC Tuning Strategy

The proposed DMC tuning strategy referred from [11], which includes the analytical expression for the move suppression coefficient λ. This tuning strategy can be applied to unconstrained DMC in closed loop with a broad class of SISO processes that are open loop stable, including those with challenging control characteristics such as high process order, large dead time, and noniminimum phase behavior.

The different steps of DMC algorithm used for Tuning areas,

Step1**:** Select the identification of a first order plus dead time (FOPDT) model approximation of the process.

Step 2: Selection an appropriate sample time *T*

Step3*:* computes a model horizon, *N*, and a prediction horizon, *P*, from *t*, θ and *T*.

Step4: It may be necessary to fine tune DMC for desired performance by altering *P* and λ from the starting values given by the tuning strategy. The recommended approach is to increase λ for smaller move sizes and slower output response.

*2.2. Effect of Sample Time and Control Horizon***.**

Fig. 3-6, each comprise a matrix of closed-loop response results for different *T* , *M, p,* λ Results are presented for sample times such that the ratio *T/t* is *0.1, M* is selected to be either *2* or *8* manipulated input moves. The range of *T* and *P* explored corresponds to that recommended by the proposed tuning strategy. The impact of *T* on DMC closed-loop performance when *P* is held constant is shown in Fig.3 Similar comparisons between other pairs of response lead to the same conclusion. Another interesting observation can be made about the effect of T on the analytical expression for λ. For example, response of. For a fixed M, as P decreases the system matrix becomes less singular (ill conditioned) and the overall magnitude of its elements decreases. Hence, a smaller λ is sufficient to provide the same effect as a larger λ with a larger prediction horizon.

III.PID CONTROLLER

The PID control algorithm [1] is the most common feedback controller in industrial processes. It has been successfully implemented for over 50 years, as it provides satisfactory robust performance despite the varied dynamic characteristics of a process plant [10].

The proper tuning of the PID controller aims a desired behavior and performance for the controlled system and refers to the proper definition of the parameters which characterize each term. Over the past, it has been proposed several tuning methods, but the most popular (due to its simplicity) [14] tuning method. This tuning method is based on the computation of a process's critical characteristics, i.e. critical gain Kcr and critical period Pcr .

3.1. IMC-based PID Controller

The internal model control (IMC) algorithm [10] is based on the fact that an accurate model of the process can lead to the design of a robust controller both in terms of stability and performance [3]. The basic IMC structure is shown in Fig. 2 and the controller representation for a step perturbation is described by (4).

$$G_q(s) = \frac{G_f(s)}{G_I(s)} \tag{4}$$

Where $G_I(s)$ is the inverse minimum phase part of the process model and $G_f(s)$ is a nth order low pass filter $1/(\lambda s+1)^n$. The filter's order is selected so that $G_q(s)$ is semi-proper and λ is a tuning parameter that affects the speed of the closed loop system and its robustness [13], [2].

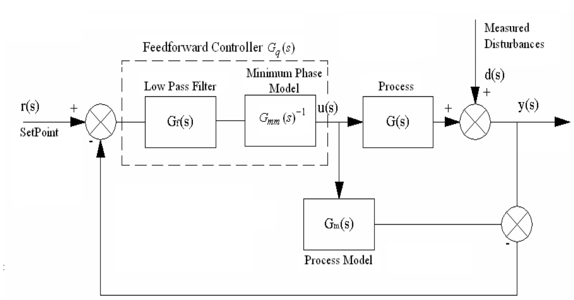

Fig. 2 IMC control structure

However, there is equivalence between the classical feedback and the IMC control structure, allowing the transformation of an IMC controller to the form of the well-known PID algorithm.

$$G_c(s) = \frac{G_q(s)}{1 - G_m(s)G_q(s)} \tag{5}$$

The resulted controller is called IMC-based PID controller and has the usual PID form (6).

$$G_c(s) = K_p\left(1 + T_D s + \frac{1}{T_I s}\right) \tag{6}$$

IMC-based PID tuning advantage is the estimation of a single parameter λ instead of two (concerning the IMC-based PI controller) or three (concerning the IMC-based PID controller). The PID parameters are then computed based on that parameter of model. Though for the case of a FOPDT, process model, the delay time should be approximated first by a zero-order Padé approximation. However, the IMC-based PID tuning method can be summarized according to the Table 1.

IV PROBLEM FORMULATION

In order to assess the practical utility of the above described advanced control algorithms, a series of implementation simulations have been conducted on a simple FOPDT process. For comparison purposes, a conventional PID controller is also designed using the Ziegler-Nichols method.

The FOPDT process model is described by (8) and initially is assumed absence of plant model mismatch, inputs constraints or measured disturbances. The model selection is based on the fact that a FOPDT model represents any typical SISO chemical process given by (7).

$$G(s) = \frac{k_c}{\tau s + 1} e^{-\theta s} \tag{7}$$

Conside the process model with following FOPDT Parameters

$$G(s) = \frac{1}{s+1} e^{-0.3s} \tag{8}$$

The critical characteristics for the estimation of PID parameters are $Kcr=5.64$ and $P_u=1.083$. The IMC-based PID parameters are estimated are shown in Table1. Selecting $\lambda = 0.1$ and $n = 1$. The calculation of DMC gain matrix includes the following parameters; input weight λ $_{=0.1}$, output weight, control horizon (M) 2, and prediction horizon (P) 10.

Table 1: IMC-based PID and ZN tuning parameters of a FOPDT process

Controller	K_P	T_I	T_D	λ/θ
ZN	3.31	0.5415	0.1353	--
IMC- PID	2.90	1.15	0.1304	>0.33

Fig 7-9, shows next simulation scenario includes constraints on the input and output variables.

$$-1 \le u(t) \le 1, , -1 < y(t) < 1 \tag{9}$$

In the final simulation scenario a simple disturbance model described by (10) is also implemented, in order to study the capability of each controller in disturbance rejection.

$$G_d(s) = \frac{0.8}{s+1} e^{-0.1s} \tag{10}$$

V PROBLEM SOLUTION

Fig 3-6 demonstrates the effect of tuning parameters of DMC With no disturbances and input constraints, the output response for the advanced control algorithms yields satisfactory step behavior with good set point tracking and smooth steady state approach. However, the response of the conventional PID seems to be rather disappointing, as it yields a large overshoot. Mainly concerning DMC and PID algorithms, the initial sharp increase of their control action signal may not be acceptable during a practical realization of the controller in an actual industrial plant. Fig.8, 9 shows the output response after the introduction of input constraints defined by (9). According to the results, both DMC and IMC-based PID controllers were unaffected by the input constraints as their constrained control action response has been within the constrained limits. Although the response of the conventional PID controller retained its large overshoot, the introduction of input constraints has optimized its smoothness. Finally DMC maintained its satisfactory performance, although the fact that its manipulated variable has been constrained the most Fig. 10,11 demonstrates the output responses of the process during the introduction of measured disturbances defined by (10). According to the results, DMC controller yields the most optimal response while IMC-PID controller sustains its performance. On the contrary IMC-based PID as well as the conventional PID yields a rather large overshoot fig 9.

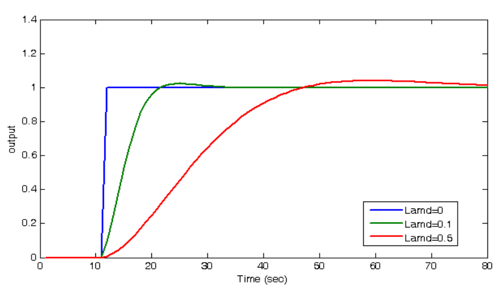

Fig. 3.Output response of DMC with weighing λ, =0, 0.1, 0.5, *M*=2.P=10 T=0.1.

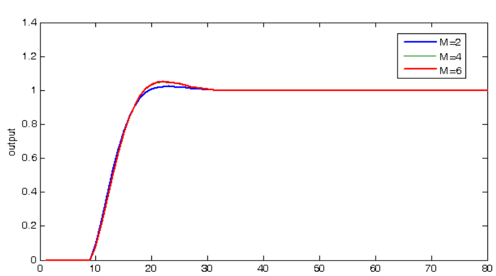

Fig. 4 Output response of DMC with control horizon *M*=2, 4, 6, P=10 T=0.1, *λ=0.1*

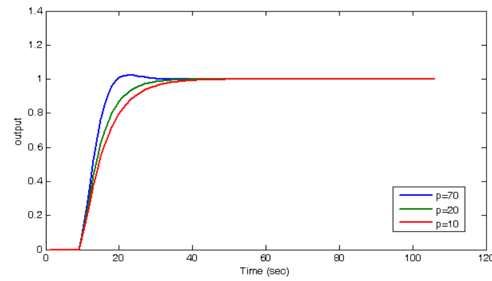

Fig. 5 Output response of DMC with, *M*=2.Prediction horizon, P=10, 20, 70 T=0.1, *λ=0.1*

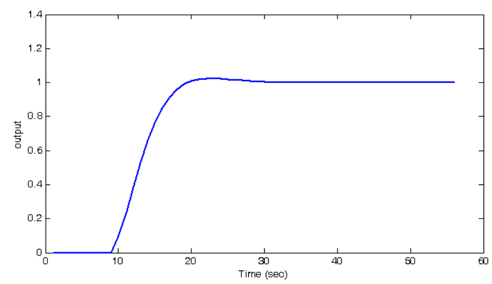

Fig. 6 Output response of DMC with, *M*=2.P=4, T=0.1, *λ=0.07*

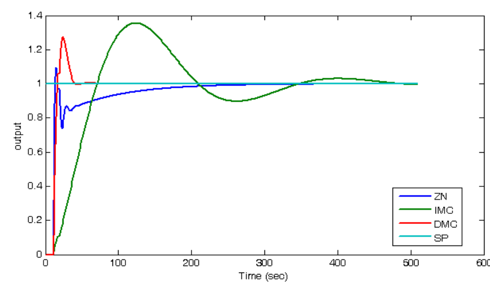

Fig. 7 Unconstrained Output Step Response with three controllers

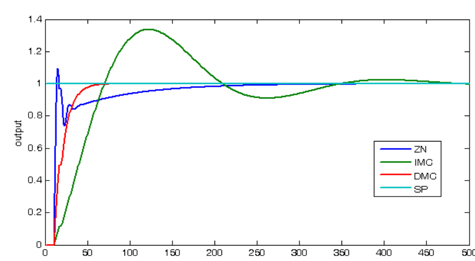

Fig. 8 Output Step Response with Input Constraints with three controllers.

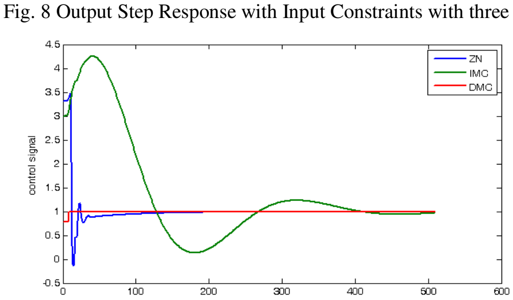

Fig. 9 Constrained Control Action step response with controllers.

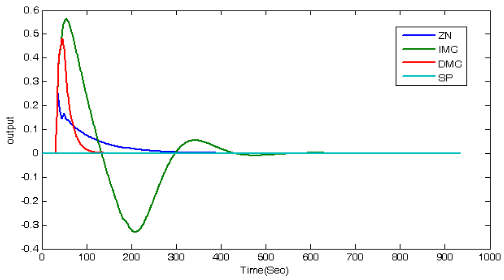

Fig. 10 Output Response with Measured Disturbances t=2 sec for three controllers.

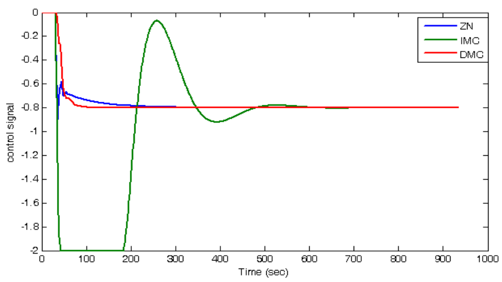

Fig. 11 Control Action response with Measured Disturbances t=2 sec for three controllers.

VI CONCLUSION

In this paper simulation effect of two advanced control algorithms on a FOPDT process model in terms of type 1 servomechanism carried out. These algorithms are the IMC-based PID controller, and the DMC controller. After their implementation in the FOPDT process their step response was simulated using the Matlab/Simulink software and compared with the conventional PID controller tuned with ZN method in various practical scenarios. Such scenarios include the implementation of input constraints or measured disturbances. According to the simulations results, all the advanced control algorithms perform satisfactory step behavior with good set point tracking and smooth steady state approach. They also sustain their robustness and performance during the introduction of input constraints or measured disturbances. Surprisingly, the step response of the conventional PID controller wasn't as optimal as it has been expected as its overshoot exceeds any typical specification limits.

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