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Piston Position Control In Double Acting Pneumatic Cylinder: Comparative Study

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ABSTRACT

The comparative study of position control of piston in double acting pneumatic cylinder by considering three different methods which include MPC (Model Predictive Control), GPC (Generalized Predictive Control), and NPID Controller (Nonlinear Proportional-Integral-Derivative). MPC is the method to solve mathematical program in on-line, to overcome from the drawback of MPC, an explicit MPC is introduced to solve through off-line to compute the control action of piston position. GPC is basically used for calculating the sequence of control signals, to minimize the long-range of the cost function. It is most effective in self tuning control in industrial fields. NPID Controller also mostly used in industry and continued as an important method in control engineering. Most of the control process industries are related to PID controller. An Elaborative comparative study has been done for piston position control of a double acting cylinder.

KEYWORDS: MPC, GPC, Nonlinear PID controller.

1. INTRODUCTION

Model predictive control(MPC), an important control technique fordifficult multivariable control problems, to control a multiple-input, multiple-output process, inequality constraints on the input and output variables. Model predictive control is applied in control process industrieslike chemical plants and other dynamical systems. MPC has the capability to predict the sequence of control signal infuture behavior and can implement in control actions accordingly. Basically the MPC relates to linear optimal control systems. However, MPC can be in two ways, one is linear and other is nonlinear time varying systems.

The GPC is used to obtain a sequence of future control signals and it minimizes a complex cost function over a prediction control method. The content to be optimized in the expected quadratic function for measuring the distance between the desiredsystem output and some desired reference. It has been successfully implemented in many control process industrial applications, which shows the high performance and a degree of robustness. The principle of predictive control method isto make attractive applications for many sources, either as linear or nonlinear control. Thechoice of GPC is available to lead a greater variety of control objectives compare to other approaches, some of which can be considered as subsets or limiting cases of GPC.

The PID controller is used as a widely common control schemein industries and it is simple to implement andeffective in long range of linear processes. Nonlinear control systems are used to controlthe systems, where the nonlinearitiesare playing a majorrole, either in the controller or in the controlled process. A nonlinear PID controller, process arisesin engineering and environmental systems, including mechanical andbiological systems, aerospace and automotive control, industrial process control, and manyothers.

In further sections the brief description of Model predictive control, Generalized predictive control and Nonlinear PID controller methods are described along with the position control of piston in a double acting pneumatic cylinder.

2. LITERATURE SURVEY ON DIFFERENT METHODS

Based on the motivated research topics, the related literature surveys have been given in this section. Firstly, the fields of Model Predictive Control (MPC) have been briefly surveyed. In the next subsection discussed about the Generalized Predictive Control (GPC) survey have been done. The last part is dedicated to the field of the Nonlinear PID Controller.

2.1. MODEL PREDICTIVE CONTROL

Model predictive control is the advanced control techniques widely applied in the process industries. The Model Predictive Control does not designate a specific control strategy, but rather a long range of the control methods, which make an explicit model of the process to obtain the control signal by minimizing an objective function [1].

2.1.1. MODEL PREDICTIVE CONTROL FOR POSITION CONTROL

MPC was introduced in 1960's and 70's in the control process industries;the basic principle is to solve an open-loop optimal control problem at each step time [2]. The variables are set of sequence of future manipulated variables and the objective is to minimize the deviations from a desired source; state and output variables are naturally handled in through the basicformula. Feedback provides a model update for step time and performs the optimization [3].MPC uses an explicit control process model and provides information about input and output values to compute the process inputs, so that the future controller process behavior is optimized over the prediction control horizon method [4].

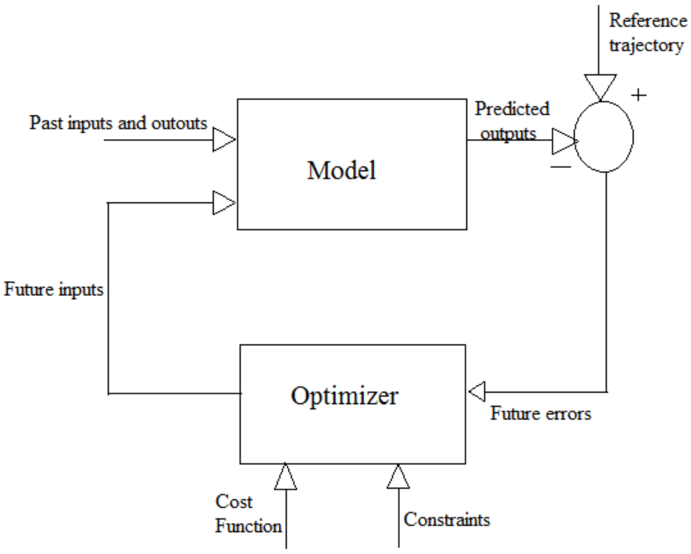

Figure:1-Basic structure of modelpredictive control

In the figure:1 shows the basic structure of model predictive structure of a model is used to predict the future plant outputs, based on pastand current values and on the proposed optimal future control actions. Theseactions are obtained by the optimizer taking into account the cost function as well as the constraints.The process model plays a major role in the controller.The chosen model must be able to capture the process dynamics to preciselypredict the future outputs and be simple to implement and understand.The issues of feasibility of the on-line optimization, stability and performance are largely understood for systems described by linear models [5]. Much progress has been made onthese issues for nonlinear systems which includes the reliability and efficiency ofthe on-line computation scheme.

Basic Formulation

Given a set of plant dynamics

$(k+1) = Ax(k)+ Bu(k)$

z (k)= Cx(k)

and a cost function

$$J = \sum_{j=0}^{N}\{||z(k+j|k)||R_{zz} + ||u(k+j|k)||R_{uu}\} + F(x(k+N|k))$$

||z(k + j|k)||Rxx is just a short hand for a weighted norm of the state, and to be consistent with earlier work, would take

$||z(k + j|k)||Rzz = z(k + j|k)^T RzzZ (k + j|k)$

F(x(k + N|k)) is a terminal cost function. In the nominal case, there is no difference between these two implementation approaches which includes feedforward and feedback. But with modeling errors and disturbances, the state feedback form is much less sensitive.This is the main reason for using feedback [6].

2.2. GENERALIZED PREDICTIVE CONTROL

The Clarke toned the GPC method andit is one of the most familiar methods in MPC methodinthefield,industry and academia.The basic idea of GPC is to calculate a sequence of future control signals in such a way that it minimizes a multiple stage of cost function defined by prediction control method. Compared to other predictive controllers, the GPC consists of many ideas, since it has same concepts but there is some differences. It provides solution and deals with unstable and non-minimum phase plants and incorporates the concept of predictive control horizon as well as the consideration of weighting of control increments in the cost function. The general set of choices available for GPC leads to a greater variety of control objective compared to other approaches, some of which can be considered as subsets or limiting cases of GPC [7].

2.2.1. GENERALIZED PREDICTIVE CONTROL FOR POSITION CONTROL

The GPC scheme can be seen in Fig. 2. It consists of the plant to be controlled, a reference model that specifies the desired performance of the plant, a linear model of the plant, and the Cost Function Minimization (CFM) algorithm that determines the input needed to produce the plant's desired performance. The GPC algorithm consists of the CFM block.

The GPC system starts with the input signal, r (t), which is presented to the reference model. This model produces a tracking reference signal, w (t) that is used as an input to the CFM block. The CFM algorithm produces an output, which is used as an input to the plant. Between samples, the CFM algorithm uses this model to calculate the next control input, u (t+1), from predictions of the response from the plant's model. Once the cost function is minimized, this input is passed to the plant. This algorithm is outlined below [8].

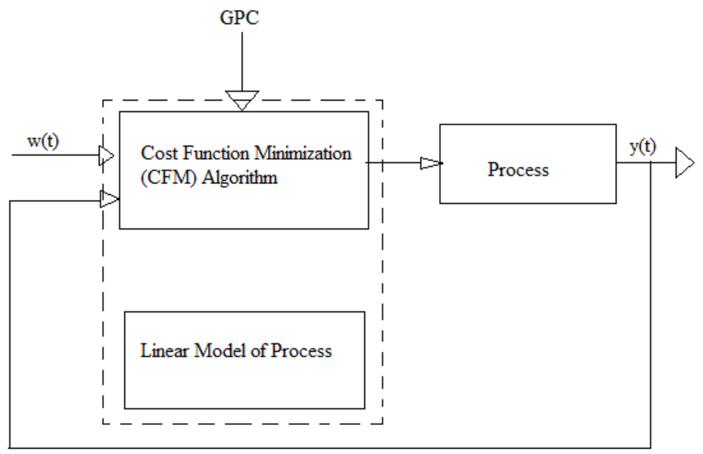

FIGURE:2 Basic structure of Generalized Predictive Control

2.2.2. FORMULATION OF GENERALIZED PREDICTIVE CONTROL

Most single-input single-output plants, when considering operation around particular set points and after linearization.

$$A(z^{-1})y(t)= z^{-d} B(z^{-1})u(t-1) + C(z^{-1})e(t)$$

Where u(t) and y(t) are the control and output sequence of the plant and e(t) is a zero mean white noise. A, B ,and Care the following polynomials in the backward shift operator z^{-1}:

$$A(z^{-1})= 1+ a_1 z^{-1} + a_2 z^{-2}+\ldots\ldots.+ a_{na} z^{-na}$$
$$B(z^{-1})= b_0+ b_1 z^{-1} + b_2 z^{-2}+\ldots\ldots.+ b_{nb} z^{-nb}$$
$$C(z^{-1})= 1+ c_1 z^{-1} + c_2 z^{-2}+\ldots\ldots.+ c_{nc} z^{-nc}$$

Where, d is the dead time of the system. This model is known as a Controller Auto-Regressive Moving-Average (CARIMA) model. It has been argued that for many industrial applications in which disturbances are non-stationary an integrated CARMA (CARIMA) model is more appropriate.

A CARIMA model is given by Equation:

$$A(z^{-1})y(t) = z^{-d}B(z^{-1})u(t+1) + C(z^{-1})\frac{e(t)}{\Delta}$$

For simplicity, C polynomial is chosen to be 1. Notice that if C^{-1} can be truncated it can be absorbed into A and B [9].

2.2.3. COST FUNCTION

GPC algorithm consists of applying a control sequence that minimizes a multistage cost function

$$J(N_1, N_2, N_u) = \sum_{j=N1}^{N2} \delta(j)[\hat{y}(t+j\,|t) - w(t+j)] + \sum_{j+1}^{Nu} \lambda(j)[\Delta u(t+j-1)]^2$$

Where ŷ(t+j|t) is an optimum j-step ahead prediction of the system output on data up to time k, $_{N1 and\ N2}$ are the minimum and maximum costing horizons, $_{Nu}$ control horizon, δ(j) andλ(j) are weighing sequences and w(t+j) is the future reference trajectory, which can considered to be constant.

The objective of predictive control is to compute the future control sequence u(t), u(t+1),….u(t+N_u) in such a way that the future plant output y(t+j) is driven close to w(t+j) . This is accomplished by minimizing J(N_1, N_2, N_u) [10].

2.3. NONLINEAR PID CONTROLLER

Proportional-integral-derivative (PID) controllers have been the most popular and the most commonly used industrial controllers in the past years. The popularity and widespread use of PID controllers are attributed primarily to their simplicity and performance characteristics. PID controllers have been utilized for control of diverse dynamical systems ranged from industrial process to aircraft and ship dynamics. Although linear fixed-gain PID controllers are often adequate for controlling a nominal physical process, the requirements for high-performance control with changes in operating conditions or environmental parameters are often beyond the capabilities of simple PID controllers. In order to enhance the performance of linearPID controllers, many approaches have been developed to improve the adaptability and robustness by adopting the self-tuning method, general predictive control, fuzzy logic and neural networks strategy, and other methods.

2.3.1. NONLINEAR PID CONTROLLER FOR POSITION CONTROL

Amongst these approaches, nonlinear PID (N-PID) control is viewed as one of the most effective and simple method for industrial applications. Nonlinear PID control may be any control structure of the following form:

$$u(t) = k_p(.)\int e(\tau)d\tau + k_d(.)\dot{e}(t)$$

Where kp(.), ki(.) and kd(.) are time-varying controller gains, which may depend on system state, input, or other variables, and u(t) and e(t) are the system input and error, respectively.

The nonlinear PID (N-PID) control has found two broad classes of applications:

(1) nonlinear systems, where N-PID control is used to accommodate the nonlinearity,usually to achieve consistent response across a range of conditions;

(2) Linear systems, where N-PID control is used to achieve performance notachievable by a linear PID control, such as increased damping, reduced risetime for step or rapid inputs, improved tracking accuracy, and friction compensation.

For linear systems, two broad categories of N-PID control are found: thosewith gains modulated according to the magnitude of the state, and those withgains modulated according to the phase of the state. The former category ofN-PID will be used in this paper. According to the magnitude of the state, theenhancement of the controller is achieved by adapting its response based on the performanceof the closed-loop control system. When the error between the commandedand actual values of the controlled variable is large, the gain amplifies the error substantiallyto generate a large correction to rapidly drive the system output to its goal.

As the error diminishes, the gain is automatically reduced to prevent excessive oscillationsand large overshoots in the response. Because of this automatic gain adjustment,the N-PID controllers enjoy the advantage of high initial gain to obtain a fastresponse, followed by a low gain to prevent an oscillatory behavior.In this study, a performance enhancement to the conventional linear PID controlleris proposed by incorporating a sector-bounded nonlinear gain into linear fixedgainPID control architecture. To achieve the high robustness against noise, twononlinear tracking differentiators are used to select the high-quality differential signalin the presence of measurement noise.

3. CONCLUSION

In this paper, the comparative study has been done for piston position control of double acting cylinder using three different methods which includes MPC (Model Predictive Control), GPC (Generalized Predictive Control), and NPID Controller (Nonlinear Proportional-Integral-Derivative). MPC is the method to solve mathematical program in on-line, to overcome from the drawback of MPC, an explicit MPC is introduced to solve through off-line to compute the control action of piston position. GPC is basically used for calculate the sequence of control signals, to minimizes the long-range of cost function. It is most effective in self tuning control in industrial fields. NPID Controller also mostly used in industry and continued as an important method in control engineering. Most of the control process industries are related to PID controller. From the study, analyzed that the MPC method is best to minimize the complex program can be solve in sequence.

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