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A new IMC controller design method using a low pass filter and variation effects of its order*

First M. TOUZRI, Second M. NACEUR, and Third D. SOUDANI, *Member, IEEE*

Abstract— **This paper contains a description of a new IMC controller design method, for a first order system with time delay. This new design method uses a low pass filter to fit model inverse, which offers parameters to ensure the robustness of the process behavior. This document shows the influence of filter order on the system behavior in order to obtain an optimal filter that ensures robustness and rapidity for the process. In this paper a brief description of the Internal Model Control will be given, a brief description of time delay effects on system behavior, a description of the new IMC controller design method and effects of filter order variation on the system behavior.**

I. INTRODUCTION

The control of a process with time delay is one of the most attractive research domains on this period, due to their wide presence in industry. However controlling a process including time delay is difficult because of the constraints imposed by the presence of time delay. [9]

For this purpose many command structure where made to surpass these constraints, then an approach using concepts of robust control where developed such as the Internal Model Control; which will be described on the next section of this document. This command structure will be used to control a first order system with time delay as application for a new IMC based method.

This document describes a new command structure based on IMC concept, using Padé approximations and a low pass filter; which is presented in four section, the first one contains a description of Internal Model Control, the second section describes command constraints due to time delay and utility of using a Padé approximation, the third section presents the new IMC controller design method and the last section presents the obtained results of the new IMC controller design method applied to a system with time delay.

II. IMC DESCRIPTION

Many command structures were developed using the feedback concept; which uses mathematical approaches to solve problems related to processes command, these approach was implemented by the apparition of the first calculator.[2,5,11] Internal Model Control, noted as IMC, uses feedback concept and uses the robust command characteristics, which can ensure an acceptable degree of performance even on the presence of parameters uncertainties and/or modelisations errors [1,3]. The basic structure of an IMC command is composed by the process compared to its model, and a controller as it shown on fig.1 .[10]

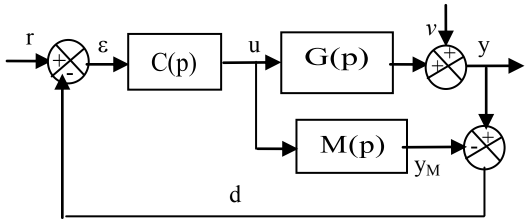

Figure 1. Basic IMC structure

Where C(p) represents the IMC controller, G(p) the process and M the model of the process which is an approximation of the plant G(p). This command structure applies the command signal u for both of the process G(p) and its model M(p), d is a disturbance signal which attacks the output directly and r is the reference signal, the output signal of the plant is compared to the set point signal in order to minimize the error between the reference and the output.

Internal model Control is one of the most popular command structure used for its simplicity and its robustness; this control method gives the possibility to realize a perfect set point tracking in the case of the use of a controller similar to the inverse of the model. [7]

Achieving the inverse of the model is the main problem associated to this command structure, because of the denominator order generally greater than the numerator on the model expression or the presence of time delay or/and instable zeros. [4,6]

III. CONSTRAINTS IMPOSED BY TIME DELAY

Systems with delays are found in many industrial processes. Time delay presence is due to many factors such as transfer of information, energy or chemical reactions. [9,12] Then presence of delays makes system analysis and controller design more complex, [12] due to the time delay effects on the system behavior which imposes many constraints on system command. Delays constraints may cause instability and deterioration on the system performances of the closed loop system.

Time delay also can cause a lag on the system phase especially for its great values [9] and for elevated frequency, which can be the cause of closed loop system performances deterioration or instability. Time delay presence makes also

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F. M. TOUZRI is with the Laboratory of Research on Automatic (LARA) of the National Engineers School of Tunis, BP 37, LE BELVEDERE 1002 TUNIS. TUNISIA, (email: touzri.mustapha@gmail.com).

S. M. NACEUR, is with the Laboratory of Research on Automatic (LARA) of the National Engineers School of Tunis, BP 37, LE BELVEDERE 1002 TUNIS. TUNISIA, (e-mail: m.naceur@ttnet.tn).

T. D. SOUDANI is with the Laboratory of Research on Automatic (LARA) of the National Engineers School of Tunis, BP 37, LE BELVEDERE 1002 TUNIS. TUNISIA, (e-mail: dhaou.soudani@enit.rnu.tn).

the effect of the disturbances not felt until a considerable time has elapsed, the effect of the control action takes some time to be felt in the controlled variable and the control action that is applied based on the actual error tries to correct a situation that originated some time before.[9]

Using the IMC structure, the associated controller can be used as the inverse of the process model; however in the case of presence of a time delay gives a prediction system, when the inverse is calculated, making the realization of this type of systems difficult. For this purpose a Padé approximation is used to surpass these constraints, of inversion and realization, and giving a rational representation for the process making possible the inversion of the process model. But this approximation gives an alternative to modelisations errors which can destroy the system performances and drive its behavior to the instability, to face this constraint we use on our command structure three Padé order approximation a first order, a second order and third order Padé approximation to decrease the effects of modelisations errors by elevating the approximation order to have a model which can behave as the original process for high frequency, then higher order approximations gives same behavior of the plant for more higher frequency. The obtained model using Padé approximation will be used to calculate the IMC controller, and then next section objective is to give a command approach which can solve the realization problem of the IMC controller.

IV. REALIZATION OF THE IMC CONTROLLER

This section describes the IMC controller design method, that uses a low pass filter to fit inverse of the process model.

Using this method IMC controller is realized by the multiplication of the filter and the inverse of the process model; which can be made by modifying the filter parameter to fit inverse of the process model. The main objective of using this filter is to eliminate the instable zeros which can appear on the process model, to make the IMC controller proper and to offer the possibility of controlling the robustness level of the command.

The used filter on this command structure can be written on this form [8]:

$$F(p)=\frac{\sum_{i=0}^{m}\beta_i p^i}{(1+\alpha p)^n} \tag{1}$$

Where: $\sum_{i=0}^{m}\beta_i p^i$ represents the instable zeros which can appear on the process model

n: is a natural integer chosen to make the controller C proper.

α :is a float used to adjust the performance of the controlled process.

Then the IMC controller can be written on this form [10]:

$$C(p)=F(p).M^{-1}(p) \tag{2}$$

and the command structure can be described using figure 2:

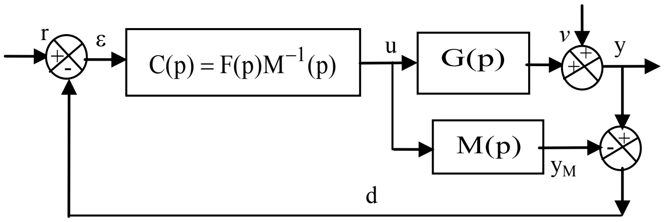


Figure 2. IMC structure

IMC controller can be calculated using this method:

$$M(p)=\frac{N_{ZS}(p)\times N_{ZI}(p)}{D(p)} \tag{3}$$

$$M^{-1}(p)=\frac{D(p)}{N_{ZS}(p)\times N_{ZI}(p)} \tag{4}$$

$$F(p)=\frac{N_{ZI}(p)}{(1+\alpha p)^n} \tag{5}$$

$$C(p)=F(p)\times M^{-1}(p)=\frac{D(p)}{N_{ZS}(p)\times(1+\alpha p)^n} \tag{6}$$

Where: $N_{ZS}(p)$: represents the stable zeros on the numerator of the process model.

$N_{ZI}(p)$: represents the instable zeros that can be present on the process model

$D(p)$: represent the denominator of the process model

n: is a natural integer chosen to make the controller proper

α: is a float used to adjust the system performances.

The main objective of this IMC approach is to ensure the robustness of the command in spite of the presence of disturbances and modelisations errors; for this purpose we impose zeros and poles of the commanded process by adjusting the filter parameters. In fact the good choice of α must confirm an acceptable compromise between stability and performances; then if α=0 the system response will be H_2- optimal,[8] if α is chosen greater than the poles of the controlled system the filter dynamics will dominates the closed loop response of the system, and if α is chosen inferior to the poles of the system the filter effect will not dominates the closed loop response of the system.[8] Then the parameter filter α allow us to control the speed of the closed loop response and that the adjusting of α is the same as adjusting the speed of the closed loop response. [8]

In the same time the filter order “n” represents an important parameter for the command configuration; that can be influent on the system response speed for this purpose this parameter should be adjusted to get the required response which should be robust and fast. In fact the filter order should be chosen greater or equal to the model order minus order of stable zeros of the model to make the controller C(p) proper; then much greater values of the filter order could make system response more robust but more slow for this reason adequate filter order must be chosen, that's will be the topic of the next section which shows results of system with time delay commanded using the new IMC command approach associated with different filters.

V. OBTAINED RESULTS FOR A TIME DELAY FIRST ORDER SYSTEM USING DIFFERENT PADÉ APPROXIMATION

The objective of this section is to show; the obtained results for a first order system with a time delay, its transfer function is: $G(p)=\frac{e^{-4p}}{1+p}$, using a first order, a second order and third order Padé approximations for the time delay obtaining then a rational model that will be used on the controller design procedure and the effect of changing the filter order on the system response, for this purpose we fix the value of the parameter α to 2.5 and we change the filter order in each simulation.

This section contains three subsections; the first one presents the obtained results using a first order Padé approximation, the second one shows obtained results for a second order Padé approximation and the third one presents results for a third order Padé approximation.

A. Obtained results using a first order Padé approximation

Using a first order Padé approximation for the considered system $G(p)=\frac{e^{-4p}}{1+p}$; the obtained model is a second order system which is described by $M(p)=\frac{1-2p}{1+3p+2p^2}$ then associated filters are:

- $F_1(p)=\frac{1-2p}{(1+2.5p)^2}$ filter order is two associated with

the controller $C_1(p)=\frac{1+3p+2p^2}{(1+2.5p)^2}$

- $F_2(p)=\frac{1-2p}{(1+2.5p)^3}$ filter order is three associated

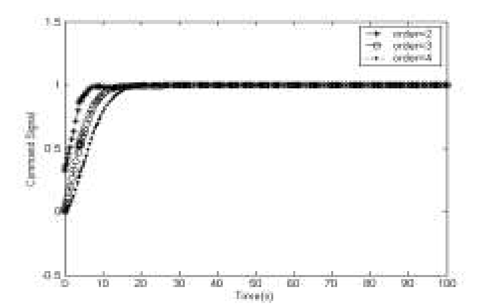
with the controller $C_2(p)=\frac{1+3p+2p^2}{(1+2.5p)^3}$

- $F_3(p)=\frac{1-2p}{(1+2.5p)^4}$ filter order is four associated

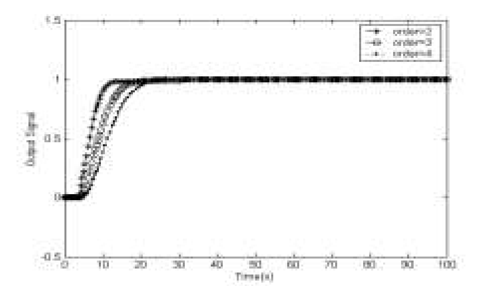
with the controller $C_3(p)=\frac{1+3p+2p^2}{(1+2.5p)^4}$

Then system response will be presented on the figures below to show the process behavior in case of using different filter orders and its dynamics on the case of great filter order in the case of presence and absence of disturbances.

Case of disturbance absence



Command Signal

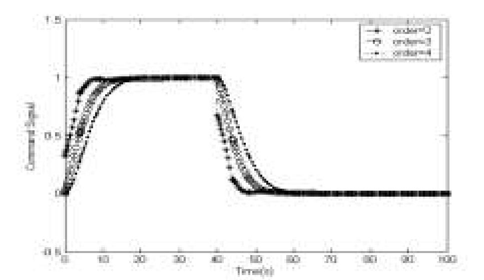


Output signal

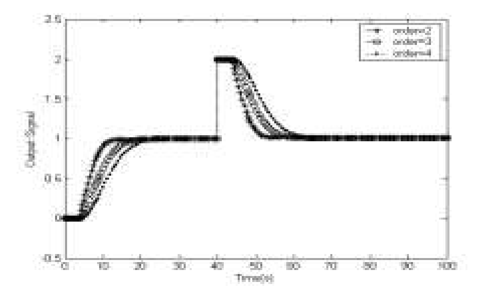
Figure 3. System evolution for different values of n on disturbance absence.

It can be seen on this presented simulations that the three used controller associated to the different filters order gives a robust behavior; however making the filter order greater gives slower step response this is remarkable when we compare the two obtained response of the controller which use a second order filter and the controller which use a third order filter.

Case of disturbance presence at t=40s



Command signal



Output signal

Figure 4. System evolution for different values of n on disturbance presence.

These simulations shows a fast set-point tracking for the three used controllers, which use three different filter order even on the presence of a disturbance which attacks directly the process output, but it is remarkable that the step response of the controller that uses the second order filter is the fastest one compared to the obtained system step response of the controllers associated to third order filter and to fourth order filter.

B. Obtained results using a second order Padé approximation

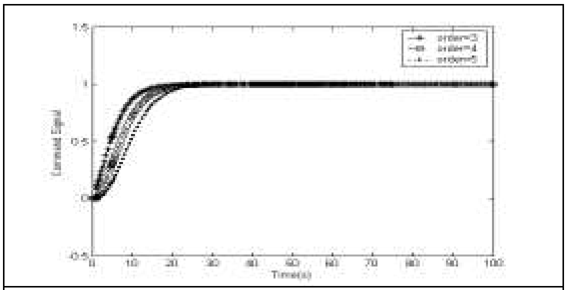
Using a second order Padé approximation for the considered system $G(p)=\frac{e^{-4p}}{1+p}$; the obtained model is a third order system which expression is $M(p)=\frac{1-2p+\frac{4}{3}p^2}{1+3p+\frac{10}{3}p^2+\frac{4}{3}p^3}$

then associated filters are:

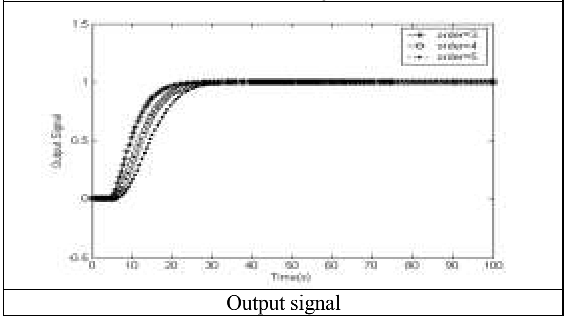
- $F_1(p)=\frac{1-2p+\frac{4}{3}p^2}{(1+2.5p)^3}$ filter order is three associated with the controller $C_1(p)=\frac{1+3p+\frac{10}{3}p^2+\frac{4}{3}p^3}{(1+2.5p)^3}$
- $F_2(p)=\frac{1-2p+\frac{4}{3}p^2}{(1+2.5p)^4}$ filter order is four associated with the controller $C_2(p)=\frac{1+3p+\frac{10}{3}p^2+\frac{4}{3}p^3}{(1+2.5p)^4}$
- $F_3(p)=\frac{1-2p+\frac{4}{3}p^2}{(1+2.5p)^5}$ filter order is five associated with the controller $C_3(p)=\frac{1+3p+\frac{10}{3}p^2+\frac{4}{3}p^3}{(1+2.5p)^5}$

These figures below shows simulations for the considered system using these three controller associated to the different listed filter in the case of absence and presence of disturbance at t=40s.

Case of disturbance absence



Command signal

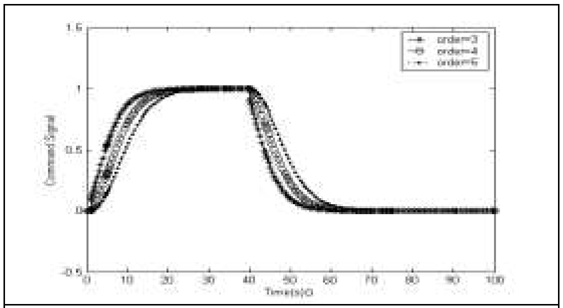


Output signal

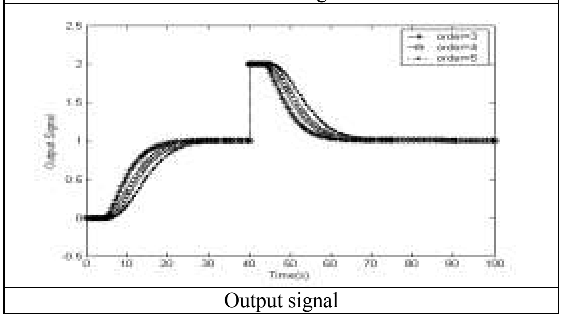
Figure 5. System evolution for different values of n on disturbance absence.

It is remarkable that using the three controllers, associating the three different order filter, the system realizes a fast set-point tracking and show a stable behavior but the more the filter order became great, the more the system behavior became slow which can be seen by comparing the step response of the system using controller associated to a filter its order is three and the step response of the system using controllers associated to filters its orders is four or five.

Case of disturbance presence at t=40s



Command signal



Output signal

Figure 6. System evolution for different values of n on the presence of disturbance.

It can be seen that the process realizes a robust behavior by a fast set-point tracking on the three case of using different filter order; however elevating the filter order make the system response more slow and spend more time to rejects disturbances this is remarkable by comparing the system step response on the case of using a controller associated to filter its order is three and controllers associated to a filter its order is five and a filter its order is four.

C. Obtained results using a third order Padé approximation

Using a third order Padé approximation for the considered system $G(p)=\frac{e^{-4p}}{1+p}$; the obtained model is a fourth order system its expression is:

$$M(p)=\frac{1-2p+\frac{8}{5}p^2-\frac{8}{15}p^3}{1+3p+\frac{18}{5}p^2+\frac{32}{15}p^3+\frac{8}{15}p^4}$$

then the associated filters are:

- $F_1(p)=\frac{1-2p+\frac{8}{5}p^2-\frac{8}{15}p^3}{(1+2.5p)^4}$ filter order is four

associated with the controller

- $C_1(p)=\frac{1+3p+\frac{18}{5}p^2+\frac{32}{15}p^3+\frac{8}{15}p^4}{(1+2.5p)^4}$

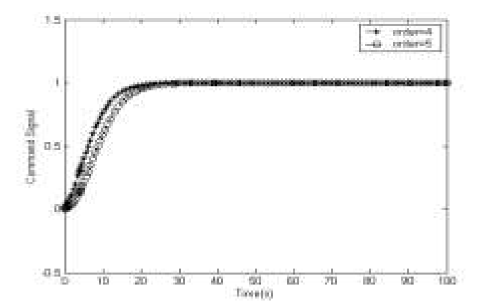
- $F_2(p)=\frac{1-2p+\frac{8}{5}p^2-\frac{8}{15}p^3}{(1+2.5p)^5}$ filter order is five

associated with the controller

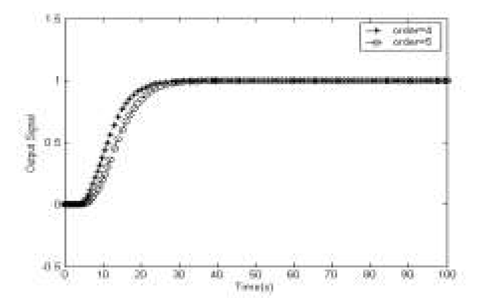
- $C_2(p)=\frac{1+3p+\frac{18}{5}p^2+\frac{32}{15}p^3+\frac{8}{15}p^4}{(1+2.5p)^5}$

These figures shows step response of the considered system using these three controller associated to the different listed filter in the case of absence and presence of disturbance at t=40s.

Case of disturbance absence



Command signal

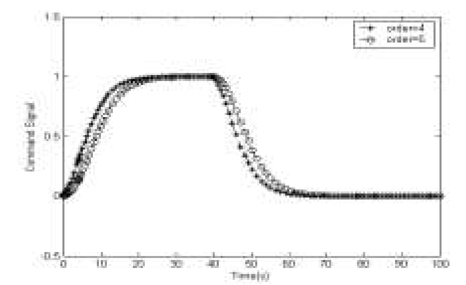


Output signal

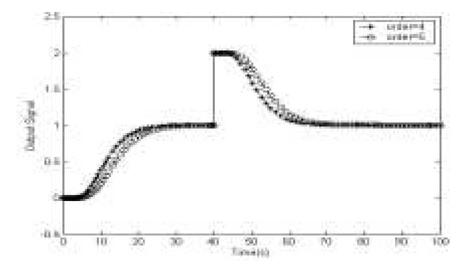
Figure 6. System evolution for different values of α on disturbance absence.

It can be seen that the process realizes a robust behavior marked by a rapid set-point tracking, for the tow used controllers (a controller its filter order is four and a controller its filter order is five), however elevating the filter order slows the system dynamics, which is remarkable on the system response using the controller associated to a filter its order is five.

Case of disturbance presence at t=40s



Command signal



Output signal

Figure 8. System evolution for different values of n on the presence of disturbance.

These simulations shows a robust behavior even on the presence of disturbance affecting directly the process output; for the two cases, using a filter its order is four and using a filter its order is five, however the system response using a controller its filter order five is slower than the system response using a controller its filter order is four; which can be seen on the faster step response and the faster set-point tracking by the system when we use a fourth order filter and the rejecting disturbance time which is shorter than when use a controller its filter order five.

VI. CONCLUSION

In this paper a new Internal Model Control controller design method was developed, which uses a low pass filter. This method is based on multiplication of model inverse and a low pass filter to fit model inverse controller in order to ensure optimal performances. This document shows also effects of filter order variation on the process behavior; which become robust but slow by using greater filter order.

This method shows interesting results for the considered system, first order with time delay, by using adequate filter order for the considered controller that ensures robustness and rapidity.

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