

Efficient Disturbance Rejection for Dead-Time Processes using Internal Model Control

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Abstract: Dead-time processes are quite frequent in industrial applications. Because of its simple tuning procedure and good set-point tracking capabilities, Internal Model Control (IMC) has established good results for these processes. However, disturbance rejection is an important issue in process control, especially in delayed systems. The basic tuning rules for IMC exhibits rather sluggish disturbance rejection performance, especially for delay dominant processes (i.e. the relative delay to the process time constant). In this paper we propose a special tuning for effective disturbance rejection with IMC. The proposed disturbance filter compensates nicely for the dead-time, when stochastic disturbance signals have their main spectral energy in a limited frequency interval. The tuning method is using the Diophantine equations to determine the disturbance filter coefficients. Simulation results demonstrate the effectiveness of the proposed approach, as well as its intrinsic robustness when compared to the basic IMC tuning.

Keywords: internal model control, disturbance rejection, modified filter design, delay dominant processes, robustness

1. INTRODUCTION

Dead-times are common in practice and complicate the closed loop dynamics. In addition, disturbances acting upon the process can lead to poor performance and increased risk for instability of the closed loop. Developing efficient, practical and successful disturbance rejection schemes for dead-time processes is one of the main interests of the control community. A successful algorithm for delay processes is the Internal Model Control (IMC) [1-2]. It is a model based control techniques, consisting of an inversion of the invertible part of the process model and an additional filter added to make the final controller proper. The non-invertible part of the process, such as dead-times, non-minimum phase zeros, are not included in the design procedure. IMC has been successfully implemented on real applications [3-5]. The well-known IMC-PID (Proportional-Integral-Derivative) tuning rule achieves a compromise between closed loop performance and robustness to model uncertainties, by using only one tuning parameter, i.e. the filter time constant [2], [6]. Load disturbance rejection is one of the most problematic issues in process control [7]. Even though, as indicated in [8], the IMC-PID tuning rules demonstrate good set-point tracking, they exhibit sluggish disturbance rejection, especially for delay dominant processes, i.e. when $0 \ll \frac{\tau}{\tau_p} < 1$, with τ the time delay and τ_p the dominant process time constant.

In [5], an extension of the IMC filter for efficient disturbance rejection has been proposed. The approach is based on ideas from model based predictive control and Diophantine equation derivation. Also, an improved IMC filter is proposed for effective disturbance rejection and robust operation of first order process with time delay in [7]. The design of such filter is based on the

cancellation of the slow (dominant) pole. Their results indicate that the proposed approach ensures a good disturbance rejection irrespective of the type of disturbance and also achieves good robustness to model mismatch in terms of sensitivity. To test the method, various processes with different dead-time relative to time-constant ratios were analyzed. The simulation results demonstrate that the suggested IMC filter provides good disturbance rejection response for process delay dominant processes.

A similar approach is presented in [8], where an optimal IMC filter structure is used in the design of a PID controller for improved disturbance rejection response. The proposed method is suitable for lag-time dominant processes, with the controllers tuned to have the same degree of robustness according to the measure of maximum sensitivity. The study includes several processes and a guideline regarding the selection of the closed-loop time constant guideline is also proposed to cover a wide range of dead-time/time-constant ratios. In [9], the disturbance rejection problem is linked to a novel control scheme of active disturbance rejection internal model control (AD-IMC). The concept of active anti-interference is introduced into the IMC algorithm by analyzing the relationship between IMC and disturbance observer control. The AD-IMC is intended to improve the anti-interference ability and robustness for the dead-time process. In addition to this concept, a disturbance filter is used to implement the active anti-interference ability for AD-IMC scheme. The proposed method achieves a compromise between the dynamic performance and the robustness of the system.

Following the Ziegler-Nichols tuning procedure based on the process step response, a modified tuning scheme for IMC has been proposed in [10] for the disturbance rejection problem. The controller

parameters are obtained as a result of numerous studies and simulations of a wide range of first-order with dead-time approximated processes. As a result, the controller gain, integral and derivative time constants are given as a function of the overshoot obtained in the closed loop set point experiment and the peak time.

In [11] the authors propose to add to the PID output, in steady-state, a value that depends on the difference between the system output and the PID output itself. It is shown that such an approach leads to a significant improvement of the load disturbance rejection capabilities of the control system. Analytical tuning rules for the selection of the new parameters are given. A modified design of the IMC filter is proposed based on constructing one or more asymptotic canceling constraints for disturbance rejection in [12]. The purpose of the design is to reduce the influence from the time constant(s) of the process or repetitive-type load disturbance to the closed-loop disturbance rejection performance. The design requires the tuning of a single adjustable parameter, which can be monotonically tuned to meet with the compromise between the achievable disturbance rejection performance and the closed-loop system stability. Since the application is directed towards slow processes in industrial and chemical engineering practices, which can be generally described by first or second order process models with dead-time, quantitative tuning formulae and guidelines for the selection of this adjustable parameter are given.

In the present work, we introduce a novel extension of the IMC controller for improved disturbance rejection. The disturbance filter design is based on the assumption that most disturbances in industrial practice have a stochastic nature. Such disturbances can be estimated by their power spectrum, which is within a limited frequency interval and possibly concentrated around some frequency, ω (rad/s). This disturbance signal and its afferent main frequency can be easily extracted from the measured process output and estimated model output. The IMC filter is then designed such that it compensates for the dead-time effects, by using information of the disturbance signal around ω . In the case of a disturbance having a single frequency component ω , the disturbance will be completely rejected at the output. The final solution is obtained by solving a Diophantine equation, made possible solely through the dead-time compensation provided by the proposed novel IMC filter tuning procedure. Simulation results demonstrate the effectiveness of the proposed approach for the disturbance rejection problem. A comparison to the classical IMC filter design is included to further illustrate its advantages.

The paper is structured as follows. Section 2 presents the proposed disturbance rejection methodology, as well as the original aspects of the approach. Section 3 illustrates the design using a second order plus dead-time process. Section 4 demonstrates the robustness of the approach. Comparisons with the basic IMC approach and the advantages of using the proposed method are given. Section 5 concludes the work and

identifies some further research possibilities.

2. DISTURBANCE REJECTION METHODOLOGY

2.1 Basic Assumptions

Assume in what follows that the process is a stable dead-time system with the model described by the approximated transfer function:

$$\hat{P}(s) = \frac{B(s)}{A(s)} e^{-s\tau}, \quad (1)$$

where s is the Laplace variable and τ is the dead-time. The numerator in (1) can be decomposed into:

$$B(s) = B_g(s)B_b(s), \quad (2)$$

where $B_b(s)$ contains all non-minimum phase zeros and $B_b(0) = 1$. From IMC design rules it follows the controller structure:

$$C(s) = \frac{A(s)}{B_g(s)} F(s) = \frac{A(s) F_n(s)}{B_g(s) F_d(s)}, \quad (3)$$

where $F_d(s)$ and $F_n(s)$ are design filters. For the special case of the basic IMC approach, the filter $F_n(s) = 1$ and

$$F_d(s) = (1 + \lambda s)^n \quad (4)$$

with λ the tuning parameter for closed loop speed/robustness and n sufficiently large to make the IMC compensator $C(s)$ proper or semi-proper. The IMC closed loop diagram is given in Fig. 1, with $P(s)$ denoting the actual process and $\hat{P}_g(s) = \frac{B_g(s)}{A(s)}$ the invertible part of the process model. At this stage in the paper, since the approach deals with the rejection of the disturbance $D(s)$ and not with robustness, we assume perfect modeling with $\hat{P}(s) = P(s)$.

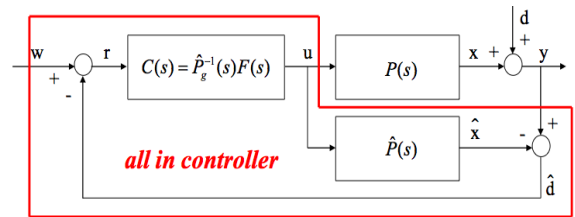


Fig. 1 Block diagram of the IMC control strategy

The closed loop response is:

$$Y(s) = P(s)U(s) + D(s)$$

which can be rewritten as:

$$Y(s) = H(s)W(s) + (1 - H(s))D(s), \quad (5)$$

where $W(s)$ is the Laplace transform of the reference setpoint signal and $H(s) = e^{-s\tau} B_b(s) \frac{F_n(s)}{F_d(s)}$.

Assume that the main spectral energy of the disturbance $d(t)$ is within a limited frequency interval

from which we can approximate a main frequency ω , as illustrated in Fig. 2.

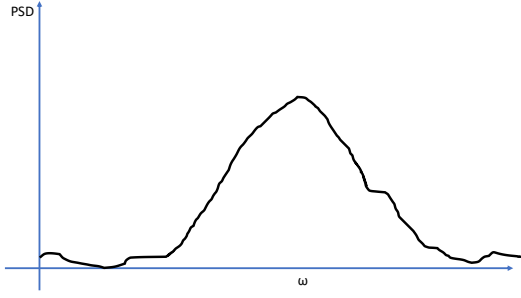


Fig. 2 Illustrative example of stochastic disturbance signal with spectral energy (PSD) in limited interval from which a main frequency ω can be approximated.

The Laplace transform of the disturbance can be approximated by:

$$D(s) = \frac{Ms+N}{s^2+\omega^2} \quad (6)$$

Notice that (5) assumes that the disturbance $D(s)$ is a pure sinusoidal signal. In practice, however, the disturbance will be a stochastic signal, but represented by a main frequency, as illustrated in Fig. 2.

The reader will see in the next section that even with this simple model for $D(s)$, the proposed method leads to spectacular improvements in the disturbance rejection results. Relations (5)-(6) indicate that the output $Y(s)$ will contain the oscillation caused by the disturbance $D(s)$, unless the oscillatory poles (corresponding to $s^2 + \omega^2$) are removed. Hence, the effect of the disturbance on the process output is given by the inverse Laplace transform of:

$$(1 - H(s))D(s) = \frac{F_d(s) - e^{-s\tau} B_b(s) F_n(s)}{F_d(s)} \frac{Ms+N}{s^2+\omega^2} \quad (7)$$

When tuning the IMC filters, the user can decide to ignore the fact that the process has a dead-time. Or, even better, the process itself has no dead-time. In this case, compensation of the oscillatory poles can be achieved by solving the polynomial Diophantine equation:

$$F_d(s) - B_b(s)F_n(s) = (s^2 + \omega^2)Q(s) \quad (8)$$

where $F_d(s)$ and $B_b(s)$ are known polynomials and $F_n(s)$ and $Q(s)$ are the resulting polynomials. Re-arranging (7) leads to:

$$F_d(s) = B_b(s)F_n(s) + (s^2 + \omega^2)Q(s) \quad (9)$$

Provided that the process has dead-time, i.e. $\tau \neq 0$, the procedure described above is no longer valid and the next section summarizes the proposed solution for this case.

2.2 Proposed tuning method

If the process has a dead-time then the following rationale can be applied. The essential and original idea

is to add a filter $T(s)$ in the numerator of the IMC controller:

$$C(s) = \frac{A(s) F_n(s) T(s)}{B_g(s) F_d(s)} \quad (10)$$

The closed loop response is then:

$$Y(s) = G(s)W(s) + (1 - G(s))D(s) \quad (11)$$

with $G(s) = H(s)T(s) = e^{-s\tau} B_b(s) \frac{F_n(s)T(s)}{F_d(s)}$. Ideally, the filter $T(s)$ is designed such that it compensates for the dead-time, i.e.:

$$T(s) = e^{s\tau} \quad (12)$$

However, the problem with the filter in (12) is that it is a non-causal filter. The compensation in this form is not possible, but we propose to re-define it for a specific frequency ω . Using the trigonometric form:

$$\begin{aligned} e^{j\omega\tau} &= \cos(\omega\tau) + j \sin(\omega\tau) \quad \text{or} \\ e^{j\omega\tau} &= \cos(\omega\tau) + j \frac{\sin(\omega\tau)}{\omega} \omega \end{aligned} \quad (13)$$

the filter $T(s)$ that compensates for the dead-time if the signal has a specific frequency ω is:

$$T(s) = \cos(\omega\tau) + \frac{\sin(\omega\tau)}{\omega} s \quad (14)$$

and this is the key element in the novel design methodology of the IMC algorithm for disturbance compensation in processes with time delay.

2.3 Tuning Procedure

The following notations are used:

$$B_b(s) = 1 + b_1s + b_2s^2 + \dots \quad (15)$$

$$F_n(s) = x_0 + x_1s + x_2s^2 + \dots \quad (16)$$

$$F_d(s) = (1 + \lambda s)^n = 1 + f_1s + \dots + f_ns^n \quad (17)$$

$$Q(s) = q_0 + q_1s + q_2s^2 + \dots \quad (18)$$

The polynomial $F_d(s)$ is chosen of appropriate order to obtain a proper or semi-proper transfer function for $C(s)$, while $F_n(s)$ is the result of solving the Diophantine equation given in (9):

$$\begin{aligned} 1 + f_1s + \dots + f_ns^n = \\ (1 + b_1s + b_2s^2 + \dots)(x_0 + x_1s + x_2s^2 + \dots) + \\ (s^2 + \omega^2)(q_0 + q_1s + q_2s^2 + \dots) \end{aligned} \quad (19)$$

by considering $F_n(s)$ and $Q(s)$ to be the unknown polynomials. Once the polynomial $F_n(s)$ is determined, the IMC controller is given by (10) with the filter $T(s)$ coefficients as given in (14):

$$T(s) = \cos(\omega\tau) + \frac{\sin(\omega\tau)}{\omega} s = t_0 + t_1s \quad (20)$$

The nominal closed loop equation is given in (11). In order to have zero steady state-error for step reference signals and disturbances, the following condition must hold:

$$G(0) = 0$$

$$B_b(0) \frac{F_n(0)T(0)}{F_d(0)} = 1 \quad (21)$$

which leads to the analytical solution:

$$x_0 t_0 = 1 \Rightarrow x_0 = \frac{1}{t_0} = \frac{1}{\cos(\omega\tau)} \quad (22)$$

valid for frequencies $\omega \neq \frac{(2n+1)\pi}{2\tau}$, $n=0,1,2,\dots$

At this moment, all necessary steps are available for the design of IMC controller for processes with time-delay.

3. RESULTS

Consider the following dead-time process:

$$P(s) = \frac{2}{(10s+1)(5s+1)} e^{-s\tau} \quad (23)$$

The task is to design an IMC controller using the proposed method for setpoint trajectory $W(s)=5$. It must also perform well for the disturbance rejection, for a stochastic disturbance signal with offset value 10 and main energy around frequency $\omega=0.2$ rad/s.

Two cases for the dead-time will be considered: $\tau = 3$ (lag dominant process) and $\tau = 15$ (delay dominant process). Since the problem of robustness is not addressed in the section, perfect modeling is considered, with the model equal to the process in (23).

The model polynomials $A(s)$, $B_g(s)$ and $B_b(s)$ determined through equivalence of (1) and (23), and using (2), are:

$$\begin{aligned} A(s) &= 1 + 15s + 50s^2 \\ B_b(s) &= 1 \\ B_g(s) &= 2 \end{aligned} \quad (24)$$

Three types of IMC designs will be considered:

- the basic IMC controller $IMC_1(s)$,
- the IMC controller designed with the Diophantine equation, but without the $T(s)$ filter $IMC_2(s)$ and
- the IMC controller designed with the Diophantine equation, with the $T(s)$ filter $IMC_3(s)$, as proposed in Section 2.

In each case, the order n of $F_d(s)$ is chosen such that the controller is semi-proper.

For each IMC design case, the same value of the tuning parameter $\lambda=5$ is used. In this way, the comparison/analysis is enforced around the effects of the disturbance filter alone and not any other parameter from the tuning step.

3.1 The basic IMC controller

In this case, the IMC compensator has the form given in (3), with $F_n(s) = 1$ and $F_d(s) = (1 + 5s)^2$

$$IMC_1(s) = \frac{A(s) F_n(s)}{B_g(s) F_d(s)} = \frac{1+15s+50s^2}{2} \frac{1}{(1+5s)^2} \quad (25)$$

3.2 The IMC controller designed with the Diophantine equation, no $T(s)$ filter

In the absence of the $T(s)$ filter, $T(s)=1$, the following relation holds, computed based on (22):

$$x_0 t_0 = 1 \Rightarrow x_0 = 1 \quad (26)$$

The Diophantine equation in (19) becomes in this case:

$$\begin{aligned} 1 + f_1 s + f_2 s^2 + f_3 s^3 + f_4 s^4 &= \\ (x_0 + x_1 s + x_2 s^2) + & \\ (s^2 + \omega^2)(q_0 + q_1 s + q_2 s^2) & \end{aligned} \quad (27)$$

where f_1, f_2, f_3 and f_4 are computed according to:

$$1 + f_1 s + f_2 s^2 + f_3 s^3 + f_4 s^4 = (1 + 5s)^4 \quad (28)$$

yielding $f_1=20, f_2=150, f_3=500$ and $f_4=625$.

From (27), the following system of equations is obtained:

$$\begin{cases} 1 = x_0 + \omega^2 q_0 \\ f_1 = x_1 + \omega^2 q_1 \\ f_2 = x_2 + \omega^2 q_2 + q_0 \\ f_3 = q_1 \\ f_4 = q_2 \end{cases} \quad (29)$$

and the coefficients of the $F_n(s)$ filter are obtained:

$$\begin{cases} x_0 = 1 \\ x_1 = f_1 - \omega^2 f_3 = 0 \\ x_2 = f_2 - \omega^2 f_4 = 125 \end{cases} \quad (30)$$

The IMC controller is then:

$$IMC_2(s) = \frac{1+15s+50s^2}{2} \frac{(1+125s^2)}{(1+5s)^4} \quad (31)$$

3.3 The IMC controller designed with the Diophantine equation, with $T(s)$ filter

In this case, the Diophantine equation becomes:

$$\begin{aligned} 1 + f_1 s + f_2 s^2 + f_3 s^3 + f_4 s^4 + f_5 s^5 &= \\ (x_0 + x_1 s + x_2 s^2) + & \\ (s^2 + \omega^2)(q_0 + q_1 s + q_2 s^2 + q_3 s^3) & \end{aligned} \quad (32)$$

with the filter $T(s)$ as in (20) and x_0 as in (22). The coefficients f_1, f_2, f_3, f_4 and f_5 are computed from:

$$1 + f_1 s + f_2 s^2 + f_3 s^3 + f_4 s^4 + f_5 s^5 = (1 + 5s)^5 \quad (33)$$

yielding $f_1=25, f_2=250, f_3=1250, f_4=3125$ and $f_5=3125$.

From (31) the following system of equations is obtained:

$$\begin{cases} 1 = x_0 + \omega^2 q_0 \\ f_1 = x_1 + \omega^2 q_1 \\ f_2 = x_2 + \omega^2 q_2 + q_0 \\ f_3 = \omega^3 q_3 + q_1 \\ f_4 = q_2 \\ f_5 = q_3 \end{cases} \quad (34)$$

and the coefficients of the $F_n(s)$ filter are obtained:

$$\begin{cases} x_0 = \frac{1}{\cos(\omega\tau)} = \frac{1}{\cos(0.2\tau)} \\ x_1 = f_1 - \omega^2(f_3 - \omega^2 f_5) = -20 \\ x_2 = f_2 - \omega^2 f_4 - \frac{1-x_0}{\omega^2} = 125 - \frac{\cos(0.2\tau)-1}{0.04 \cos(0.2\tau)} \end{cases} \quad (35)$$

The IMC controller is then:

$$IMC_3(s) = \frac{1+15s+50s^2}{2} \frac{F_n(s)(\cos(0.2\tau) + \frac{\sin(0.2\tau)}{0.2}s)}{(1+5s)^5} \quad (36)$$

with the dead-time being either $\tau = 3$ or $\tau = 15$, as mentioned previously and the filter:

$$F_n(s) = \left(\frac{1}{\cos(0.2\tau)} - 20s + \left(125 - \frac{\cos(0.2\tau)-1}{0.04 \cos(0.2\tau)} \right) s^2 \right).$$

3.4 Simulation results

The closed loop disturbance rejection results considering the three controllers previously designed and a dead-time $\tau = 3$ and $\tau = 15$, are given in Fig. 3 and Fig. 4, respectively.

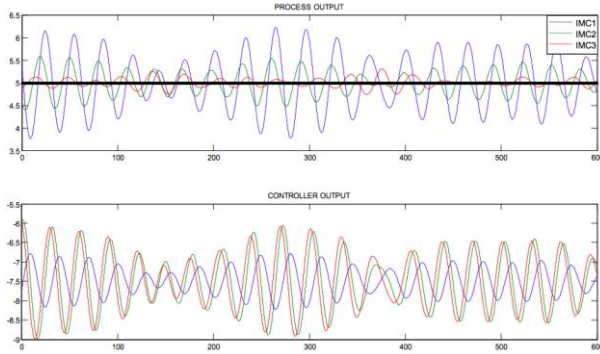


Fig. 3. Closed loop disturbance rejection results in case of $\tau = 3$

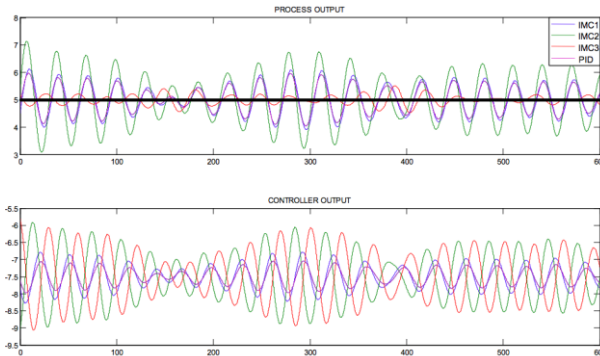


Fig. 4. Closed loop disturbance rejection results in case of $\tau = 15$

The simulation results indicate that the proposed design is effective, especially when using the $T(s)$ filter. Furthermore, in the case of delay dominant processes, i.e. when $\tau = 15$ in our example, the results from Fig.4. show that without the $T(s)$ filter are even worse than those obtained in the case of the IMC_1 (the basic compensator). For sake of completeness, a PID controller is also designed and the results are similar to the basic IMC compensator. The designed PID controller has a proportional gain $k_p=0.4$, an integral time constant $T_i=20$ and a derivative time constant $T_d=5$.

Overall, in both cases, the proposed design with the IMC compensator and the $T(s)$ filter proves to be the most effective in rejecting the disturbance signal.

4. ROBUSTNESS ANALYSIS

Consider now a higher order system described by the following transfer function:

$$P(s) = \frac{1}{(s+1)^6} \quad (37)$$

To mimic industrial practice, this high-order process will be approximated by a low-order model for IMC design:

$$\hat{P}(s) = \frac{1}{(1.7s+1)(2.2s+1)} e^{-2.2s} \quad (38)$$

with the parameters of (38) identified based on the process step-response from (37). These responses are similar, as depicted in Fig. 5.

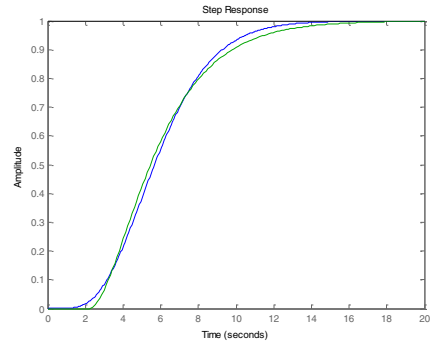


Fig. 5. Step response of the high order and the approximated system

The task is to design an IMC controller using the proposed method for a setpoint $W(s)=10$. The controller must also reject a stochastic disturbance signal with nonzero mean value -5 and main energy around frequency $\omega=0.5$ rad/s.

The model polynomials $A(s)$, $B_g(s)$ and $B_b(s)$, are:

$$\begin{aligned} A(s) &= (1.7s + 1)(2.2s + 1) \\ B_b(s) &= 1 \\ B_g(s) &= 1 \end{aligned} \quad (39)$$

Two designs of IMC will be compared, both based on the approximate model in (38):

- the basic IMC controller $IMC_1(s)$ and

- the IMC controller designed with the Diophantine equation, with the $T(s)$ filter $IMC_2(s)$.

In each case, the order n of $F_d(s)$ is chosen such that the compensator is semi-proper.

For each IMC design, the same value of the tuning parameter $\lambda=2$ is used.

4.1 The basic IMC controller

In this case, the IMC compensator has the form given in (3), with $F_n(s) = 1$ and $F_d(s) = (1 + 2s)^2$

$$IMC_1(s) = \frac{A(s) F_n(s)}{B_g(s) F_d(s)} = \frac{(1.7s+1)(2.2s+1)}{1} \frac{1}{(1+2s)^2} \quad (40)$$

4.2 The IMC controller designed with the Diophantine equation, with $T(s)$ filter

In this case, the Diophantine equation is the same as in (31), with f_1, f_2, f_3, f_4 and f_5 computed according to:

$$1 + f_1s + f_2s^2 + f_3s^3 + f_4s^4 + f_5s^5 = (1 + 2s)^5 \quad (41)$$

yielding $f_1=10, f_2=40, f_3=80, f_4=80$ and $f_5= 32$.

The same system of equations is obtained as in (32), with the following coefficients of the $F_n(s)$ filter:

$$\begin{cases} x_0 = \frac{1}{\cos(\omega\tau)} = \frac{1}{\cos(0.5 \cdot 2.2)} = 2.2 \\ x_1 = f_1 - \omega^2(f_3 - \omega^2 f_5) = -8 \\ x_2 = f_2 - \omega^2 f_4 - \frac{1-x_0}{\omega^2} = 24.82 \end{cases} \quad (42)$$

The IMC controller is then:

$$IMC_2(s) = \frac{(1.7s+1)(2.2s+1)}{1} \frac{(2.2-8s+24.82s^2)(0.45+1.78s)}{(1+2s)^5} \quad (43)$$

4.3. Simulation results

The closed loop disturbance rejection results are given in Fig. 6. The simulation results show that in comparison with the basic IMC, better disturbance rejection results are obtained. The proposed method is robust, even with an approximate process model, since the disturbance rejection remains highly effective.

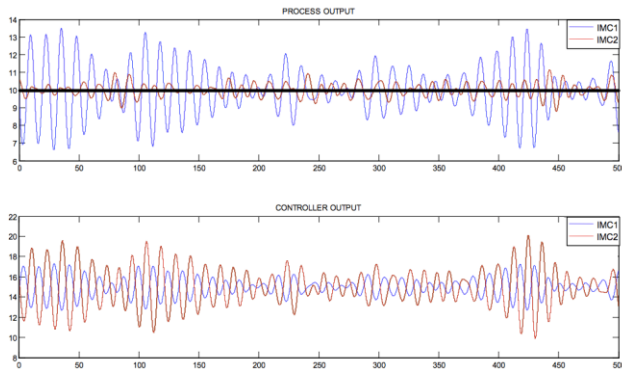


Fig. 6. Closed loop disturbance rejection results

5. CONCLUDING REMARKS

Dead-time processes are commonly encountered in industrial applications. All processes are subjected to stochastic disturbances, where their spectral energy can be considered as being concentrated around a specific frequency. In this context, a rationale has been presented in this paper to allow prediction of time delay at that specific frequency in the disturbance signal and thus improve significantly the ability to compensate its effects at the process output.

By means of two case studies, we demonstrate both the effectiveness in disturbance rejection, as well as the robustness to modelling errors. Comparisons with the basic IMC approach demonstrate the advantages of the proposed method.

In this paper was analyzed the performance in closed loop for disturbances of specific nature (i.e. sinusoidal). However, the same method can be applied for any kind of repetitive disturbances or stochastic disturbances with energy spectrum of the form in Fig.2 (i.e. from which some main frequency can be approximated).

Furthermore, for processes where sinusoidal references are desired, the proposed method with the specific filter design will allow perfect following without any time lag. This is enabled by an appropriate choice of the frequency in the $T(s)$ filter, i.e. to coincide with the frequency of the sinusoidal reference setpoint signal.

Further research includes the experimental validation of the proposed IMC filter, as well as some possible extensions of the proposed method that consider other disturbance models, step/ramp disturbances instead of stochastic ones and an analysis of the approach for set-point tracking. A multivariable approach, in a decentralized or decoupling control scheme, could also be considered as a further research approach.

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