# A NEW METHODOLOGY FOR THE REDESIGN OF SIMPLIFIED DECOUPLER FOR TITO PROCESS USING RELAY-BASED EXPERIMENT

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**Abstract**— In this paper the decoupling control with simplified structure of two-inputs two-outputs (TITO) processes is considered. A new decoupler redesign methodology to reach effective decoupling at a frequency interval of interest is proposed. Simulation examples are used to illustrate the methodology.

**Keywords**— Decoupling Control, Simplified Decouplers, Relay Experiment

**Resumo**— Neste trabalho, o controle desacoplado com estrutura simplificada para processos com duas-entradas duas-saídas (TITO) é considerado. Uma nova metodologia de reprojeto de desacopladores para alcançar o desacoplamento efetivo num intervalo de frequência de interesse é proposta. Exemplos simulados são usados para ilustrar a metodologia.

**Palavras-chave**— Controle com Desacoplamento, Desacoplador Simplificado, Experimento do Relé

## 1 INTRODUCTION

Most industrial processes are multi-input/multi-output (MIMO). In such process the interactions between inputs and outputs make multiloop control difficult. Thus, many multivariable control approaches, mainly using model-predictive control, has been proposed. Although it offers satisfactory performance, it is applied to provide setpoints for regulator-level, PI/PID based control, (Nordfeldt and Hägglund, 2006).

PI/PID based control for multivariable processes can generally be classified into two main groups: descentralized control and decoupling control. Descentralized control consists a set of single-input/single-output (SISO) controllers which are designed for each loop by taking interations into account. When loop interations are modest it is normally adequate. Nevertheless, descentralized control may fail to give acceptable responses if there exist severe loop interations. In order to overcome this problem, decoupling control scheme can be adopted.

In decoupling control scheme a decoupler $\mathbf{D}(s)$ is introduced between the descentralized controller $C(s)$ and a MIMO process $\mathbf{G}(s)$ to minimize the effect of undesirable loop interactions. This makes the resulting system $\mathbf{G}(s)\mathbf{D}(s)$, namely decoupled system, diagonal dominant. Thus, the decoupled system can be handled as multiple SISO system and a less conservative single-loop control design methods can be directly applied (Cai et al., 2008). The decoupler combined with the descentralized controller constitute the multivariable controller.

The basic structures for dynamic decoupler design can be classified into: (i) ideal decoupling, (ii) simplified decoupling and (iii) inverted decoupling. A comparison between these structures is presented in Gagnon et al. (1998) and in Naik et al. (2017). Among these the simplified decoupling is more popular because of its simplicity in design. In Wu et al. (2017) is demonstrated the advantage of Active Disturbance Rejection Control (ADRC) based simplified decoupling.

The decoupler design is usually based on simplified models of the actual process, so it becomes effective only at the frequencies where the model is accurate. A methodology to evaluate dynamic simplified decoupling for TITO processes and to redesign it to be effective in the frequency of interest for control is proposed in Acioli Júnior and Barros (2011). In this methodology, the evaluation and redesign consider only the frequency where the phase of each direct loop (ex. $G_{11}$) is $-90^o$ ($\omega_{90}$). In Acioli Júnior and Barros (2012) is presented an application of this methodology in a TITO laboratory-scale thermal process.

In this paper, the aim is propose a new methodology to redesign the simplified decoupler. It is an improvement an the methodology proposed in Acioli Júnior and Barros (2011). For this purpose the redesign equations are rewritten in order to consider a frequency interval. Thus, an initial simplified decoupler is designed using a estimated first-order plus dead time (FOPDT) model. Here the decoupling delay is disregarded due to the difficulty of implementation in the programmable logic controller (PLC), where the control logic and the decoupler are to be implemented. The simplified decoupler is evaluation using relay-based experiment. There, one find the error index at two frequency points that will be used for the evaluation and redesign, using the least square algorithm.

The paper is organized as follows. In section II, the problem statement is presented. The initial decoupler design is present in section III. In section IV, the simplified decoupler evaluation method is presented. The simplified decoupler redesign technique is proposed in section V. In section VI, the simulation result is discussed. The conclusion is presented in section VII.

## 2 THE PROBLEM STATEMENT

Consider a TITO process $\mathbf{G}(s)$:

$$\mathbf{G}(s) = \begin{bmatrix} G_{11}(s) & G_{12}(s) \\ G_{21}(s) & G_{22}(s) \end{bmatrix}. \tag{1}$$

The model used to design the decoupler is the estimated FOPDT model:

$$\hat{\mathbf{G}}(s) = \begin{bmatrix} \frac{K_{11}}{T_{11}s+1}e^{-sL_{11}} & \frac{K_{12}}{T_{12}s+1}e^{-sL_{12}} \\ \frac{K_{21}}{T_{21s+1}}e^{-sL_{21}} & \frac{K_{22}}{T_{22}s+1}e^{-sL_{22}} \end{bmatrix}. \tag{2}$$

Given the model, the decoupler $\mathbf{D}(s)$ must be designed so that $\mathbf{G}(s)\mathbf{D}(s)$ is diagonally dominant. Considering the simplified structure, the initial decoupling is given by:

$$\mathbf{D}(s) = \begin{bmatrix} 1 & -\frac{\hat{G}_{12}(s)}{\hat{G}_{11}(s)} \\ -\frac{\hat{G}_{21}(s)}{\hat{G}_{22}(s)} & 1 \end{bmatrix}. \tag{3}$$

A general control scheme with simplified decoupling is shown in Fig. 1.

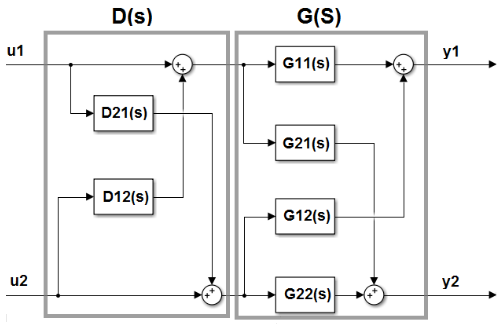


Figure 1: TITO System with Simplified Decoupler

An effective dynamic decoupling is not achieved due to model mismatch in the decoupler design.

The problem statement is: given an estimated TITO FOPDT model $\hat{\mathbf{G}}(s)$, 1) design an initial simplified decoupler $\mathbf{D}^0(s)$, 2) the decoupled system $\mathbf{G}(s)\mathbf{D}^0(s)$ will be experimentally evaluated at frequency interval using a relay-based experiment and 3) if necessary, the decoupler is redesigned to achieve effective decoupling.

## 3 INITIAL DECOUPLER DESIGN

In this section the initial decoupler design is presented.

**Lemma 1** *Consider an estimated FOPDT model (2), the initial decoupler given by:*

$$\boldsymbol{D}^0 = \begin{pmatrix} 1 & D_{12}^0 \\ D_{21}^0 & 1 \end{pmatrix}, \tag{4}$$

*where:*

$$D_{12}^0(s) = -\frac{K_{12}(T_{11}s+1)}{K_{11}(T_{12}s+1)}, \tag{5}$$

$$D_{21}^0(s) = -\frac{K_{21}(T_{22}s+1)}{K_{22}(T_{21}s+1)}. \tag{6}$$

**Proof:** Considering the simplified structure show in Fig. 1, the resultant system $\mathbf{H}(s) = \mathbf{D}(s)\mathbf{G}(s)$ is given by:

$$\mathbf{H}(s) = \begin{bmatrix} G_{11} + G_{12}D_{21} & G_{11}D_{12} + G_{12} \\ G_{21} + G_{22}D_{21} & G_{21}D_{12} + G_{22} \end{bmatrix}. \tag{7}$$

Since $\mathbf{H}(s)$ must be diagonal, then the terms of the off-diagonal must be null, that is, $G_{11}(s)D_{12}(s) + G_{12}(s) = 0$ and $G_{22}(s)D_{21}(s) + G_{21}(s) = 0$, then:

$$D_{12}(s) = -\frac{G_{12}(s)}{G_{11}(s)}, \tag{8}$$

$$D_{21}(s) = -\frac{G_{21}(s)}{G_{22}(s)}. \tag{9}$$

□

Note that the delay was not considered in equations 5 and 6, because it has the dificult implementation in PLC, where the control logic and the decoupler are implemented.

## 4 DECOUPLER EVALUATION

In this section the decoupler evaluation procedure is presented.

### *4.1 Decoupler Evaluation Excitation*

To evaluate the initial decoupler an excitation is applied to $\mathbf{G}(s)\mathbf{D}^0(s)$. The evaluation should be done considering frequency interval between $\omega_{90}^i$ and $\omega_{90}^i/4$, where $\omega_{90}^i$ is the frequency at which the phase of each direct loop is $-90°$. Thus the excitation choose is a relay-90 plus pulse, that is, a square wave with frequency $\omega_{90}^i$ plus pulse with width equal 3 periods of the square wave. The frequency $\omega_{90}^i$ was obtained from the model.

The decoupler evaluation excitation is illustrated by the curves shown in Fig. 2. For each loop ($u_1 - y_1$ and $u_2 - y_2$) the excitation is sequentially applied. For each direct loop (ex. $G_{11}$) $N_{ii}$ (appropriate $N_{ii} = 3$) periods of a square wave with frequency $\omega_{90}^i$ (ex. $\omega_{90}^1$) plus pulse is applied at the opposite input (ex. $u_2$) and the decoupler term is evaluated (ex. $D_{12}$).

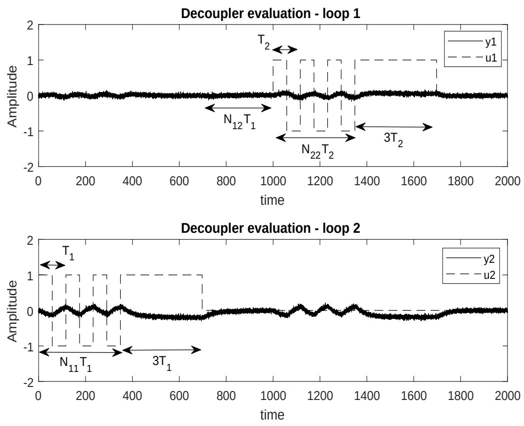


Figure 2: Decoupler Evaluation Excitation

### 4.2 Decoupler Evaluation Equation

Consider the TITO system with initial decoupler shown in Fig. 1. Applying the decoupler evaluation excitation at the input $u_2$, an input/output relation is given by:

$$\frac{Y_1(s)}{U_2(s)} = G_{12}(s) + G_{11}(s)D_{12}^0(s), \quad (10)$$

and applying the decoupler evaluation excitation at the input $u_1$:

$$\frac{Y_2(s)}{U_1(s)} = G_{21}(s) + G_{22}(s)D_{21}^0(s). \quad (11)$$

Based on (10) and (11) can define the simplified decoupling error index equation.

Definition 1: The simplified decoupling error index at frequency $\omega^i$ for the loop $i$ is defined by equation:

$$H_i(j\omega^i) = G_{ij}(j\omega^i) + G_{ii}(j\omega^i)D_{ij}^0(j\omega^i), \quad (12)$$

where $i, j = 1, 2$ and $i \neq j$.

If the error index is not approximated to zero, the simplified decoupler is redesigned.

## 5 DECOUPLER REDESIGN

The simplified decoupling redesign is done to achieve effective decoupling at frequencies interval where the initial decoupler was evaluated. For effective decoupling at frequency the following equation must be satisfied:

$$G_{ij}(j\omega^i) + G_{ii}(j\omega^i)D_{ij}^1(j\omega^i) \approx 0, \quad (13)$$

where $D_{ij}^1$ is the redesigned of $D_{ij}^0$ and the decoupler term is given by:

$$D_{ij}^{0,1}(j\omega^i) = \bar{K}_i^{0,1}\frac{(j\omega^i T_{ii}^{0,1} + 1)}{(j\omega^i T_{ij}^{0,1} + 1)}. \quad (14)$$

Definition 2: The simplified decoupling redesign equation for loop $i$ is given by:

$$[D_{ij}^1(j\omega^i) - D_{ij}^0(j\omega^i)] = \frac{-H_i(j\omega^i)}{G_{ii}(j\omega^i)}, \quad (15)$$

where $i, j = 1, 2$ and $i \neq j$.

For an effective decoupling the decoupled term $D_{ij}^1$ must meet the redesign equation (15) and the parameters $\bar{K}_i^1$, $T_{ii}^1$ and $T_{ij}^1$ can be modified in respect to $\bar{K}_i^0$, $T_{ii}^0$ and $T_{ij}^0$. Three redesign possibilities are defined. Case 1 is the arithmetic mean of the calculated gains for each frequency. Cases 2 and 3 are solved using mean least square algorithm. Here will be denoted $\omega_1^i = \omega_{90}^i$ and $\omega_2^i = \omega_{90}^i/4$.

### 5.1 Case 1

In case 1, only the gain $\bar{K}_i^1$ is modified for each decoupling term.

**Lemma 2** *The redesign gain $\bar{K}_i^1$ is given by:*

$$\bar{K}_i^1 = [(\Delta\bar{K}_i(\omega_1^i) + \Delta\bar{K}_i(\omega_2^i))/2] + \bar{K}_i^0. \quad (16)$$

**Proof:** Substituting (14) into (15), the gain must be modified as:

$$\Delta\bar{K}_i = real\left(-H_i\frac{(j\omega^i T_{ij} + 1)}{\bar{K}_{ii}e^{-j\omega^i L_{ii}}}\right), \quad (17)$$

where $\Delta\bar{K}_i = (\bar{K}_i^1 - \bar{K}_i^0)$, $i, j = 1, 2$ and $i \neq j$. Substituting, in the equation 17, $\omega^i$ for $\omega_{90}^i$ and $\omega_{90}^i/4$ obtain two $\Delta\bar{K}_i^1$. So calculating the arithmetic mean the two $\Delta\bar{K}_i^1$ and knowing that $\Delta\bar{K}_i = (\bar{K}_i^1 - \bar{K}_i^0)$, find the value of $\bar{K}_i^1$. □

### 5.2 Case 2

In case 2, to loop $i$ the gain $\bar{K}_i^1$ and the time constant $T_{ij}^1$ are changed.

**Lemma 3** *The redesign equation to case 2 is given by:*

$$\bar{K}_i^1(j\omega^i T_{ij} + 1) + T_{ij}^1(\Upsilon_i) = \Gamma_i, \quad (18)$$

*where*

$$\Upsilon_i = \left(-\bar{K}_i^0 j\omega^i + \frac{H_i((j\omega^i)^2 T_{ij} + j\omega^i)}{\bar{K}_{ii}e^{-j\omega^i L_{ii}}}\right), \quad (19)$$

$$\Gamma_i = \bar{K}_i^0 - \frac{H_i(j\omega^i T_{ij}+1)}{\bar{K}_{ii}e^{-j\omega^i L_{ii}}}. \quad (20)$$

*Thus, $\bar{K}_i^1$ and $T_{ij}^1$, considering the frequency interval, are given by solving the linear regression:*

$$\begin{bmatrix} (\omega_1^i T_{ij}) & Imag(\Upsilon_i)_{\omega_1^i} \\ 1 & Real(\Upsilon_i)_{\omega_1^i} \\ (\omega_2^i T_{ij}) & Imag(\Upsilon_i)_{\omega_2^i} \\ 1 & Real(\Upsilon_i)_{\omega_2^i} \end{bmatrix} \begin{bmatrix} \bar{K}_i^1 \\ T_{ij}^1 \end{bmatrix} = \begin{bmatrix} Imag(\Gamma_i)_{\omega_1^i} \\ Real(\Gamma_i)_{\omega_1^i} \\ Imag(\Gamma_i)_{\omega_2^i} \\ Real(\Gamma_i)_{\omega_2^i} \end{bmatrix}. \quad (21)$$

**Proof:** Substituting (14) into (15):

$$\left[\frac{\bar{K}_i^1(j\omega^i T_{ij}+1) - \bar{K}_i^0(j\omega^i T_{ij}^1+1)}{(j\omega^i T_{ij}^1+1)(j\omega^i T_{ij}+1)}\right] = \frac{-H_i}{\bar{K}_{ii}e^{-j\omega^i \tau_{ii}}}, \quad (22)$$

$$\bar{K}_i^1(j\omega^i T_{ij}+1) + T_{ij}^1(\Upsilon_i) = \Gamma_i. \quad (23)$$

□

### 5.3 Case 3

In case 3, the gain $\bar{K}_i^1$ and the time constant $T_{ii}^1$ are modified.

**Lemma 4** *The redesign equation to case 3 is given by:*

$$\bar{K}_i^1 + T_{ii}^1\bar{K}_i^1 j\omega^i = \Psi_i, \quad (24)$$

*where*

$$\Psi_i = \left[\frac{-H_i(j\omega^i)}{G_{ii}(j\omega^i)} + D_{ij}^0(j\omega^i)\right](j\omega^i T_{ij}+1). \quad (25)$$

*Thus, $\bar{K}_i^1$ and $T_{ii}^1$, considering the frequency interval, are given by solving the linear regression:*

$$\begin{bmatrix} 0 & \omega_1^i \\ 1 & 0 \\ 0 & \omega_2^i \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \bar{K}_i^1 \\ T_{ii}^1\bar{K}_i^1 \end{bmatrix} = \begin{bmatrix} Imag(\Psi_i)_{\omega_1^i} \\ Real(\Psi_i)_{\omega_1^i} \\ Imag(\Psi_i)_{\omega_2^i} \\ Real(\Psi_i)_{\omega_2^i} \end{bmatrix}. \quad (26)$$

**Proof:** Substituting (14) into (15) is obtained the equation 27:

$$\frac{\bar{K}_i^1(j\omega^i T_{ii}^1+1)}{(j\omega^i T_{ij}+1)} - D_{ij}^0(j\omega^i) = \frac{-H_i(j\omega^i)}{G_{ii}(j\omega^i)} \quad (27)$$

thus,

$$\bar{K}_i^1 + T_{ii}^1\bar{K}_i^1 j\omega^i = \Psi_i. \quad (28)$$

□

## 6 SIMULATION RESULTS

In this section a new methodology to redesign decouplers for TITO process is applied. For each example, the initial decoupler is evaluated and the redesigned. The step response of the decoupled system and mean square error (time) is used to compare the methodology proposed with the presented in Acioli Júnior and Barros (2011), here called Method 1 and Method 2, respectively.

Table 1: Modified Parameters in Decoupler Terms - Example 1

| | $K_1$ | $T_{11}$ | $T_{12}$ |
|---|---|---|---|
| Initial | 1.4928 | 16.6139 | 21.0599 |
| Case 1 | 1.4777 | - | - |
| Case 2 | 0.9859 | - | 14.0775 |
| Case 3 | 2.2599 | 10.0755 | - |
| | $K_2$ | $T_{22}$ | $T_{21}$ |
| Initial | 0.3338 | 14.4541 | 10.6242 |
| Case 1 | 0.3314 | - | - |
| Case 2 | 0.3851 | - | 13.4826 |
| Case 3 | 0.3972 | 10.9239 | - |

Table 2: Time Domain Decoupling Error Index - Example 1

| | Method 1 | | Method 2 | |
|---|---|---|---|---|
| | $\varepsilon_1$ | $\varepsilon_2$ | $\varepsilon_1$ | $\varepsilon_2$ |
| Case 1 | 0.9812 | 0.0429 | 1.8118 | 0.0302 |
| Case 2 | 19.9860 | 0.1565 | 2441.7 | 3465.3 |
| Case 3 | 45.9389 | 0.2251 | 174.0365 | 0.8345 |

### 6.1 Example 1

The Wood-Berry (Wood and Berry, 1973) binary distillation column process estimaded TITO FOPDT model is given by (Acioli Júnior, 2012):

$$\hat{\mathbf{G}}(s) = \begin{bmatrix} \frac{12.693e^{-1.009s}}{(16.614s+1)} & \frac{-18.949e^{-2.988s}}{(21.06s+1)} \\ \frac{6.498e^{-7.053s}}{(10.624s+1)} & \frac{-19.465e^{-2.986s}}{(14.454s+1)} \end{bmatrix}. \quad (29)$$

Thus, the initial decoupler designed is given by:

$$\mathbf{D}^0(s) = \begin{bmatrix} 1 & \frac{1.493(16.614s+1)}{(21.06s+1)} \\ \frac{0.334(14.454s+1)}{(10.624s+1)} & 1 \end{bmatrix}. \quad (30)$$

The evaluation excitation frequencies are given by: $\omega_1^1 = 0.246$, $\omega_1^2 = 0.138$, $\omega_2^1 = 0.0615$ and $\omega_2^2 = 0.0345$. The modified parameters for decoupler terms in each redesign are shown in Table 1.

The step response decoupler system is shown in Figs. 3 and 4. The mean square error is shown in Table 2. In this example, can observe that in the case 2 the Method 2 had not a satisfactory result.

### 6.2 Example 2

Consider the Wardle-Wood (Luyben, 1986) column process. The estimaded TITO FOPDT model is given by (Acioli Júnior, 2012):

$$\hat{\mathbf{G}}(s) = \begin{bmatrix} \frac{0.123e^{-6.07s}}{(58.55s+1)} & \frac{-0.108e^{-28.53s}}{(123.51s+1)} \\ \frac{0.092e^{-8.16s}}{(36.84s+1)} & \frac{-0.12e^{-8.03s}}{(34.9s+1)} \end{bmatrix}. \quad (31)$$

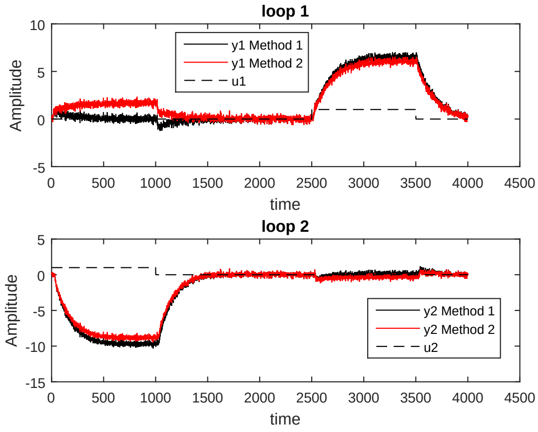


Figure 3: Case 1 - Example 1

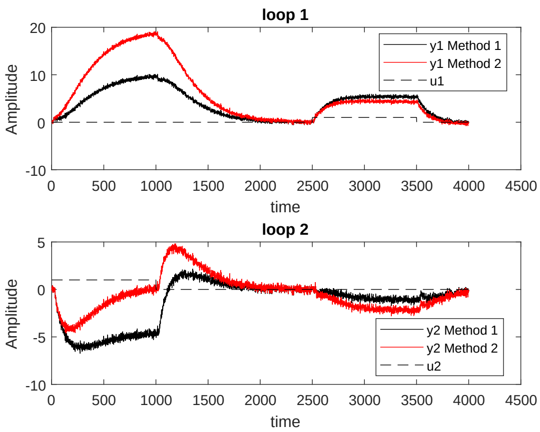


Figure 4: Case 3 - Example 1

Thus, the initial decoupler designed is given by:

$$\mathbf{D}^0(s) = \begin{bmatrix} 1 & \dfrac{0.8780(58.55s+1)}{(123.51s+1)} \\ \dfrac{0.7667(34.9s+1)}{(36.84s+1)} & 1 \end{bmatrix}. \tag{32}$$

The evaluation excitation frequencies are given by: $\omega_1^1 = 0.054$, $\omega_1^2 = 0.054$, $\omega_2^1 = 0.0135$ and $\omega_2^2 = 0.0135$. The modified parameters for decoupler terms in each redesign are shown in Table 1.

The step response decoupler system is shown in Figs. 5 and 6. The mean square error is shown in Table 4. In this example, can observe that in the case 2 the Method 2 had not a satisfactory result.

### *6.3 Example 3*

The estimaded TITO FOPDT model for Tavakoli (Tavakoli et al., 2006) distillation methanol-ethanol process is given by

Table 3: Modified Parameters in Decoupler Terms - Example 2

| | $K_1$ | $T_{11}$ | $T_{12}$ |
|---|---|---|---|
| Initial | 0.8780 | 58.55 | 123.51 |
| Case 1 | 0.3968 | - | - |
| Case 2 | -0.1024 | - | 0.7527 |
| Case 3 | 1.7838 | -13.8114 | - |
| | $K_2$ | $T_{22}$ | $T_{21}$ |
| Initial | 0.7667 | 34.9 | 36.84 |
| Case 1 | -0.7241 | - | - |
| Case 2 | -0.5143 | - | 18.2132 |
| Case 3 | -0.4337 | 67.8883 | - |

Table 4: Time Domain Decoupling Error Index - Example 2

| | Method 1 | | Method 2 | |
|---|---|---|---|---|
| | $\varepsilon_1$ | $\varepsilon_2$ | $\varepsilon_1$ | $\varepsilon_2$ |
| Case 1 | 0.0012 | 0.0003 | 0.0011 | 0.0004 |
| Case 2 | 0.0025 | 0.0004 | 1.2550 | $5 \cdot 10^9$ |
| Case 3 | 0.0013 | 0.0008 | 0.9510 | 0.0319 |

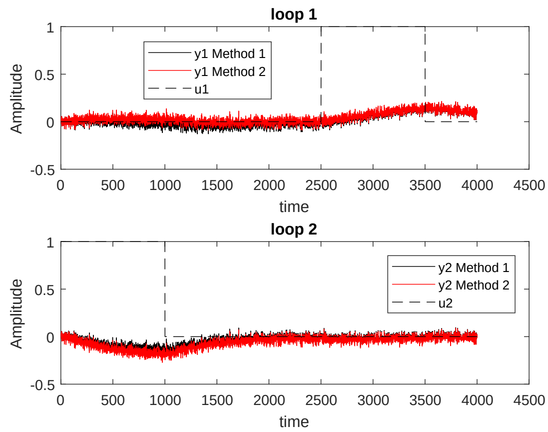


Figure 5: Case 1 - Example 2

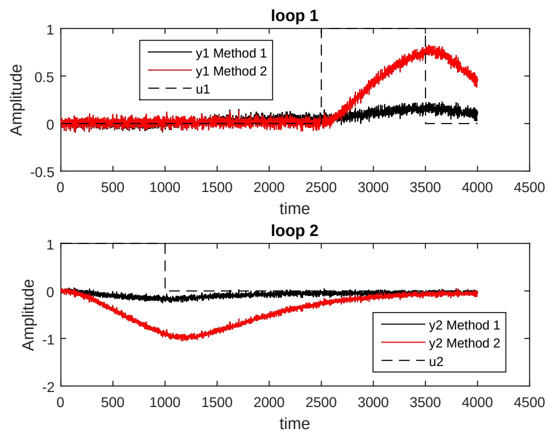


Figure 6: Case 3 - Example 2

(Acioli Júnior, 2012):

$$\hat{\mathbf{G}}(s) = \begin{bmatrix} \dfrac{0.474e^{-15.39s}}{(55.22s+1)} & \dfrac{0.4999e^{-16.09s}}{(45.82s+1)} \\ \dfrac{0.797e^{-23.63s}}{(136.72s+1)} & \dfrac{-0.8424e^{-25.36s}}{(89.05s+1)} \end{bmatrix}. \tag{33}$$

Table 5: Modified Parameters in Decoupler Terms - Example 3

| | $K_1$ | $T_{11}$ | $T_{12}$ |
|---|---|---|---|
| Initial | -1.0527 | 55.22 | 45.82 |
| Case 1 | -1.0132 | - | - |
| Case 2 | -0.9967 | - | 45.342 |
| Case 3 | -1.0197 | 53.0188 | - |
| | $K_2$ | $T_{22}$ | $T_{21}$ |
| Initial | 0.9561 | 89.05 | 136.72 |
| Case 1 | 1.0991 | - | - |
| Case 2 | 0.9921 | - | 111.302 |
| Case 3 | 1.1863 | 95.4578 | - |

Table 6: Time Domain Decoupling Error Index - Example 3

| | Method 1 | | Method 2 | |
|---|---|---|---|---|
| | $\varepsilon_1$ | $\varepsilon_2$ | $\varepsilon_1$ | $\varepsilon_2$ |
| Case 1 | 0.0011 | 0.0121 | 0.0011 | 0.0132 |
| Case 2 | 0.0011 | 0.0149 | 0.0011 | 0.0131 |
| Case 3 | 0.0011 | 0.0130 | 0.0011 | 0.0134 |

Thus, the initial decoupler designed is given by:

$$\mathbf{D}^0(s) = \begin{bmatrix} 1 & \frac{-1.0527(55.22s+1)}{(45.82s+1)} \\ \frac{0.9561(89.05s+1)}{(136.72s+1)} & 1 \end{bmatrix}. \quad (34)$$

The evaluation excitation frequencies are given by: $\omega_1^1 = 0.031$, $\omega_1^2 = 0.019$, $\omega_2^1 = 0.0077$ and $\omega_2^2 = 0.0047$. The modified parameters for decoupler terms in each redesign are shown in Table 5.

The error index is shown in Table 6. In this example, can observe that redesign methods presented similar results.

## 7 CONCLUSION

In this paper a new methodology to redesign simplified decouplers for TITO process using relay plus pulse experiment was presented. Three decoupler redesign cases are defined. The delay of decoupler was disregarded. This methodology was compared with the presented in (Acioli Júnior and Barros, 2011). It can be observed that with the proposed methodology the redesigned decoupler is more effective than using the method present in (Acioli Júnior and Barros, 2011), especially in the case 2.


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