Non-invasive Identification of Servo Drive Parameters

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Abstract:
For the tuning of servo controllers as well as for monitoring functions, significant parameters of the controlled system are required. In contrast to identification methods with determined input signals, the paper focuses on the problem of identification with regular process movements (non-invasive identification), leading to a lack of power density in some frequency ranges. A nonlinear Least Squares (LS) approach with single mass system and friction characteristic is investigated regarding the accomplishable accuracy and necessary constraints. The proposed method is applicable on industrial motion controllers and has been carried out with a multitude of input sequences. To verify the performance of the approach, achieved experimental results for the model parameters are exposed.

Keywords: *Identification, Parametric Model, Natural Excitation, Least Squares Method, SIMOTION*

1. Introduction

With an increasing number of installed position controlled servo drives in production machines and machine tools, the importance of parameter identification grows as well. The optimal setting and adoption of controller parameters requires automatic strategies, which again need informative models. Consequently, a wide range of identification methods from control engineering was adjusted to the needs of drive control [1, 2]. This paper focuses on the field of non-invasive (i.e. not interfering with the process) parameter identification and explores the possibility of using regular movements of the servo drives, so called "natural excitations" [2]. Hence, a non-invasive, online capable approach is presented in the following chapter. In addition, experimental results with a variety of input signals are shown in section 3. Furthermore one possible approach for excitation detection is discussed in the 4th chapter. The paper is closed with some conclusions.

2. Non-invasive parameter identification in drive control

In contrast to identification with determined test signals, there is a need for the identification of plant parameters during regular operation of machine tools or production machines. Consequently, established identification methods have to be explored, whether they provide convenient results despite the insufficiency of only natural excitation. Another fact to consider is the online capability of the approaches for industrial motion controllers or numerical controllers.

For the example of the velocity control loop of a cascaded position control (Fig. 1), [2] and [3] compare the applicability of extended Kalman Filters and Basis Function Networks. Furthermore, [4] presents an identification approach for mechanical systems, where a Least Squares method is used. Although it is combined with a Pseudo Random Binary Signal (PRBS) excitation, it seems promising to consider this method for non invasive identification as well.

Generally it is not necessary to take high model orders into account for non-invasive identification after a model structure choice and complete parameter estimation during commissioning. In truth it is worthwhile to narrow the models down to significant parameters. This concurs with several publications, where only a single mass system (characterized by a total moment of inertia) and a friction model are taken into account for the chosen example [4, 5, 6].

According to [2] there is a limitation in the non-invasive identification quality for higher order models. Hence, a single mass system with a total moment of inertia (J_{tot}) and a friction characteristic, consisting of a constant friction moment (M_{RC}) and a speed depending friction coefficient (μ_R) is chosen (Fig. 2).

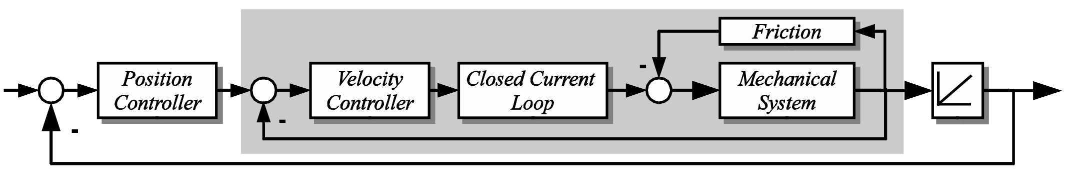

Fig. 1. Cascaded position control with velocity loop (grey)

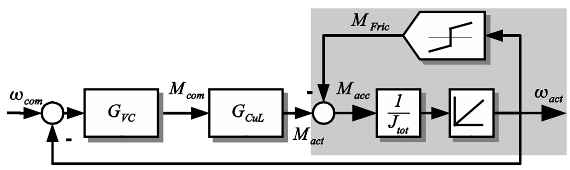

Fig. 2. Scheme of the velocity loop [9] with:
ω_{com}... command velocity, ω_{act}... actual velocity,
M_{com}... command torque, M_{act}... actual torque,
M_{fric}... friction torque, C_{VC}... velocity controller,
G_{CuL}... closed current loop

Table 1. Variety of input sequences

Input sequence	Controller setting G_{VC}			Time period [ms]	Magnitude [1/ min]	Offset
	Nr.	KP [Nm s/rad]	TN [ms]			
Rectangle	1	1,309	6,85	100 ms	50	0
Stairs	2	0,8	20		250	2 x Magnitude
Sinus	3	0,3	50	300ms	500	3 x Magnitude
Trapezoid						

$$\dot{\omega}_{act} = \frac{1}{J_{tot}} \cdot (M_{act} - M_{fric}) = \frac{1}{J_{tot}} \cdot (M_{act} - M_{RC} \cdot sign(\omega_{act}) - \mu_R \cdot \omega_{act}) \tag{1}$$

With respect to the intended online capability of the identification procedure, the introduced parametric model will be combined with the LS method. For the realization, equation (1) has to be discretizised with the sample time T_{sample}. The resulting difference equation (2) with parameters (3) and (4) is further transformed to match the nomenclature of [1] (5). Notice that the parameters a_1 and b_1 still depend on J_{tot} and μ_R directly:

$$n_{act}(k) + a_1 \cdot n_{act}(k-1) = b_1 \cdot \left[M_{act}(k-1) - M_{RC} \cdot sign(n_{act}(k-1))\right] \tag{2}$$

with:

$$a_1 = -e^{\frac{-\mu_R \cdot T_{sample} \cdot 60}{J_{tot} \cdot 2\pi}} \tag{3}$$

$$b_1 = \frac{1}{\mu_R} \cdot (1 + a_1) \tag{4}$$

$$y(k) = -a_1 \cdot y(k-1) + b_1 \cdot \left[u(k-1) - M_{RC} \cdot sign(y(k-1))\right] \tag{5}$$

This leads to the description of the LS problem with a data vector ψ and a parameter vector Θ:

$$\psi^T(k) = \left[-y(k-1)\; u(k-1)\; sign(y(k-1))\right] \tag{6}$$

$$\Theta^T = \left[a_1 \quad b_1 \quad b_1 \cdot M_{RC}\right] \tag{7}$$

With this definition, the LS problem is carried out recursively [1]. The calculation is feasible on industrial controllers due to the relatively small order of the resulting matrices (max. 3).

3. Identification Results

Experimental results were obtained on a test rig with known moment of inertia, which is equipped with an industrial motion controller SIMOTION with a sample time of 500 µs (Fig. 3).

Despite the aspired non-invasiveness of the presented identification approach, test signals were used to investigate and develop the method. On the one hand, this is done to evaluate the performance of the identification technique and to locate minimum requirements, detached from a restricting case of application. On the other hand,

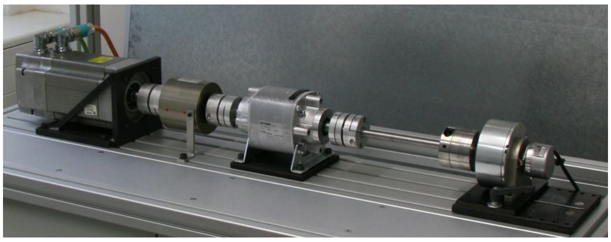

Fig. 3. Test rig with known moment of inertia

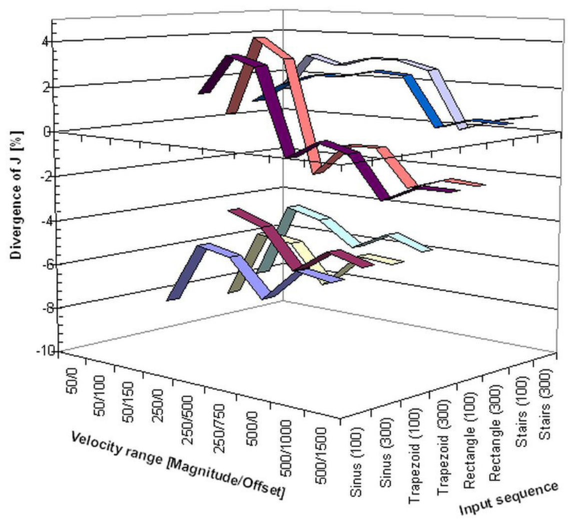

Fig. 4. Identification results for the moment of inertia J_{tot} with velocity controller setting 1

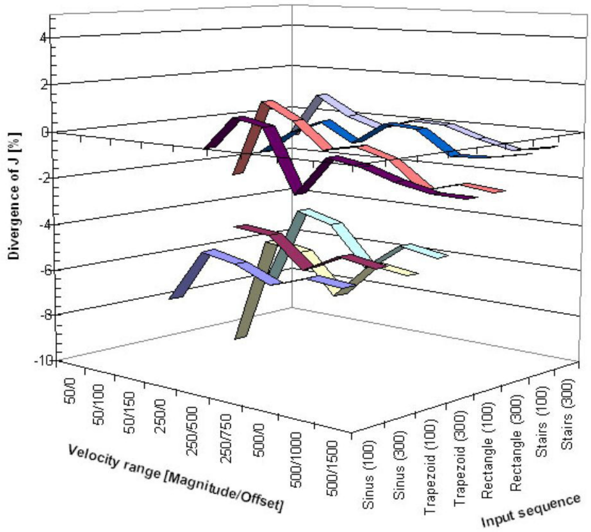

Fig. 5. Identification results for the moment of inertia J_{tot} with velocity controller setting 2

it allows a comparison of the accuracy of the approach with other invasive identification methods. The experimental results in this chapter are based on variety of input sequences (Table 1).

The identification procedure is started in a phase of acceleration or deceleration of the drive, when a minimum value of torque (20% of the nominal torque) is present. Consequently, some experiments do not lead to any results due to the lack of excitation. Filtering of the input and output signals with the same filter helps to improve the accuracy [1, 2, 4]. Hence, the identification approach was extended by a moving average filter with the length of 5 elements. The main focus is the determination of the total moment of inertia J_{tot}, which is displayed in the Figures 4 and 5.

It is noticeable, that the shape of the input sequence has the biggest influence to the accuracy, followed by the present velocity controller setting. Another fact is that all experiments with a velocity offset lead to discrepancies of less than five percent. The biggest divergence is about -10%, while 86% of the experiments provide results with a divergence less than ±5%, which is a typical value for invasive identification as well.

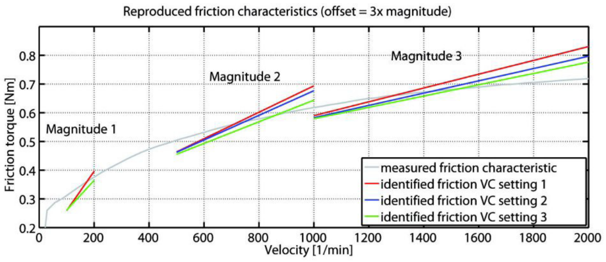

Fig. 6. Identification results for the friction parameters

The Results for the identification of friction parameters are displayed in figure 6. The presented curves result from the reproduction of the friction characteristic based on the estimated parameters M_{RC} and μ_R. Notice, that the identification results for those values are only relevant for the specific velocity range of the process movement. For a better illustration, three experiments with rectangular input sequences and the introduced magnitudes 1-3 (Table 1) were combined in Figure 6. Additionally, a measured friction characteristic was included for verification. The identified characteristics match the measured curve in the linearization points, but vary towards lower or higher velocity values. A more precise image of the friction in the mechanical system could be issued by carrying out further movements in different velocity ranges.

4. Excitation detection

A second aspect in developing a non invasive identification procedure is the detection of suitable process excitation. The multitude of experimental results provides a basis for finding an adequate criterion. One promising approach is the analysis of the power density spectra S_{uu}. They are computed by fourier transforming the autocorrelation Φ_{uu} of each input sequence signal (with the length N) according to equations 8 and 9 [4]. One example is displayed in Figure 7 whereat the discrete vector S_{uu} is converted and plotted over frequencies.

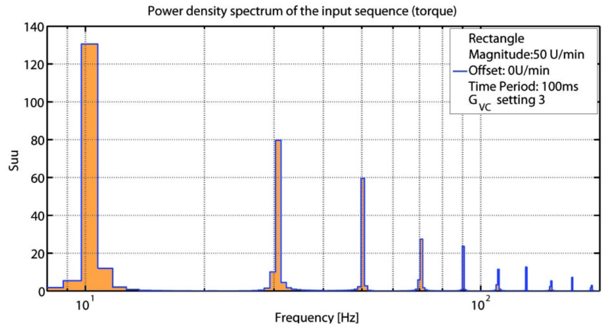

Fig. 7. Power density spectrum of a rectangular input sequence

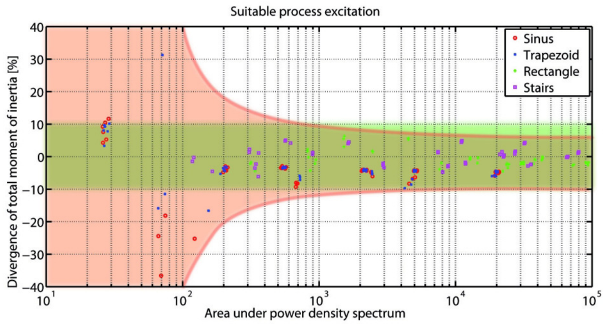

Fig. 8. Divergence of moment of inertia over power density area A_{SUU}

$$\Phi_{uu}(\tau) = \left\{ \frac{1}{N} \cdot \sum_{k=1}^{N-\tau} u(k) \cdot u(k+\tau) \right\} \; for\; 1 \le \tau \le N \qquad (8)$$

$$S_{uu}(k) = \left| FFT(\Phi_{uu}(\tau)) \right| \qquad (9)$$

In the next step, the area under the power density spectrum is calculated (eq. 10) to represent the level of excitation (orange area in Figure 7).

$$A_{S_{uu}} = \sum_{k=1}^{N/2} S_{uu}(k) \qquad (10)$$

The results are proportioned with the identified moment of inertia of equation 3 (red area in Figure 8). Identification results with a divergence of less then ± 10% are rated as sufficient (green area) and were achieved for rather high excitation. Hence, a minimum size of the excitation representative is about A_{SUU}=200. Whether this statement can be generalized for other drives and thereby serve as excitation detection, future investigations will show.

5. Conclusions

An identification method for the estimation of an order reduced parametric model was presented. The approach is online capable on industrial motion controllers and has been implemented as an automatic application. Experimental results for a variety of input sequences were presented to prove the independency of specific test signals and thus the suitability for non invasive identification. Furthermore one possibility for excitation detection was introduced and carried our for the available test rig.

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