Closed-loop Identification of Twin-Screw Extruder in Powder Coatings Application

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Abstract

The aim is to produce a low order efficient model in order to assist the scaling-up and the control design of the manufacturing process. Various identification techniques, such as Prediction Error and Subspace Methods are exploited to first generate candidate closed-loop models that fit to the original input-output process data. Then, a comparison and a model validation of the estimated models was performed on the basis of closed-loop step responses and by means of the mean square error and data fitting criteria, in order to select the model that best describes the dynamic behavior of the underlying process.

1. Introduction

In CHEMICAL PROCESS CONTROL and particularly in the polymer industry there is a strong demand to produce *efficient models* for control design applications. For the majority of the industrial processes open-loop experiments are prohibited due to safety, economic considerations, efficiency of operation and stability issues and therefore closed-loop identification methods should be performed.

The Powder Coatings Manufacturing Process

Powder coatings manufacturing is a semi-continuous multi-stage process:

1. Weighing of the raw materials and Pre-mixing (i.e. dry blending of the polymer binder granules with the cross linker and the necessary additives);
2. Extrusion, where the premix is fed into an extruder where it is compacted and heated until it melts, while shear forces break down the pigment aggregates to form a homogeneous dispersion;
3. Solidification process, which involves the cooling of the the processed material via an industrial cooling belt and then flaking it using a breaker;
4. Milling and sieving of the chips to produce a fine powder with a specified particle size range.

The Twin-Screw Extruder (TSE)

The Twin-Screw Extruder (TSE) system for which we seek to estimate a model is shown in Fig.1 and is manufactured and supplied by Steel Belt System (S.B.S.). It is a co-rotating TSE with a 21mm screw diameter and a modular, openable type barrel 28 L/D divided in 6 temperature zones. The capacity (throughput) is 0.5– 50 kg/h.

Figure 1: *The Twin-Screw Extruder manufactured by S.B.S.*

We consider as *manipulative Inputs*:

u_1: Screw-Speed (SS)

u_2: Barrel Temperature (BT) of the last 3 zones

and as *measured Outputs*:

y_1: Motor Torque (MT)

y_2: Product Temperature (PT) at the die, i.e. the exit point.

The real process data were gathered by a series of identification experiments with sampling time $T_s = 1$sec.

2. Objectives

The experimental identification of a small-scale Twin-Screw Extruder (TSE) for powder coatings applications.

- Use an Indirect Approach and a variety of Identification Algorithms to derive candidate closed-loop models.
- Estimate a 2-input, 2-output open-loop model of the TSE system based on real experimental data and the knowledge of the controller parameters (Inverse filtering).
- The main purpose is to derive low-order accurate models for the TSE process that may be used as a basis for the control system design and the scaling-up of the powder coatings manufacturing process.

3. Methodology: The Identification Strategy

The overall identification strategy can be summarized in the following steps:

1) Development of the data-acquisition system and perform the identification experiments in order to gather real process data;
2) Pre-treatment and classification of the data with the aim to choose a representative of the process behavior data-set;
3) Estimate the input sensitivity functions (closed-loop system) by using both Prediction Error Methods (PEM) and Subspace Identification Methods (SIM) with various model structures;
4) Comparison of the estimated models and validation with a fresh data-set and selection of the most accurate identified model;
5) Based on the identified model of (4) and the knowledge of the controller recover the open-loop plant dynamics of the TSE via inverse filtering.

The closed-loop feedback configuration includes the TSE system and two (SISO) PI-controllers as it is shown below:

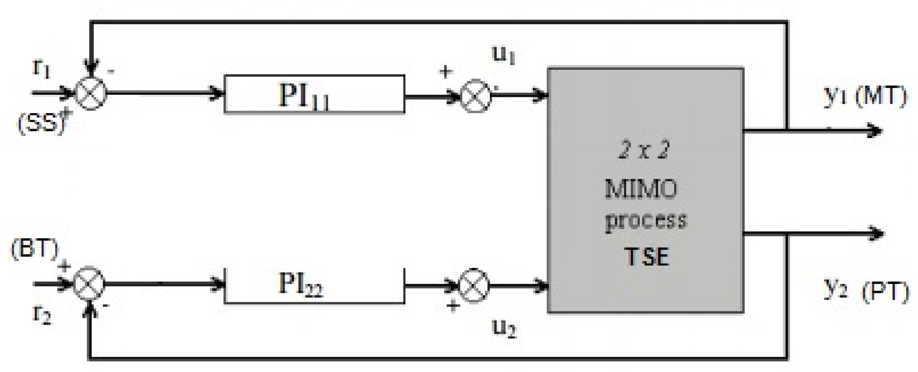

Figure 2: *The TSE process feedback system.*

4. Results and Discussion

The model validation and verification is performed on the basis of the closed-loop step responses produced by a fresh input-output data set as shown in Fig.3. In addition a comparison is performed on the basis of error and data fitting criteria. The results are summarized in Table I.

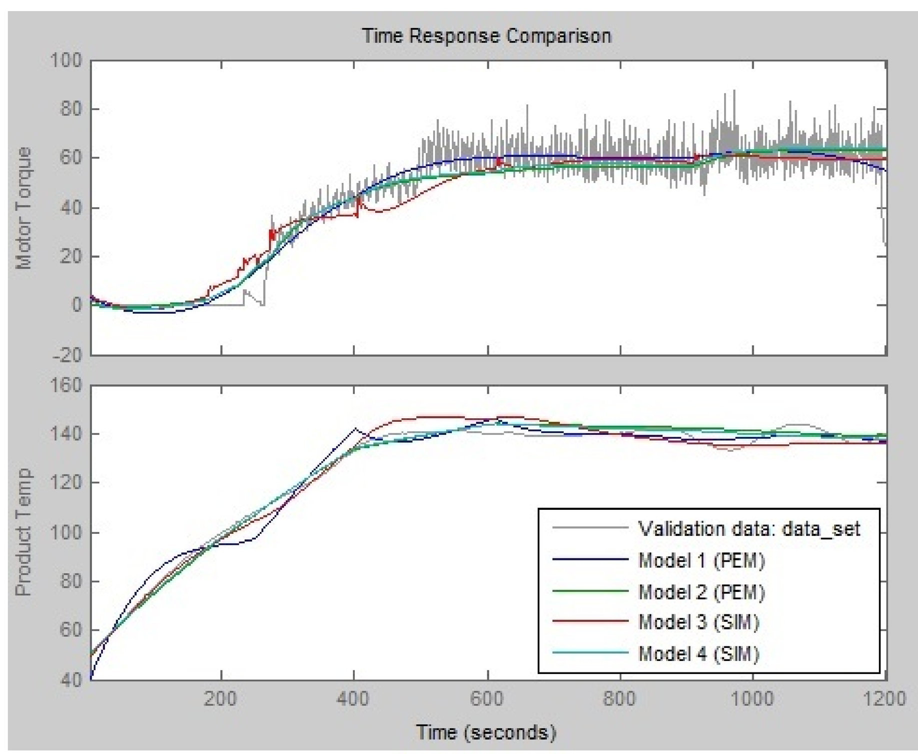

Figure 3: *Validation of the estimated models via closed-loop Step responses*

Table 1: *Comparison of Identified Models*

Estimated models	Fit to Data (%)	FPE	MSE
Model 1 (PEM)	[74.16;83.69]	666.4	29.08
Model 2 (PEM)	[76.63;99.57]	0.3917	17.34
Model 3 (SIM)	[80.05;99.63]	**0.2112**	**12.64**
Model 4 (SIM)	[76.53;99.21]	1.333	17.50

Estimation of the open-loop TSE model

Based on the estimated Model (3) and the knowledge of the controller parameters we are in position to recover the dynamics of the open-loop TSE process.

$$\hat{G}_{OL}(s) = \frac{1}{\Delta(s)} \begin{bmatrix} n_{11}(s) & n_{12}(s) \\ n_{21}(s) & n_{22}(s) \end{bmatrix}$$

where,

$$\Delta(s) = s^4 - 0.003829s^3 + 5.498 * 10^{-6}s^2 + 3.5 * 10^{-9}s + 8.398 * 10^{-13}$$

$$n_{11}(s) = -8.99 * 10^{-7}s^4 + 2.582 * 10^{-9}s^3 + 2.47 * 10^{-12}s^2 + (7.88s - 5.372) * 10^{-16}$$

$$n_{12}(s) = 0.0014s^4 - 4.25 * 10^{-7}s^3 + 0.468s^2 - - 1.298 * 10^{-13}s + 1.77 * 10^{-16}$$

$$n_{21}(s) = -7.93 * 10^{-6} - 3.75s^4 + 2.28 * 10^{-8}s^3 - 2.18 * 10^{-11}s^2 + 6.963 * 10^{-15}s + 4.318 * 10^{-16}$$

$$n_{22}(s) = 0.0013s^4 - 3.75 * 10^{-6}s^3 + 3.592 * 10^{-9}s^2 - - 1.146 * 10^{-12}s + 2.717 * 10^{-19}$$

5. Conclusions

The identification of a powder coatings extrusion process via real closed-loop data has been examined using 2 *PEM* and 2 *SIM* identification algorithms based on the indirect (two-step) approach. The key idea was to first estimate a candidate model for the closed-loop behavior and then extract the open-loop dynamics via inverse filtering using knowledge of the controller parameters. From the comparison of the identification results by the various methods/algorithms the model corresponding to the SIM (N4SID) method was the one with the *lower mean square error* and fitted most with the underlying process data. As a result a $2-$input, $2-$output, 4^{th} order transfer function matrix was derived for the powder coatings extrusion process in order to assist the scaling-up and the control design of the manufacturing process.

6. Future Work

Future work aims to improve the identification models and provide solutions to the practical problems encountered in this work:

- Process estimation directly from input-output data may result in biased models due to the correlation between the inputs and the noise from measurements. To avoid this we aim to design and exploit a two-stage identification method.
- Design a multiple data-set identification method where the experimental data are obtained from a combination of step-type excitation signals (low frequency power distribution) and a P-RBS (Pseudo-Random Binary Sequence) input signals with a high-switching probability (high frequency power distribution) in order to capture the dynamics of the underlying process within a broader frequency range.

7. Acknowledgments

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