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# MODELLING AND PARAMETER ESTIMATION OF THERMAL PROCESS

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**ABSTRACT**

*Thermal process plays a major role in the field of Mechanical Engineering. In most of the food industries, chemical industries, controlling of Temperature proves to be an important job. Dead time and overshoot are the most vital performance criteria which should handled precisely. First stage is to develop the mathematical model of the thermal process using conventional Process Reaction Curve method. Then the derived models for each temperature ranges are tested by Parameter estimation techniques such as, ARX, ARMAX, BJ and OE methods using System Identification Tool Box in MATLAB. The parameters are estimated based on the final prediction error, best percentage fit and co-relation of residue for the output.*

**Keywords**: Modelling, Parameter Estimation, ARX, ARMAX, BJ, OE Model

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## 1. INTRODUCTION

The models of dynamic systems are determined by estimation of parameter from experimental data, also used in combination with a physical model. Therefore the parameters obtained will indicate certain physical properties of the system that is being examined. The models may be linear as well as non-linear. The complexity of the parameter estimation does not depend on the system being examined or the linearity of the model. More specifically, the linear parameters is feasible for deriving a set of equations for a non-linear system.

The “best” parameter set can be uniquely determined using a straightforward procedure. Inversely, the equations with non-linear parameters and the non-linear optimization techniques can be obtained from a linear system. As mentioned earlier, the dynamic systems or the time dependency plays a major role. Time derivatives are present in the differential equation of the model that describes the system. However the techniques like curve fitting are commonly used to match experimental data and non-dynamic models in which the time parameter is not considered.

A System is a physical device that performs an operation on an input signal and produces processed signal as output. It is an interconnection of components, cause and effects between two or more signals.

**System Identification:** From measured data using statistical methods, the mathematical models are built.

**State Estimation:** Use of mathematical models in order to estimate the internal states of a process.

## 2. PROCESS DESCRIPTION

The temperature of the outlet air, which is blown out by the blower through the heating element is controlled in this process. The sensor used here to measure temperature is K-type thermocouple. The error detector circuitry finds the difference of actual temperature in the process and the set temperature. The control action is given to the power control circuit. The thyristor based power regulatory circuit is formed by connecting the two silicon controlled rectifiers in the anti-parallel forms. The controller output is passed to the silicon controlled rectifier, through a full wave rectifier after converting that to AC Voltage. Thus the Silicon controlled rectifier receives the positive gate pulses. The DC signal will be converted to ramp signal, which will be given to the op-amp as the inverting input. According to the incoming voltages to the inverting output of the operational amplifier, this pulse width modulation circuit generates square pulse. Figure 1 shows the block diagram of the Temperature process.

## 3. PROCESS MODELLING

The Thermal process present in the lab has SCR based power control. The process model is obtained using the conventional process reaction curve method. This method has the following steps to obtain the process model of the thermal process:

- Find the ΔPV (Change in Process Variable) by subtracting the final and initial steady state values.
- Compute the Process variable of the initial steady state + (0.63 * ΔPV)
- Find the time taken to reach the value obtained in the previous step.
- Determine the time taken by the system to respond for the step change.
- Calculate $T_p$ by finding the time taken between step 4 and step 3.

Using the above steps, mathematical models of the thermal process are obtained and tabulated in Table 1

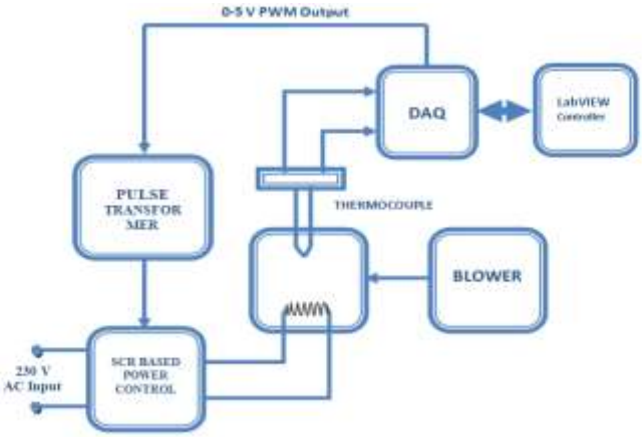


**Figure 1** Block Diagram of the Thermal Process

**Table 1** Transfer Functions Obtained for Process using PRC Method

| Voltage RangeV | Temperature range℃ | Transfer function |
|---|---|---|
| 0-1 | 28-33 | $\frac{1.654}{255s+1}e^{-4s}$ |
| 1-2 | 33-41.5 | $\frac{9.385}{214s+1}e^{-3s}$ |
| 2-3 | 41.5-55 | $\frac{13.8}{213s+1}e^{-3s}$ |
| 3-4 | 55-68.5 | $\frac{11.898}{217s+1}e^{-2s}$ |
| 4-5 | 68.5-74.5 | $\frac{6.528}{184s+1}e^{-0.5s}$ |

## 4. PARAMETRIC ESTIMATION TECHNIQUES

The system models are obtained for various regions are validated using Parameter estimation techniques. The perfect fit of the original system curve is compared with the parameter estimated methods. This fit proves that the derived system identification is same as the parameter estimated system identification techniques. Further the system validation is done by giving step input to the derived transfer function and the real system at the same time. Various parameter estimation techniques are:

- Auto-Regressive Model
- Auto-Regressive Moving Average Model
- Box Jenkins Model
- Output Error Model

## 5. RESULTS AND DISCUSSIONS OF PARAMETER ESTIMATION TECHNIQUES

The mathematical model for a temperature control system is found using the MATLAB System Identification tool box that gives an easy way by simulation to select the best model that results in maximum model estimation and validation when compared with the real time system. Similar to J.H. Lee et al. (2013) the real-world measurement information is taken directly from the temperature process for identifying the model. The sample data taken at desired sample interval of a temperature system are as follows:

- U denoted as Voltage input (V)
- Y denoted as Temperature (°C)
- Sampling interval - 0.6 seconds
- Total number of samples - 600 samples

The above mentioned parameters are initialized in the MATLAB workspace. The measurement data of the temperature control system which consists of input voltage, output temperature and sampling time is loaded to the system identification toolbox in MATLAB.

The complete measurement data is partitioned into two parts, the first part is assigned for parameter estimation and the second part for validation of data. The estimation and validation of the data set are shown in Figure 2. The estimation data which is considered as the input are helpful in predicting the model.

The various parameter estimation methods are analyzed to determine the appropriate model for the proposed non-linear temperature process by implementing methodical approach depending on the following steps: (a) selecting the suitable identification technique. (b) finding the best model configuration with low order (c) depending on the model performance apply the model estimation and validation methods.

## 5.1. Various Options to Determine Time Delay

- By means of the [DELAYEST] function.
- A non-parametric approximation of Impulse Response by means of [IMPULSEEST] function
- By means of estimating the state space model by $N_4SID$

### *5.1.1. Using DELAYEST*

This function evaluates an ARX structure:

$$y(t) + a_1^* y(t-1) + ........ + a_{na}^* y(t-na) = b_1^* u(t-nk) + ...... + b_{nb}^* u(t-nb-nk+1) \quad (1)$$

Choose second order model ($n_a$,$n_b$) which is kept default

$$V = arxstruc(z_e, z_r, struc(n_a, n_b, 1:10)); \quad (2)$$

The delay is selected in order to achieve the best fit for the validation data by using the function:

$$\text{selstruc(V,o)} \quad (3)$$

### *5.1.2. Using IMPULSE*

**impulseest** is the function used for calculating the model of the impulse response

$$\begin{aligned} &FIRModel = impulseest(z_e); \\ &clf \\ &h = impulseplot(FIR\,\text{mod}\,el); \\ &showconfidence(h,3) \end{aligned} \quad (4)$$

Then the impulse response curve generates for Amplitude Vs Time

### *5.1.3. Using $n_4$sid based state space evaluation*

Here parametric model is found for delay corresponding to best model. In the State space model the orders are obtained and the best order is selected from Hankel Singular value plot.

$$m = n_4sid(z_e, 1:15); \text{ // all orders between 1 and 15.} \quad (5)$$

The plot appears and the plot indicates an order of the chosen value.

## 5.2. Choosing a Reasonable Model Structure

- **State Space Models:** $n_4sid$ evaluates the range of orders instantly for estimating the best order.
- **ARX Estimator:** ARX estimator which chooses the Polynomial models.
- **Output Error Models:** It is simple and good choice for starting polynomial models.

## 5.3. Estimation of possible model orders

The order of the ARX model is selected in the structure list.

$$V = arxstruc(z_e, z_r, struc(n_a, n_b, 1:10)); \quad (6)$$

From the result obtained, the best fit ARX model **ARX 9106,**

Number of poles, $n_a = 9$

Number of b parameters, $n_b = 10$

Number of samples before the input affects the output, $n_k = 6$.

By using $n_4sid$ State space evaluation:

The $n_4sid$ is activated using the following command

$$m = n_4sid(z_e, 1:15); \quad (7)$$

The plot appears and the plot indicates an order of the chosen value.

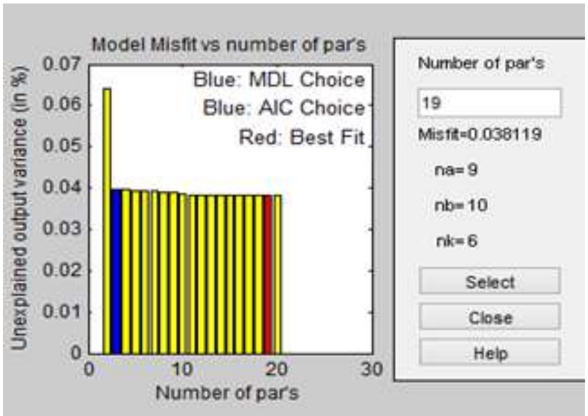


**Figure 2** Estimation of ARX model order

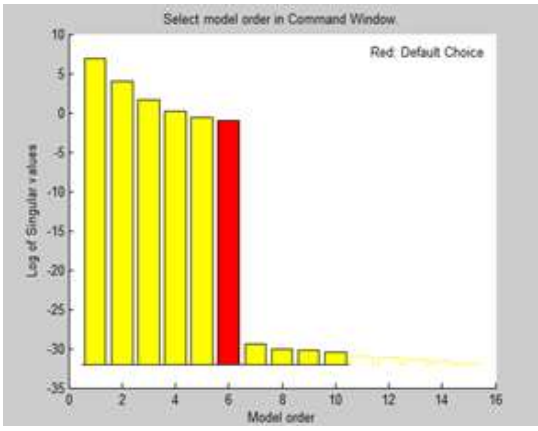


**Figure 3** Estimation of State Space model order

## 5.4. Simulation using system identification toolbox

The following steps were used:

### *5.4.1. Measurement data loaded in workspace of MATLAB:*

**load** Temperature

Temperature and voltage information are loaded into the workspace of the MATLAB.

### *5.4.2. System identification tool graphical user interface opening:*

To access the toolbox **ident** is typed in the command window

### *5.4.3. Importing data in the system identification toolbox:*

Figure 4 shows the Import data block and Figure 5 shows the GUI of the import data module.

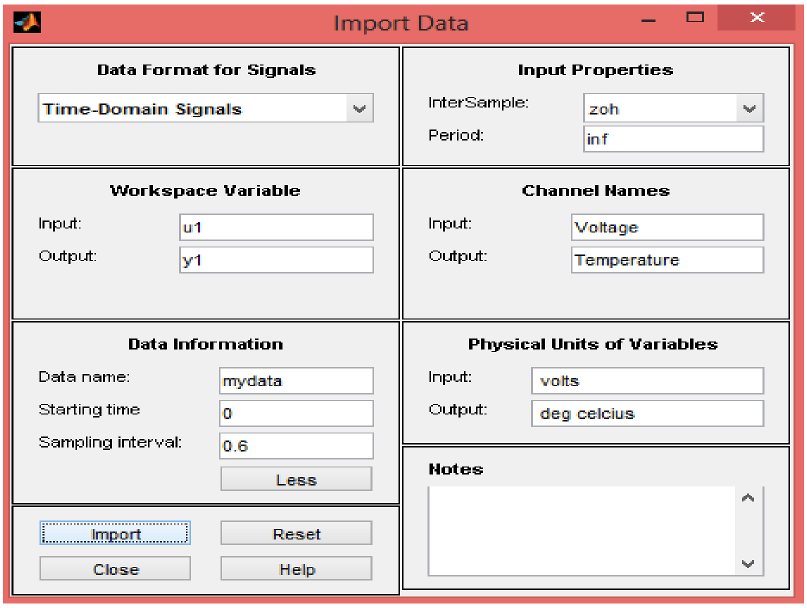


**Figure 4** Import data in toolbox

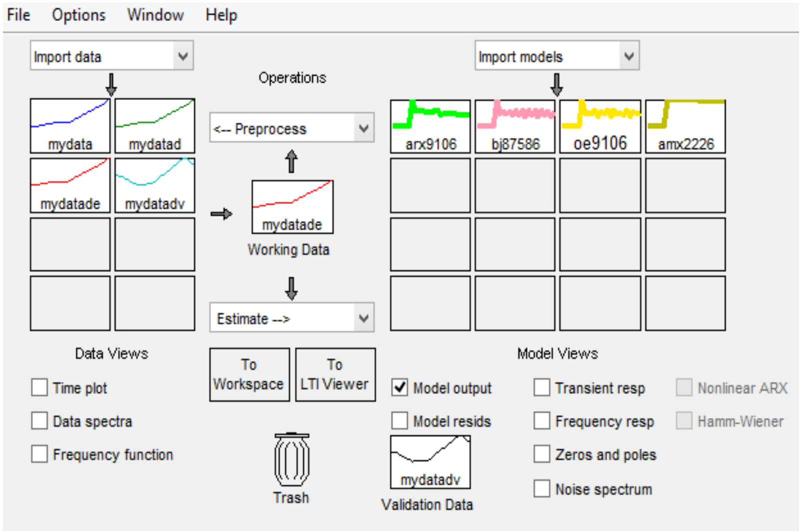


**Figure 5** System Identification Toolbox

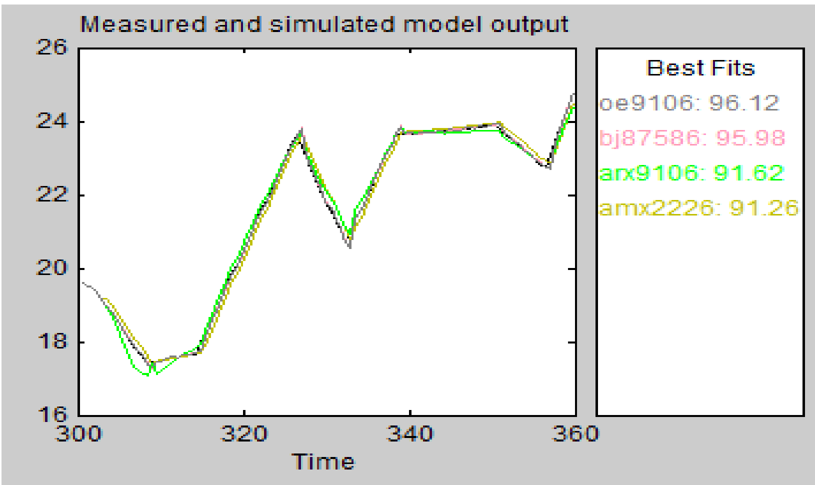


**Figure 6** Comparative study result of Parametric Model Identification Technique

Using the System identification Toolbox shown in Figure 5, various parameter estimation techniques were performed and the results are obtained in Figure 6.

**Table 2** Comparative Results of Parametric Model Identification Techniques

| Model | LF (Loss Function) | FPE (Final Prediction Error) | Best Fit % |
|---|---|---|---|
| ARX(9,10,6) | 0.00601325 | 0.00646934 | 91.62 |
| AMX(2,2,2,6) | 0.00626448 | 0.00641666 | 91.26 |
| BJ(8,7,5,8,6) | 0.00461233 | 0.00461233 | 95.98 |
| OE(9,10,6) | 0.00591325 | 0.00637561 | 96.12 |

From the Table 2 it is inferred that the ARX gives 91.62% best fit, ARMAX gives 91.26% best fit and Box Jenkins method gives 95.98% best fit. Compared to all the methods OE method provides the best fit of 96.12%, which also has low loss function and less final prediction error.

## 6. CONCLUSION

Process reaction curve method was used for finding the transfer functions for the various regions. The real time system identification method was done more than 10 times since the tests were carried out during different time period. Due to environmental condition, different readings were obtained and different transfer functions were obtained. Finally average values were found to finalise the transfer functions for the different regions. Among ARX ARMAX BJ and OE modelling structure, it seems that the OE method gives better fit. Also the BJ method gives good fit and reasonable Loss function & Final Prediction Error. But due to more fit, OE gives better parameter estimation. Parameters are estimated and it is inferred that the obtained models for various regions from the real time system identification very close to the real plant.

## REFERENCES


[1] Åström, K. J., &Hägglund, T. (2001) “The future of PID control. Control” Engineering Practice, 9(11), 1163–1175.

[2] Bradley T. Burchett and Richard A. Layton (2005) “An Undergraduate System Identification Experiment”, American Control Conference.

[3] Francesco Beneventi, Andrea Bartolini, Andrea Tilli, and Luca Benini, (2014) “An Effective Gray-Box Identification Procedure for Multicore Thermal Modeling”, IEEE Transactions on Computers 63 (5), 1097-1110.

[4] J.H. Lee, H.J. Shin, S.J. Lee, S. Jung (2013) “Model identification and validation for a heating system using MATLAB system identification toolbox”, IOP Conf. Series: Materials Science and Engineering 51.

[5] L.D.Vijay Anand, P. Poongodi, J. Jayakumar, Hepsiba. D (2017) “Analyzing the effect of pre-heater in the temperature process”, International Journal of Mechanical Engineering and Technology (IJMET) Volume 8, Issue 11, November 2017, pp. 113–120.

[6] L.D.Vijay Anand, Hepsiba. D (2018) “Real-Time System Identification of Thermal Process”, International Journal of Mechanical Engineering and Technology (IJMET) Volume 9, Issue 11, November 2018, pp. 2076-2084.

[7] L. Ljung (1999) “System identification - Theory for the User”, Prentice-Hall, USA.

[8] Skvortsova S.V, Gvozdeva O.N, Orlov A.A, Stepushin A.S and Volodin A.V, the Study of Structure Development Regularities in Vt35 Alloy after Strengthening Thermal Processing, International Journal of Civil Engineering and Technology, 9(11), 2018, pp. 1471–1478.