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IDENTIFICATION OF HEAT EXCHANGER QAD MODEL BDT 921 BASED ON HAMMERSTEIN-WIENER MODEL

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Heat exchanger is widely used in the process industries and in others area that it is a plant that is used to change the temperature distribution of two fluids, particularly in process industries. A heat exchanger which it is called Heat Exchanger QAD Model BDT 921 is real system that it is installed in the Control Laboratory in University Tun Hussein Onn Malaysia (UTHM) and there is a shell and tube type heat exchanger where identification of this system is not yet determined, so the background for this paper to purpose to develop a system identification that used to ensure the capability and performance of the heat exchanger based on real data. Hammerstein-wiener model as a method in order to get the mathematic modelling of dynamic system where the process of the identification is requires select model structure, choice of criterion to fit, parameter estimation and model validation. The estimation algorithm is using linear least square method and model validation use means square error method. The simulation output will be compared with actual data to estimation and validate by using m-file MATLAB program. This simulation get to process 1000 data collected which it is got of the graph experiment resulted where half of data for parameter estimation and half another of data for model validation. Model simulated to analyses to determine of the plant performance such as loss function (LF), final prediction error (FPE), mean square error (MSE) and percentages of model fit (%MF). The best model is chosen based on fitting which it has value approximate to 100%. In this paper, a new system identification algorithm is developed to purpose to determine performance of the shell and tube heat exchanger could be further analysed and improved. The technique developed in this paper could also be generally and applicable for development and validation of other heat exchanger system models.

Keywords: Hammerstein-wiener model, heat exchanger, m-file MATLAB program, linear least square, means square error, loss function, final prediction error, percentages of model fit.

1. INTRODUCTION

A heat exchanger is widely used in the process industries and in others area which it is a plant that is used to change the temperature distribution of two fluids, particularly in process industries [1], [2] - [3]. A real system of heat exchanger is called Heat Exchanger QAD Model BDT921 that it is installed in the Control Laboratory in Universiti Tun Hussein Onn Malaysia (UTHM) and there is a shell and tube type. Since system identification is not yet determined to this plant, so for this study in this paper is to purpose system identification designed that it is used to ensure the capability and performance based on real data of this plant. In system identification has a goal to find mathematical equation modelled that give approximation to the actual behaviour of a real physical system. Unfortunately the experimental procedures produced by the manufacturer do not provide enough information on how to obtain a mathematical equation model of the plant by using manually which it is open-loop needed since its closed-loop system that controlled by proportional integral derivative (PID) controller. Through mathematical equation model, we can study about the dynamics of the process, stability of the system, design controller etc. The mathematical equation model is used to determine a performance of the system. The experiment is designed is take the input constant temperature 25.1°C and the output is temperature from range 30°C and 50°C until 1000 data. The Hammerstein-wiener model is selected as model structure and parameter estimation is determined by linear least square method and this model will be resulted by m-file MATLAB program. The output from the actual data will be compared to the model resulted, and this model will be shown by a Discrete-time IDPOLY as parameter model. This parameter has loss function (LF), final prediction error (FPE), mean square error (MSE) and percentage of model fit (%MF) for both data estimation and data validation depend to order is selected. A few papers that it has used of Hammerstein-wiener model is obtained in the paper by Dietmar [4], Zhu [5], and Harish [6] while papers of Hammerstein-wiener system has studied by Jozef [7], Ivan [8], Ivan [9], Rimans [10], and Crama [11].

2. METHODOLOGY

The system identification is the process of deriving mathematical system model from observed data in accordance with some predetermined criterion [12] – [13]. To solve this system identification process, a model structure will be used. Hammerstein-wiener models describe dynamic systems using one or two static nonlinear blocks in series with a linear block. Fig. 1 shows a block diagram of Hammerstein-wiener model.

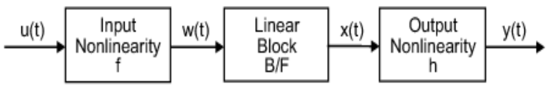

Fig. 1 Hammerstein-wiener model

Where $w(t) = f(u(t))$ is a nonlinear function transforming input data $u(t)$, $w(t)$ has the same dimension as $u(t)$, $x(t) = (B/F)w(t)$ is a linear transfer function, $x(t)$ has the same dimension as $y(t)$, B and F are similar to polynomials in the Linear Output-error model . For n outputs y and n inputs u, the linear block is a transfer function matrix containing entries $B_{j,i}(q)/F_{j,i}(q)$, where $j = 1,2,...,n$ and $i = 1,2,...,n$. $y(t) = h(x(t))$ is a nonlinear function that maps the output of the linear block to the system output while $w(t)$ and $x(t)$ are internal variables that define the input and output of the linear block, respectively. Because f acts on the input port of the linear block, this function is called the input nonlinearity. Similarly, because h acts on the output port of the linear block, this function is called the output nonlinearity. By using MATLAB program, to estimate parameters of Hammerstein-wiener model by using linear least square method, the syntax that will be used $m = nlhm(data,orders)$. The function of m will return the values with the parameter estimation of the Hammerstein-wiener model along with estimated covariance and structure information such as values of loss function (LF) and final prediction error (FPE). The data in this function is referring to data estimation. Before estimation, this data must be set as IDDATA first. For *orders* the value for the order [order] will be set randomly and will be choose the best fitting from order chosen. In this study, the order is chosen until 50 orders. These orders will be set either Hammerstein-wiener model has which types of orders and how long time delays for the models. Through a graph output data of the plant get the sampling start from 1 until 1000 data. Open MATLAB m-file to do the programming. The program will be run to get the graph fitting depend the order given. The order will be choose to use in programming and order will be select randomly to get the best fitting for the model use. From the graph fitting, get the MSE, FPE and LF for model. Select the best fit to put in table, parameter estimation model, *ze* and model validation, *zv*. It is good practice to use only a portion of the data for estimation purposes, *ze* and save another part to validate the estimated models. Finally, the results are analyses to make sure the model agrees sufficiently with the observed data. Load data is a ways to kept data before call back by MATLAB and this data will be saving in workspace MATLAB. After the all data has been load in the workspace, the next step in these system identification process is set up the data set as an IDDATA object. In this study, the 1000 data will be used to get the data estimation and data validation. For the first half data start from 1 until 500, *z* measured will be compare with *ze* (data estimation) and for the another half data start from 501 until 1000 will be compare with *zv* (data validation). In this study, the parameter estimation use is least squares method (LSM). The purpose of model validation is to verify that the identified model fulfils the modelling requirement according to subjective and objective criterion of good model approximation. In validation purpose, another half data that measured from the experiment will be used to compare the validation between the validation data and measured model. Such example of model validation is residual test, mean square error (MSE), the akaike final prediction error (FPE) and F-test of order n. For this study, the model validation use is means square error (MSE) and percentages of model fit (%MF).

3. RESULTS AND ANALYSIS

The real data collection in graph form and this graph is converted to the data in the Word Excel and then is transferred to workspace in MATLAB software. The cold water is input product and output product is hot water temperature. Data nonlinear output will sampling depends on scale 5mm in a 1 unit. The highest temperature for this process used 60°C, so the last 1000 data experiments get around 55.7°C and still in the correct temperature range. Fig. 2 shows an output data plotting using m-file MATLAB program where half of data, range between 1 until 500 are used for data estimation and another half data range between 501 until 1000 is used for data validation. Fig. 3 shows output of parameter estimation for order [151], Fig. 4 and Fig. 5 are output graph from data estimation and data validation for order [151] while Fig. 6 is output of mean square error (MSE) values for order [151].

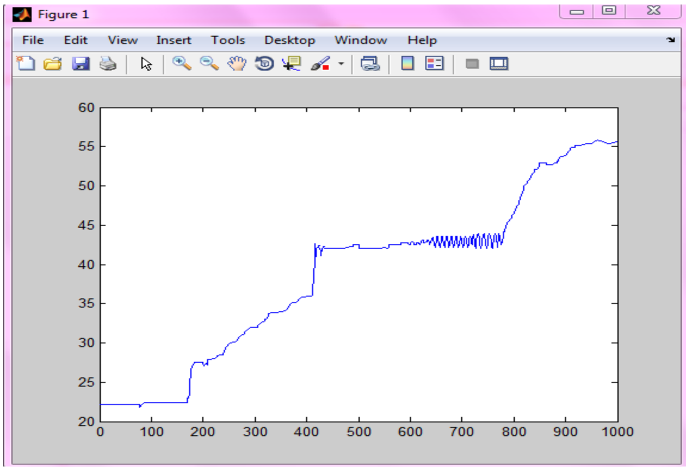

Fig. 2 Output data plotting using m-file MATLAB program

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Discrete-time IDPOLY model: y(t) = [B(q)/F(q)]u(t) + e(t)
B(q) = 8.32e-005 q^-1 + 8.32e-005 q^-2 + 8.32e-005 q^-3 + 8.32e-005 q^
                                                                    -4


F(q) = 1 - 0.1394 q^-1 - 0.847 q^-2 - 0.8543 q^-3 - 0.1509 q^-4
                                                         + 0.9918 q^-5


Estimated using OE from data set ze
Loss function 1.50204 and FPE 1.55655
Sampling interval: 1 sec
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Fig. 3 Output of parameter estimation for order [151]

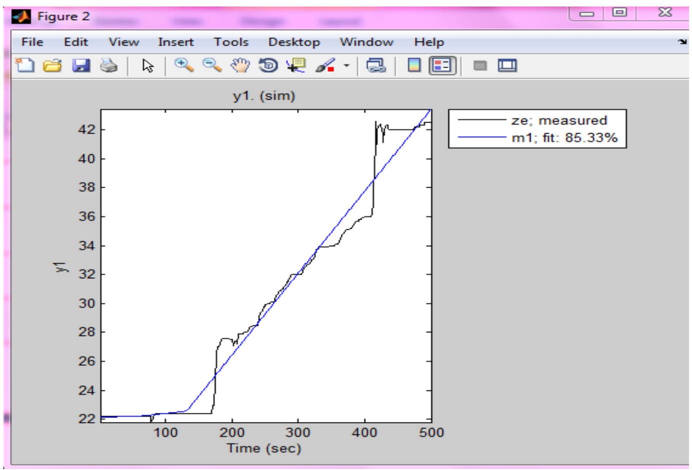

Fig. 4 Output graph of data estimation for order [151]

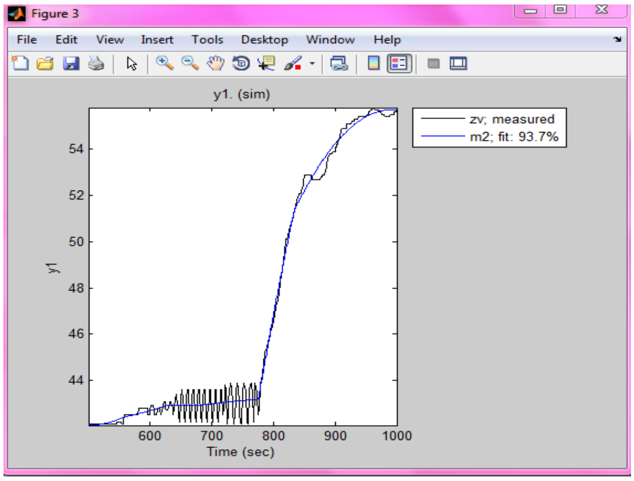

Fig. 5 Output graph of data validation for order [151]

Fig. 6 Output of mean square error (MSE) values for order [151]

Table 2 shows LF, FPE, %MF and MSE values of parameter estimation and model validation with various orders selected using m-file MATLAB program while Table 3 shows results of Discrete-time IDPOLY.

Table 2. Results of parameter estimation and model validation for various orders selected

[order]	Parameter Estimation				Model Validation			
	LF	FPE	%MF	MSE	LF	FPE	%MF	MSE
[131]	1.51709	1.53537	73.85	3.5111	2.50419	2.53436	93.79	0.1128
[151]	1.51192	1.53261	85.33	1.1042	2.50419	2.53436	93.7	0.1159
[122]	1.51789	1.53622	86.12	0.9888	2.49364	2.52375	65.17	2.52375
[123]	1.51878	1.53715	74.41	3.3614	2.48308	2.51312	92.98	2.51312
[125]	1.52079	1.53927	74.98	3.2131	2.46204	2.49194	93.73	2.49194
[321]	1.51788	1.54843	76.73	2.7784	2.49358	2.54376	93.5	2.54376
[431]	1.51281	1.55552	85.63	1.0601	2.01860	2.07558	76.43	2.07558
[451]	1.50204	1.55655	60.59	7.9739	2.44017	2.52872	87.32	2.52872

Table 3. Results of Discrete-time IDPOLY for various orders selected

[order]	Discrete-time IDPOLY
[131]	$y^{(t)} = \left[\frac{B(q)}{F(q)}\right] u^{(t)} + e^{(t)}$, $B(q) = 0.0001164\ q^{-1}$ $F(q) = 1 - 0.9943\ q^{-1} - 0.9969\ q^{-2} + 0.9913\ q^{-3}$
[151]	$y^{(t)} = \left[\frac{B(q)}{F(q)}\right] u^{(t)} + e^{(t)}$, $B(q) = 8.32e^{-005} q^{-1} + 8.32e^{-005} q^{-2} + 8.32e^{-005} q^{-3} + 8.32e^{-005} q^{-4}$ $F(q) = 1 - 0.1394\ q^{-1} - 0.847q^{-2} - 0.8543q^{-3} - 0.1509q^{-4} + 0.9918q^{-5}$
[122]	$y^{(t)} = \left[\frac{B(q)}{F(q)}\right] u^{(t)} + e^{(t)}$, $B(q) = 5.815e^{-005} q^{-2}$ $F(q) = 1 - 1.993q^{-1} + 0.9929q^{-2}$
[123]	$y^{(t)} = \left[\frac{B(q)}{F(q)}\right] u^{(t)} + e^{(t)}$, $B(q) = 5.836e^{-005} q^{-3}$ $F(q) = 1 - 1.993q^{-1} + 0.9928q^{-2}$
[125]	$y^{(t)} = \left[\frac{B(q)}{F(q)}\right] u^{(t)} + e^{(t)}$, $B(q) = 0.0003237e^{-005} q^{-1}$ $F(q) = 1 - 0.2151q^{-1} - 0.7725q^{-2} - 0.7789q^{-3} - 0.2238q^{-4} + 0.9905q^{-5}$
[321]	$y^{(t)} = \left[\frac{B(q)}{F(q)}\right] u^{(t)} + e^{(t)}$, $B(q) = 1.941e^{-005} q^{-1}\ 1.941e^{-005} q^{-2} + 1.941e^{-005} q^{-3}$ $F(q) = 1 - 1.993q^{-1} + 0.9929q^{-2}$
[431]	$y^{(t)} = \left[\frac{B(q)}{F(q)}\right] u^{(t)} + e^{(t)}$, $B(q) = 2.91e^{-005} q^{-1}\ 2.913e^{-005} q^{-2} + 2.921e^{-005} q^{-3} + 2.925e^{-005} q^{-4}$ $F(q) = 1 - 0.9931\ q^{-1} - 0.9994\ q^{-2} + 0.9925\ q^{-3}$
[451]	$y^{(t)} = \left[\frac{B(q)}{F(q)}\right] u^{(t)} + e^{(t)}$, $B(q) = 0.0003237\ q^{-1}$ $F(q) = 1 - 0.2151\ q^{-1} - 0.7725\ q^{-2} - 0.7789\ q^{-3} - 0.2238q\ q^{-4} - 0.9905\ q^{-5}$

4. CONCLUSION

In this paper, system identification of a heat exchanger has determined. The model resulted is a nonlinear. Data input-output is measured with running a shell and tube heat exchanger that it is called Heat Exchanger QAD Model BDT 921. The temperature and differential pressure (inflow) of this heat exchanger as input variables while temperature of the heat exchanger as output variables. The system identification algorithm used to applying least square method, and a set of candidate model structure assumes Hammerstein-wiener model is selected. Mathematical equation model of a process control plant is important because it provides key information as to the nature and characteristic of the system which is vital for the investigation and prediction of the system operation. The simulation model resulted has compared with real model where in this paper, m-file MATLAB program has used and model resulted for various order has shown a result is satisfy.

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