MATLAB based TF Estimation and Verification of Moisture-Free PVC Temperature

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ABSTRACT
Insulated wire manufacturing process goes through number of phases before yielding a desired quality of insulated wire. The first phase of wire manufacturing is the controlling of PVC-temperature to make it free from the moisture. In this paper, we describe the estimation of first order Transfer Function (TF) with dead time for the PVC placed in the tray of Electric Oven (EO). The TF is estimated using the real time measured response of PVC temperature in EO for the applied step change in power to EO and with the help of MATLAB. The estimated TF was verified by making simulation model for it in MATLAB and comparing the simulated result with measured data. The time domain response of estimated TF shows closely represents the real time behavior of PVC temperature in EO.

Keywords
PVC Moisture-Free temperature, Insulated wire, Electric Oven, TF Estimation, MATLAB Simulation.

1. INTRODUCTION
In small scale PVC insulated wire manufacturing industries, there is need to make raw PVC moisture-free [1] before insert it in the extruder and also control this moisture-free temperature. In these industries to make PVC moisture-free, Electric Oven (EO) is used [2]. It has built-in tray arrangement in which raw PVC is placed. Then by applying electric power to the EO the temperature of PVC is raised to make it moisture-free. When we consider for the simulation of EO, most of the research papers [3] used the transfer function of EO. The step response of such types of oven is monotonous after an initial time. They approximated the response of EO by the transfer function as given in Equation 1. But they used the values of parameters from the literature and these are not adoptable for the EO system of PVC.

$$G(S) = \frac{K}{TS+1} e^{-\tau S} \qquad (1)$$

Where 'K' is the static gain

'τ' is the apparent time delay

'T' is the apparent time constant

Rohit Ramachandran discussed the process identification method using step response for both open-loop and closed-loop step response of process to be identified [4]. Saïda Bedoui proposed a method for the systematic determination of the model's base of time varying delay system [5]. Warren Scott Ferguson presents an approach of designing of model by closed-loop identification experiment [6] also Tony Kealy used Closed Loop Identification method under PI controller [7]. Un-Chul Moon and Kwang. Y. Lee discussed Step-Response Model Development for Dynamic Matrix Control of a Drum-Type Boiler–Turbine System [8]. Parasana Sankara Rao investigate the Performance of Regression Techniques used for estimation [9]. A.O'Dwyer briefly introduced the various techniques of parameter estimation of time delayed process model [10]. The methods discussed in most of these papers contain more and complex mathematical terms. For non-mathematicians scholar, it is difficult to understand. So we have also used the first order transfer function with time lag for moisture-free PVC temperature EO system and estimated the values of parameters fitted for our PVC moisture-free process. To estimate the TF which gives the behavior of PVC temperature contained in EO more realistic, we measure the real time change in the PVC temperature EO for the given input value applied in steps using data logger system and recorded on the computer. After it using the real time data we estimate the TF for PVC temperature change by the process reaction curve method using MATLAB [11]. The process of this parameter's value estimation is very simple.

2. EXPERIMENTAL SET-UP TO COLLECT STEP RESPONSE DATA OF PVC TEMPERATURE
In the estimation of the TF by process reaction curve method there is firstly keep the process input i.e. manipulated variable (MV) at the nominal value and allow the process output to reach the steady state value. Note the steady state input (MV) and output controlled variable (CV) i.e. PVC temperature

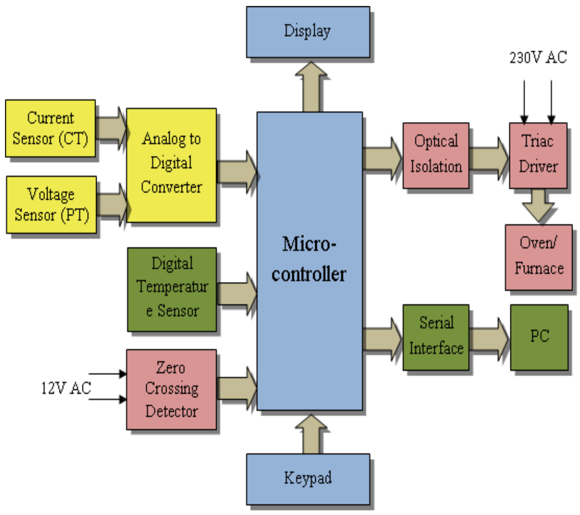

Fig.1: Block Diagram of the Data Acquisition System

values. Then we have to give a positive step change at the input and record the response of PVC temperature till a new steady state is reached. Similarly, the step response of process of change in PVC temperature for the negative step change is also to note.

To record the change in PVC temperature for corresponding change in input MV as mentioned above we construct a data logger system using microcontroller AT89S52 as an intelligent device [12]. The block diagram of this data acquisition system is shown in figure 1. It has with the facilities viz. applying step input for the MV, reading the current and voltage applied to EO with the corresponding change in temperature of PVC kept in tray of the EO and recording all these parameters values in to the memory of computer. In the circuit of data logger to sense the current CT is used and for voltage PT is used. The control over the amount of power to deliver is accomplished with the help of Zero Crossing Detector (ZCD) to sense the phase change and Triac driver circuit. The value of control signal to Triac can be set using keypad provided on system. To record the data collected by data logger system it is fed to the computer by serial communication using RS232. The recorded data is in the text file format and their sampling rate is 5 Second. The experimental set-up for collecting the data of change in PVC temperature in EO is shown in figure 2.

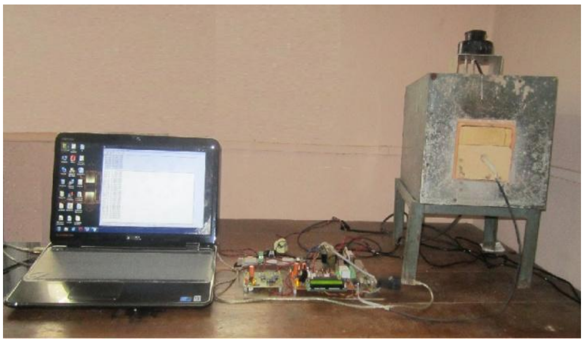

Fig.2: Experimental setup to measure the change in PVC temperature for given input control signal.

For the experiment purpose we used a simple electric heater with 39Ω resistance of heating coil as seen in the figure 2.

Fig.3: A tray containing PVC

Also for the demonstrative purpose we take 1Kg PVC and filled the tray with it as shown in figure 3. The tray is then pushed in the EO with inserting the temperature sensor TCN75 in the PVC material. The sensor gives 10 bit serial data for the temperature.

Firstly we apply more power to the EO by applying the suitable firing angle MV. Then to get maximum value for the MV, we changed it by observing the temperature of PVC such that the PVC temperature remains below the maximum value of PVC moisture-free temperature i.e. $90^{O}C$ as mentioned in our past work [13]. After trial and error by using data logger system we found that the maximum value of MV can be used is ‘6’, which saturates the temperature of PVC in the tray near to $85^{O}C$ for the used EO, which is below the $90^{O}C$. So we used the MV value ‘6’ during the applying the steps up signal at the input to kept the PVC temperature near the glass transition temperature. After this we reset the system and allowed the temperature of PVC in the EO came to the ambient temperature. Before starting the experiment we note the temperature of PVC in EO with the help of data logger system at ambient conditions. It is $24^{O}C$. Then to get initial steady state value of PVC temperature we apply value of MV equal to ‘2’ to the driver circuit built using Triac BT136. The power applied to EO due to input signal value ‘2’ rises the temperature of PVC up to $25^{O}C$ and get saturated.

As the temperature of PVC gets saturated we start to record the data in the new text file. To apply the positive step signal at input we change the MV value to ‘6’ and apply it. Using data logger system we record the corresponding change in temperature of PVC on PC till the PVC temperature reached to the new steady state value. For the ‘6’ value of MV the PVC temperature rises up to $84^{O}C$ and get saturated. After completion of readings for the step up of the PVC temperature process we start to record the data in new file. Now to apply step down at the input we make MV value equal to ‘3’ and applied to the driver circuit. After the dead time, temperature starts to decrease and gets saturate. The new steady state value of PVC temperature observed for the used EO is $32^{O}C$. Thus we collect the data of the change in PVC temperature near the operating temperature for the applied step up and step down signal at the input MV of driver circuit.

3. DEVELOPMENT OF TRANSFER FUNCTION MODEL FOR PVC TEMPERATURE

3.1 The Method of TF Estimation

For the purpose of developing control relevant dynamic model of the system, we proposed a first order plus dead time TF model relating perturbations in outputs to perturbations in inputs as,

$$\frac{\delta y\,(S)}{\delta u\,(S)} = G(S) = \frac{K}{TS+1} e^{-\tau S} \qquad (2)$$

$\delta y = y - \bar{y}$; $\delta u = u - \bar{u}$ and G(S) indicates the TF of system.

The perturbations are defined with respect to operating steady state. In principle, the process transfer function can be obtained through graphical procedure by plotting the process step response with respect to time. In this procedure the gain is calculated using the steady state change in the output per unit change in the input. The time constant is taken as time taken for the process to reach 63.3% of its final value. However, given noisy step response data collected from a plant, it is difficult to use the conventional approach of finding 63.3% of the final value. So a better approach in presence of measurement errors is used i.e. regression [14].

We formulate the parameter estimation problem as a least square estimation problem. Firstly we proposed a first order transfer function with dead time model relating deviations in input and output are defined from the steady state operating point as given in Equation 2. This is equivalent to the following differential equation given in Equation 3.

$$\tau \frac{d\delta y}{\delta t} + \delta y = K\delta u \cdot e^{-\tau S} \qquad (3)$$

For step change in input of magnitude Δu (δu), the output response can be expressed as in Equation 4.

$$\delta\hat{y}(t) = K\Delta u \cdot [1 - \exp(\frac{-(t-\tau)}{T})] \qquad (4)$$

Here $\delta\hat{y}(t)$ represents estimated value of the process output, given estimates of K, T and τ. Let us introduce notation,

$$t_k = kT_s \ ; \ \delta y(k) = \delta y(t_k)$$

Where $t_k = kT_s$ represents k'th sampling instant and T_s represents sampling interval. Since there are errors in measurement of $y(t_k) = y(k)$, we can define measurement error e(k) by Equation 5.

$$e(k) = \delta y(k) - \delta\hat{y}(k) \qquad (5)$$

The unknown parameters K, T and τ can be estimated by solving following constrained nonlinear optimization problem given in Equation 6.

$$\underset{K,T,\tau}{Min} \sum_{k=1}^{N} [e(k)]^2 = \underset{K,T,\tau}{Min} \sum_{k=1}^{N} [\delta y(k) - \delta\hat{y}(k)]^2$$
$$\textit{Subject To Constraints} \qquad (6)$$
$$T > 0 \ ; \ \tau > 0$$

This is a nonlinear optimization problem and we solved this using function 'fmincon' from Optimization Toolbox of MATLAB. k =1 in the above summation expression indicates the time instant at which the step change was introduced. The data before introduction of the step change has been neglected while formulating the optimization problem. Also, N in the above summation indicates the sampling instant where the output reaches a new steady state after the step change has been introduced.

3.2 Estimation of Values of Parameters K, T and τ

Now in order to solve the constrained optimization problem given in Equation 6, we write a function on MATLAB platform which computes function given in Equation 4. For this we put the applied step input value and corresponding PVC temperature values from the recorded data. Then to evaluate the function we write a MATLAB script file as given in Program 1.

```
===== || Program 1: myfun.m || ===================
    function f=myfun(x)
    u=4 ;
    y=[25,25,25,25,25,25,25,25,25,25,25,.....,26,25,26,26,26,2
    6,26,26,26,26,26,26,.....27,27,27,27,28,28,.......50,50,50,50
    ,50,50,......66,65,66,66,65,66,66,66,65.......,75,75,75,76,76,
    75,76,76,75,75,75,76.....80,81,81,81,81,81,81,81,80,81,81,
    81,81,81,81,81,81.....82,82,82,83,83,83,82,83,83,83,83,82,
    83,83,83,83,83,83,83,83,83,83,83,83,83,83,83,83,83,83,83
    ,83,83,83,83,.....83,83,84,84,83,83,84,83,84,84,84,84,84,8
    4,84,83,84,84,84,83,84,84,84,83,83,84,84,84,84,84,84,84,
    84,84,83,84,84,84,84.....,84,84,84,84,84,84,84,84,84,84,84
    ,84,84,84,84,84,84,84,84,84,84,84,84,84,84,84,84,84,84,8
    4,84,84,84,84,84,84,84,84,84,84,84,84,84,84,84,84,84,84,
    84,84];
    N=length(y) ;
    for i=1:N
        t(i)=(i-1)*5 ;
    end
    f=sum((y-(x(1)*u*(1-exp(-1*(t-x(3))/x(2))))).^2) ;
==========================================
```

Here u indicates the value of step input change, y accumulates the measured values of change in PVC temperature for the Δu, t gives the time vector and the f is the function of formulated optimization problem as given in Equation 6. This program need to store with the name 'myfun', so we save this script file in a separate file named 'myfun.m' in a folder, which gives a guess of vector x (vector containing values of parameters). To pass this function in 'myfun.m' file to MATLAB subroutine fmincon we write another script file in which the 'fmincon' command is used. It is given in Program 2.

The function 'fmincon' attempts to find a constrained minimum of a scalar function of several variables starting at an initial estimate. It is generally referred to as constrained nonlinear optimization [15]. We use this to find the minimum of our problem specified by,

$$A * x \leq b \qquad (7)$$

With the command

x = fmincon('myfun',x0,A,b)

Where A is linear constraint matrix and b is its corresponding vector. x0 is the initial point for x, it can be a scalar, vector, or matrix. The above mentioned command starts at x0 and attempts to find a minimizer x of the function described in myfun subject to the linear inequalities given in Equation 7.

```
===== || Program 3.1: EO_TF_Parameters.m || =========
    Parameter = fopen('TF_parameters','a')
    A=[0 -1 -1] ;
    b=0 ;
    for i=1:2:21
        for j=0.1:1:11
            for k=0.1:1:11
                x0=[i j k] ;
                x= fmincon('myfun',x0,A,b)
    fprintf(Parameter,'%4.8f\t %4.8f\t %4.8f\t %4.8f\t ........
    %4.8f\t %4.8f\n',i,j,k,x(1),x(2),x(3)) ;
            end
        end
    end
    fclose(Parameter) ;
==========================================
```

The above set of commands is also saved in the same folder with file named 'EO_TF_Parameters'. The first statement of program-3.2 creates an excel file with the name 'TF_parameters'. It used to save the values of vector x. From the constraints defined in Equation 6 we obtain the vector A as [0 -1 -1] and b as [0]. The statement with 'fmincon' passes the function 'myfun' to its subroutine to find the values of parameters which gives the minimum error in the measured value and estimated value.

The estimated values of the parameters is also depends on the initial guess values of it stored in vector defined by x0. To find the estimated parameters values with various initial guess values we used the 'for' loop as shown in second Program 2. The statement 'fprintf' writes the parameters values from the vector 'x' in excel file 'TF_parameters'. Thus after running the program file 'EO_TF_Parameters', the resulted values of parameters are stored in the file 'TF_parameters'. When opened it we observe that the parameters values are maximally repeated for the various combinations for the vector x0. In case of our measured values of PVC temperature, the obtained values for different initial values after executing the Program 2 are 14.225 for K, 10697.65 for T and 2311.76 for the τ.

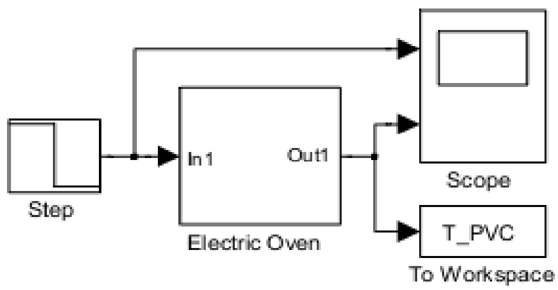

Fig.4: Simulink model to check TF model of EO

The obtained value of the parameters is used in the proposed TF model for the PVC temperature in EO. Then we create a simulink model [16] as shown in figure 4 to compare the real time measurement to the output result given by estimated TF model. We apply the step up and step down signal of the same

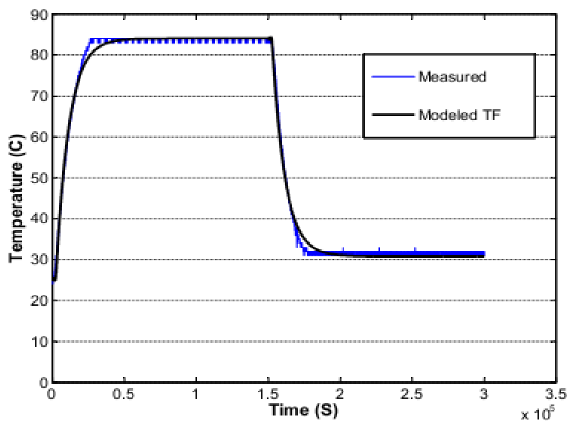

Fig.5: Comparison of Measured temperature and temperature given by modeled TF for same input

magnitude as applied during real measurement to the input of TF model. Then by observing and comparing the time response graph of real measurements and output of proposed TF, we hand tune the value of parameters to obtain optimum output from the purposed TF model of PVC temperature in EO. The optimum value for the parameters we achieved are K=14.01, T=9000, τ=2400 and the graph of comparison is shown in figure 5. Thus the proposed TF model for the PVC temperature in EO is given in Equation 8.

$$G(S) = \frac{14.01}{9000S+1} e^{-2400S} \quad (8)$$

The output time response of estimated TF given in Equation 8 and time response from the real measurement is shown in the figure 5. From it we can say that the graph of measured PVC temperature and the graph of PVC temperature given by estimated TF model are mostly overlapped. So the estimated TF model for the change in the PVC temperature in the EO is adequate and it can be used to study the PVC temperature controlling process.

4. CONCLUSION

In small scale PVC insulated wire manufacturing industries, there is need to make raw PVC moisture-free before insert it in the extruder and also control this moisture-free temperature. For that purpose they use the Electric Oven with tray arrangement to fill the PVC. So to control PVC moisture-free temperature we have to design a controller. The designing of controller using real system of EO is uncomfortable and time consuming. To bypass it we estimated a simple first order plus dead time TF model for the moisture-free PVC temperature placed in EO.

The real time behavior of PVC temperature placed in EO was collected using a data logger system. Using the step-up response of PVC temperature we estimated a first order TF by the process reaction curve method. Using the function 'fmincon' in MATLAB we estimated the TF parameters value. To verify the estimated TF, a simulation model is constructed using Simulink toolbox of MATLAB. Then by observing the both responses we again tune it to achieve the response closer to the real measurement. Finally the achieved TF model shows the closely representation of the real PVC temperature behavior in EO. This estimated TF can be used to design and develop virtually any type of controller to control the PVC temperature and then applied to real process. Thus we saved the time and also the power required for iteratively doing the real experiment during design of controller.

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