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System Identification using Closed Loop data for Power Plant Applications

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Abstract:
This paper presents system identification technique, using direct method, for deriving transfer functions of different sub-systems of a thermal power plant. The transfer functions thus derived can be used for predicting the performance of the subsystem under normal and disturbed conditions which helps in tuning the controllers. Three critical controllers of thermal power plant namely, Air flow, Fuel flow and O2 controllers have been chosen to carry out the study.

Key words: *System identification, continuous time systems, time domain, closed loop test; numerical methods; thermal power plant loops*

1.Introduction

Distributed Control System (DCS) which is a very important and integral component of thermal power plants has evolved into a powerful asset for the modern power plants. DCS vendors have been continuously striving to improve their systems in order to be competitive. They harness the power of state of the art hardware and software to provide reliable means of control improve operational efficiency and process optimization. In the last several years, much interest has been devoted to a study of modern system theory, with an emphasis on control. An integral and essential ingredient of most system theory problems is the need to know the system and make use of System Identification techniques. System Identification is the process of determining a difference equation or differential equation (or the coefficient parameters of such equations) such that it describes the physical process in accordance with some predetermined criterion. The models can be derived using the input-output data collected either in frequency domain or in time domain. The frequency domain data based methods are usually applied offline and require an estimate of the Frequency Response Function (FRF) of the system. When compared to frequency domain, the time domain measurements are easy and availability of recorded data is very high and a number of online time domain methods are already available. In the time domain, the input-output data has to be collected after the system is subjected to a natural or created disturbance which can be an Impulse, Step, Ramp, Sine or any other known signal type which is amenable to mathematical manipulation. An additional factor to be considered while collecting the data is presence or absence of initial conditions and Noise.

A dynamic engineering system is usually nonlinear and complex in nature. The system dynamics [2] may vary significantly with changes of operating conditions. Although, the use of a single nominal linear model under one operating condition is inadequate to represent any system, experience suggests that in most cases it is sufficient for control applications. It is against this background that most of the systems are approximated to either first or second order models and the identified models are used for tuning the control parameters of the PID controllers in plants. Both data collection and model identification must be done using the DCS through a digital computer. On the other hand, as the process is of continuous-time nature, its dynamic model can be described best in terms of differential equations. Thus our problem may be stated as determining a continuous-time model from samples of input-output data collected in digital domain.

There System Identification methods can be broadly categorised as Direct methods & Indirect methods. In the case of Direct methods the parameters of a continuous-time model are estimated from the input-output data, using numerical methods. In the case of Indirect method, the problem is split into two parts. The first part estimates the parameters of a discrete-time model from the input-output data, while the second part determines suitable continuous-time model that is equivalent to the discrete-time model obtained for the given sampling interval.

2.Statement Of Problem

Any multi variable continuous system can be represented by linear state space equations [1] of

the following form.

$$\dot{\boldsymbol{x}}(t) = \boldsymbol{A}\boldsymbol{x}(t) + \boldsymbol{B}\boldsymbol{u}(t),$$
$$\boldsymbol{y}(t) = \boldsymbol{C}\boldsymbol{x}(t) + \boldsymbol{D}\boldsymbol{u}(t),$$

The problem of system identification may be stated as estimation of model parameters A,B,C & D from a set of input-output data u(.kT). and y(.kT). for k . 0, 1, 2,,.,. , N, where N is a suitable large number. It may be noted that the matrix D represents direct coupling between the input and the output, and will be zero for strictly proper transfer functions. Without any loss of generality, this is assumed to be the case. It should be noted that none of the matrices A; B, and C are unique for a system with a given input-output description.

Assuming a special canonical form for the system state equations in either the continuous-time or the equivalent discrete time models overcomes this problem and also minimizes the number of parameters to be estimated. It should also be noted that it is implicitly assumed that the order of the linear state space model is known, and that the sampling interval [7], which is dependent on the time constant of the system has been suitably selected. In practice, both of these are important, and have been subjects of considerable research [3-7]. The problem is further complicated by the fact that the available data is usually contaminated with random noise that creeps in either through inherent plant disturbances or through errors in data acquisition and measurement.

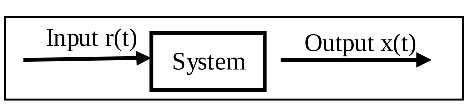

Figure 1: Open Loop System

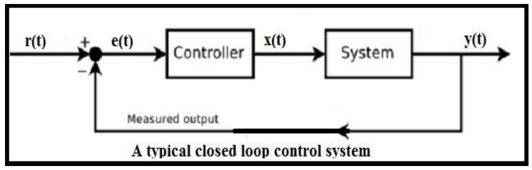

Figure 2: Closed Loop Control System

System Identification gives best results when the input-output data is collected from an open loop test as depicted in Fig 1.a, as the effects of controller, actuator etc are removed. However, in practice, as it is impractical to conduct open loop tests, closed loop tests, as shown in Fig 1.b are performed for the identification experiment. The reason being that, either the plant is unstable or it should be in closed loop control for production, economic or safety reasons, or that the plant has inherent feedback mechanism. Identification using closed loop test data can be classified as follows.

- Method-1: Use basic prediction error method in a straight forward manner, use the output ‘y(t)’ & the input ‘x(t)’ in the same way as for the open loop operation.
- Method-2: Identify the closed loop system from reference input ‘r(t)’ to output ‘y(t)’ and make use of controller information to identify the open loop system,
- Method-3: Consider ‘y(t)’ and ‘x(t)’ as outputs of a system driven by ‘r(t)’. Recover knowledge of the system & controller from the joint model.

3.Application

The control loops in Thermal Power Plants being large in number and varied in nature, provide an ideal platform for Process control engineers to experiment with new control strategies and algorithms. System Identification is implemented by applying Method-1, using data collected from power plant simulator for the Air flow, Fuel Flow & O2 Level loops. The loops have been studied and it has been verified that a simple first or second order model is good enough for their control.

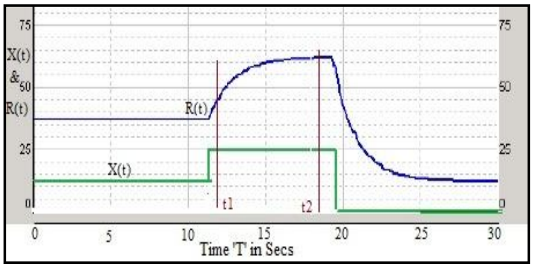

Figure 3: A system's time domain response

$$G(s) = \frac{X(s)}{R(s)} = \frac{g}{s + a}$$

Figure 4: Transfer function in s-domain

Given a system response as in Fig.2 (i.e. given values of x(t) & r(t)), and given a first order system transfer function as in Fig 3, the values of 'a' & 'g' have to be evaluated to identify the system. The transfer function can be represented by the equations given below.

$$x'(t) + x_0'(t) + a.x(t) + a.x_0(t) = g.\,r(t) + g.r_0(t) \quad \text{------------------} \ (1)$$

$$x'(t) + a.x(t) + (x_0'(t) + a.x_0(t) - g.r_0(t)) = g.\,r(t) \quad \text{------------------} \ (2)$$

Where x'(t) is the first order derivative of x(t), g is system gain, $x_0'(t)$, $a.x_0(t)$ & $g.r_0(t)$ are the terms that contribute to the initial condition. The solution is obtained using numerical methods. The dynamics of any system can be captured from its response to a pulse, step, ramp or other deterministic input signals. The step response is a convenient way to characterize the process dynamics because of its simple physical interpretation. The model thus obtained is more accurate. Further creating a Step disturbance is easy and probably the worst and widely prevalent disturbance encountered by systems in real life. Due to these reasons, system identification based on step response is a common practice. However, creating a step at x(t) in closed loop is impractical and considered best avoided as it affects the life of the actuators. As a practical and useful alternative a ramp based response is considered and tested. The closed loop response data (t, x(t), y(t)) for a step disturbance at r(t) is collected. The segment of data where in the x(t) is a ramp or close to a ramp and where the system transients are present in y(t) is identified. The approach classified as Method-1 above, is applied on the selected segments of data and the transfer function is evaluated. The model output y'(t) is calculated by replacing the 'system' in Fig1b with the above identified model. The technique is applied to all the three loops and it is found that the results as depicted in Fig.4, Fig.5 & Fig.6 below are fairly accurate

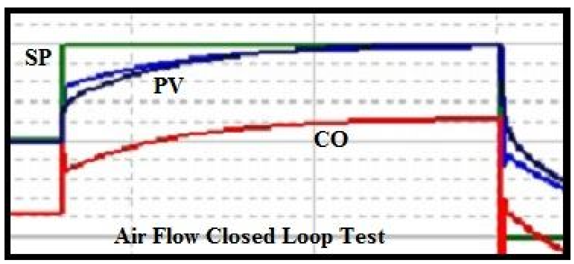

Figure 5: Air Flow Test

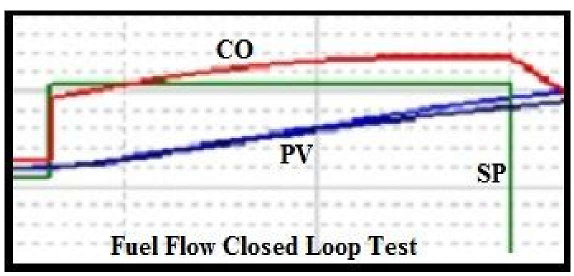

Figure 5: Fuel Flow Test

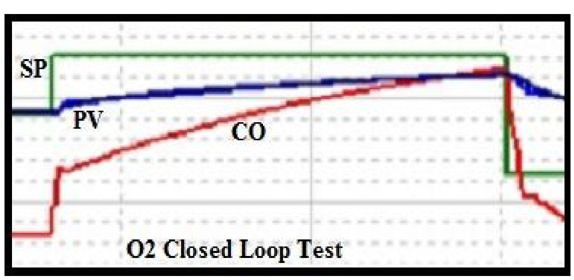

Figure 6: O2 Level Test

4.Conclusion

In this paper, System Identification using the Direct approach method as stated above has been applied on the closed loop test data for three different control loops of the thermal power plant. The data has been collected from the thermal power plant simulator using appropriate sampling time for all the three loops. It is verified that making the sampling interval too small is almost as bad as making it too large. Thus, in practice, prior knowledge of the largest natural frequency of the system is desirable. In Fig.4, Fig.5 & Fig.6 the Set Point step disturbance (closed loop test) is shown in green colour. The Controller Output (CO) is in red, the Process Value (PV) is in light blue & the Model Output is in dark blue. In all the cases the Model Output is close to the Process Value. The models thus identified can be used for system analysis & tuning of controllers. The methods can be used in online mode for identification of plant model and control loop tuning parameters over the plant's entire range of operation for implementing adaptive control. However, rigorous testing is required to verify the applicability of the model at all operating points to establish the applicability of the method for any critical online applications.

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