ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

Mathematical Modeling and Analysis of Dynamic Response of RTD using MATLAB

Surankumar V. Sawai[1], Vidya Aswar[2], SadikTamboli[3], Meera Khandekar[4]

PG Student, Dept. of Instrumentation & Control, College of Engg, Pune, Maharashtra, India[1]

PG Student, Dept. of Instrumentation & Control, College of Engg, Pune, Maharashtra, India[2]

PG Student, Dept. of Instrumentation & Control, College of Engg, Pune, Maharashtra, India[3]

Associate Professor, Dept. of Instrumentation & Control, College of Engg, Pune, Maharashtra, India[4]

ABSTRACT: Reliability in extreme conditions of the RTDs have made them widely used in process industry for temperature measurement. They have good calibration and fast dynamic response time, as compare to other temperature sensor and these are important characteristic while selecting sensor. The number of problem that can affect the response time of RTDs: dynamic response time, failure in insulation, loose connection between extension lead, thinning of sensing wire, EMF effect, seeping of chemical from connection head into thermowell, and erroneous indication. The objective of this paper is to analysis and study of the time constant of different Resistance Temperature Detector (RTDs) used in process. The Resistance Temperature detector used in this experiment is Pt100 bare, Pt500 thermowell, Pt1000 sheath. There was three main purpose of this study. The first was to demonstrate dynamic behaviour of RTD. The second was, by means of time domain analysis to find out model of RTD using System Identification Toolbox. The third purpose was to understanding the different parameter that affect the dynamic response of RTD.

KEYWORDS: Resistance Temperature Detector, Time Constant, Dynamic Response, Thermowell, MATLAB, System Identification Toolbox.

I.INTRODUCTION

In Industry critical process parameter like temperature are measured using Resistance Temperature Detector (RTDs) and thermocouple. Temperature measurement in any process should be accurate and precise and play the important role in the quality of the product and in turn increase the efficiency of process. Resistance temperature detectors, generally refereed as RTDs, are used for temperature measurements. RTDs are made up of metal like platinum, copper and nickel, who's working principle is that the resistance of a metal changes with temperature. RTDs work on a basic correlation between metals and temperature. As the temperature increases, resistance of metal to the flow of electricity increases. Most widely used RTD is platinum because of accuracy over the wide range with high degree of standardisation, it also has the linearity over the wide range among the other two metal.

Change in Resistance of an RTD with respect to the temperature can be express in following equation.

II.DYNAMIC RESPONSE OF RTD

The plunge test method and the self-heating test method are two widely experimental method for measuring the dynamic response and for analysis dynamic behaviour of temperature sensors. The Plunge test is basically used in laboratory. The typical method to identify the dynamic behaviour is to describe the mathematical model using the differential equation, that describe the system's output, which differ for the two test methods. With the help a proper transfer function describing the model for the self-heating test, we can possibly identify the sensor's dynamic response for the plunge test.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

The dynamic response of resistance temperature detector can identified theoretically, experimentally or by using a combined these two method. The main disadvantage of a solely theoretical method is that it demand for an exact and detail knowledge of the

Sensor's geometry, the properties of materials of which RTDs are manufacture and the working conditions.
This lead us to define the structure of the model theoretically, while the parameters are identified by using an appropriate experimental test method.

RTDs are placed in the path of flow to measure the fluid temperature by means of convective heat transfer. The dynamic response of RTDs depends on the thermal conductivity and heat transfer between their components (including the thermowell if this exists). In practice, the response time of the sensor is defined as ramp time delay.
In the usual application, RTDs are modelled as an only one time constant dynamic system, tau= RC, being R the surface heat-transfer resistance of the convective heat transfer process and C the device heat capacity. Beside R_1/hA, being h the film's heat transfer transfer coefficient and A the sensor area;
and C = mc, being m the device mass and c its specific heat capacity. At a certain temperature, h depends on the process conditions, whereas c is an inner parameter of the sensor. The value of T coincides with the ramp time delay. If the process conditions remain constant, the in situ measurement of T allows monitoring the sensors and foresee breakdowns before they affect the readings accuracy.

The RTDs dynamics can be modelled by applying the partial differential equation for the heat transfer. In order to reduce the problem to one dimension, it must be taken into account the cylindrical symmetry of the sensor, and the convective heat transfer is introduced as a boundary condition. The temperature gradient is not considered as negligible, it has a radial dependency.
Different methods has developed for detecting these sensors are on-line in operating plants. For the accuracy cross-calibration method is used and for the In-suit response of the temperature sensor Loop Current Step Response are developed. These methods are widely used and are most effective among all other method. Most sensor can last for more or less 10-40 years unless the engineer suspect the problem in the design, installation of the temperature sensor.

III.EXPERIMENTAL SETUP

Remote Trigger Temperature Setup is used in this experiment. This set up consist of the three RTDs \& three K-type thermocouple with one master reference K-type thermocouple. Both the RTDS and thermocoouple are with bare, sheath and thermowell. For this study we have consider dynamic characteristic of the RTDs only.

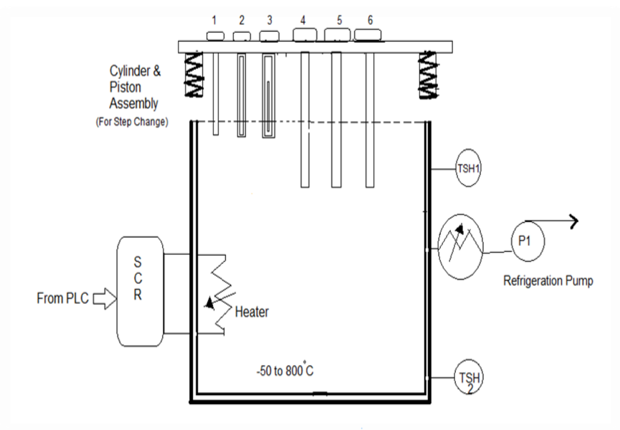

Fig. 1 P&ID for Temperature Loop

The set up work in different mode depending ranging from the manual mode to the operating from the PLC and SCADA. This set up has heating chamber and refrigeration chamber to analysis of the response of the RTDs and thermocouple. The range of this instrument is -50 °C to 800°C with allowable safe limits for experimentation is 300°C.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

Experiments are carried out in the heating chamber and response of RTDs are verified, in this paper we have taken the reading and done the analysis for different RTDs for heating chamber.

Fig. 2 Experimental Set Up

IV.EXPERIMENTATION

A number of experiments have been performed to evaluate the performance of the RTDs. The response of the RTDs was closely monitored and the best possible data were used to derive the mathematical model of the three RTDs. The number of experiment were carried out in consideration to the fact the different environment condition affect the dynamic response of RTDs, out of these experiment most possible accurate data were taken to derived the mathematical model of the RTDs using system identification toolbox.

- **System Identification Toolbox**

This toolbox is a MATLAB-based software package for the estimation of dynamic systems.
System identification toolbox is software package that let you construct the mathematical model from the measured input output data. Some of system are not easily modeled from first principle, for such system we used the measured input output data to construct the mathematical model using system identification toolbox which is data driven approach.
Model derived from the system identification toolbox are used for the simulation purpose or for the design of the control system with the help of control system toolbox, model predictive toolbox. This toolbox capable of handing the linear and nonlinear model to data, process known as black box modelling. This toolbox consist of different model low-order process models, transfer functions, state-space models.

1. Transfer function determination.
2. Estimation of the ordinary differential equations.
3. Identification of the time series function.

- **Step to derive Transfer Function Model**

1. **Importing and manipulating data sets**.

   Import test data (time domain data, frequency domain data & data object) for estimating the model and validating results.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

2. **Preprocessing data**
   View test data, filter out noise, remove offsets, remove means and select range.
3. **Estimating and validating models**
   Deriving the transfer function model, state space model, process model, polynomial model & nonlinear model.

4. **Validation of result**.

V. SCADA OVERVIEW FOR RECORDING RESPONSE

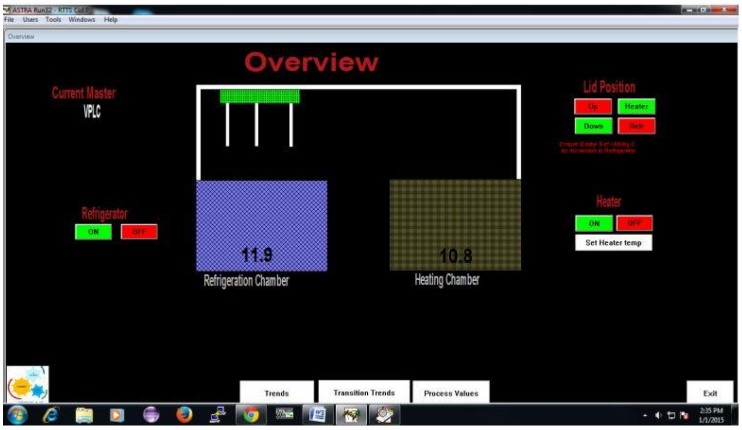

Fig. 1 SCADA Overview

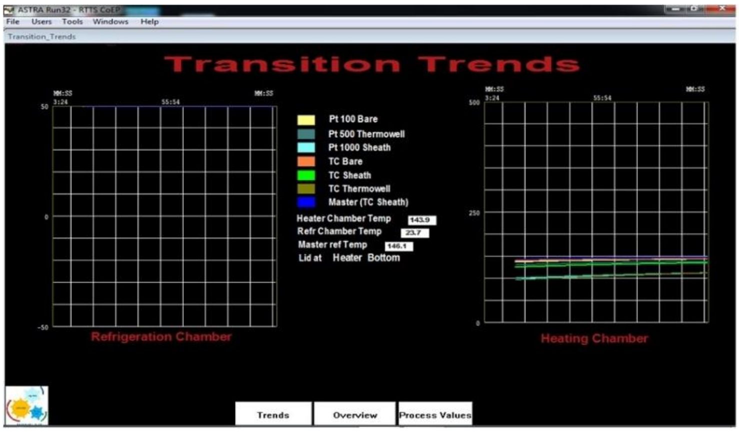

Fig. 2 Trends of different RTD & Thermocouple

VI.RESULT

After deriving the mathematical model of RTDs, its time constant and dynamic response is given with its transfer function.

1. **Pt100 bare**

Dynamic response of the Pt100 bare and its dynamic characteristic is given below along with the transfer function.

$$G(s) = \frac{0.9363}{s + 0.9224}$$

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

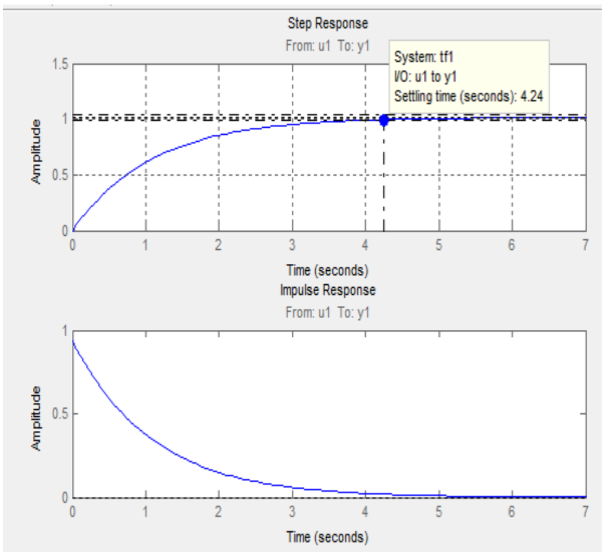

Fig. 1. Response of Pt100 Bare

- Settling Time = 4.24 sec
- Time Constant = 1.09 sec

2. Pt500 Thermowell

Dynamic response of the Pt500 thermowell and its dynamic characteristic is given below along with the transfer function.

$$G(s) = \frac{0.7154}{s + 0.7054}$$

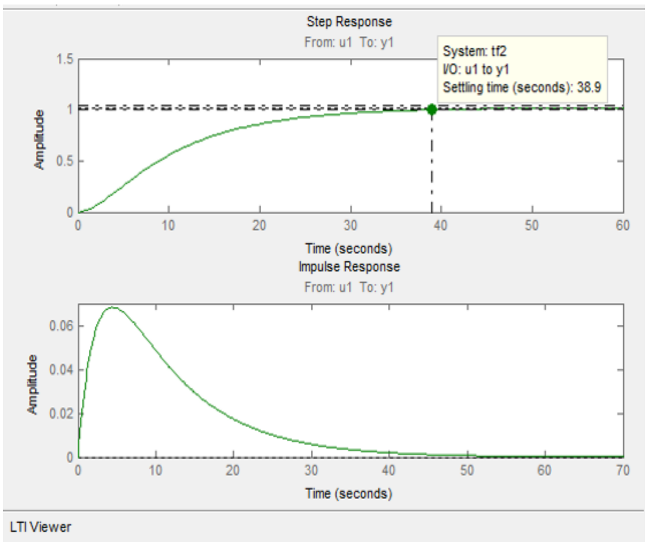

Fig.1 Response of Pt500 thermowell

1. Settling time = 38.9 sec
2. Time Constant = 9.89 sec

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

3. Pt 1000 sheath

Dynamic response of the Pt1000 sheath and its dynamic characteristic is given below along with the transfer function.

$$G(s) = \frac{0.6279}{S2 + 2.262S + 0.6134}$$

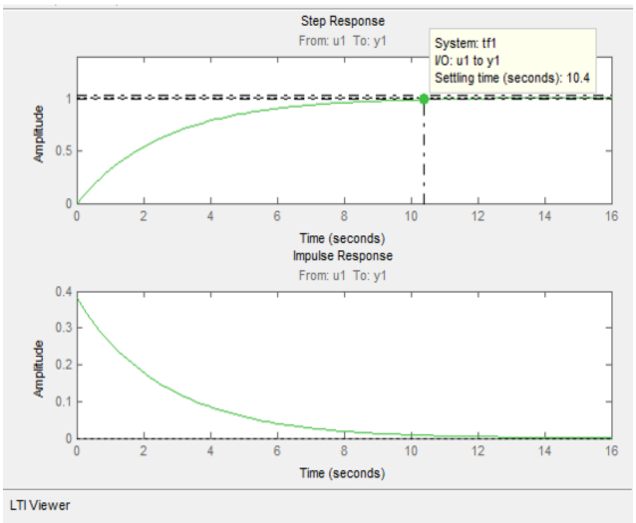

Fig.1 Response of Pt1000 sheath

- Settling Time = 10.4 sec
- Time Constant = 2.64 sec

VI.CONCLUSION

This paper describe the method for mathematical modelling of the RTDs. A simple model describing the step response of Pt100 bare, Pt500 thermowell, Pt1000 sheath was presented. They are susceptible to a range of potential problems, affecting both their accuracy and their response time. Therefore, dynamic response give the idea about the performance of the Resistance Temperature Detector.

The main limitation in this technique is to get the noise free data that can be used for development of mathematical model, this is because it will be difficult to derived mathematical model of sensor.

In order to modeled transfer function and system response, proper data have to be chosen. You have to repeat the modelling procedure several time to get the best suited transfer function, which can be compare with the system with the help of system identification toolbox.

REFERENCES

[1] M. Abo-Elmagd and A. Sadek, "Development of a model using the (MATLAB) system identification toolbox to estimate 222rn equilibrium factor from cr-39 based passive measurement", *Journal of Environmental Radioactivity.* Vol. 138, no.0, pp. 33 – 37, 2014

[2] H. Hashemian, J. Thie, B. Upadhyaya, and K. Holbert, "Sensor response time monitoring using noise analysis", *Progress in Nuclear Energy,* Vol. 21, no. 0, pp. 583 – 592, 1988.

[3] H. Hashemian and J. Jiang, "Nuclear plant temperature instrumentation", *Nuclear Engineering and Design,* Vol. 239, No. 12, pp. 3132 – 3141, 2009.

[4] M. Imran and A. Bhattacharyya, "Thermal response of an on-chip assembly of (RTD) heater, sputtered sample and microthermocouple", *Sensor and Actuators A: Physical,* Vol. 121, no. 2, pp. 306 – 320, 2005.

[5] C. Montalvo, A. Garca-Berrocal, J. Bermejo, and C. Queral, "Advance surveillance of resistance temperature detectors in nuclear power plants", *Annals of Nuclear Energy,* Vol. 65, no. 0, pp. 35 – 40, 2014.

[6] B. Ninness, A. Wills, and A. mills, "Unit: A freely available system identification tollbox", *Control Engineering Practice,* Vol. 21, no. 5, pp. 631 – 644, 2013.

[7] S.Swn, T. Pan, and P. Ghosal, "An improved lead wire compensation technique for conventional four wire resistance temperature detector", *Measurement,* Vol. 44, no. 5, pp. 842 – 846, 2011.