TPS LINAC TEMPERATURE MONITORING SYSTEM

C. L. Chen[†], H. P. Chang, K. L. Tsai, C. S. Fann, K. K. Lin
National Synchrotron Radiation Research Center, Hsin-chu, Taiwan

Abstract

TPS Linac has been providing with electron beams which conform to the specifications to the requirement since 2014. Firstly electrons are extracted from electron gun (e-gun), and they are accelerated and gained energy from 90 keV to 150 MeV in three linear accelerating sections. Then electron beams are successfully injected to the booster ring via Linac to Booster (LTB) transport line. Providing a stable and reliable operating system is next priority objective, so a temperature monitoring system is established. This temperature monitoring system is used to monitor the temperatures for each Linac sub-system and its surrounding environment. By using this temperature monitoring system, it helps to understand the relation between beam energy and working temperature for each sub-system, when Linac is under normal operation. This report will detail the temperature monitoring components, including thermocouples, PLC thermal modules, PLC programming and graphic user interface (GUI). By integrating with EPICS, this monitoring system is becoming a complete solution for ensuring any possible influence due to thermal effects.

INTRODUCTION

Firstly, in order to monitor the linac hardware to improve better stability, a thermal monitoring system is established to acquire a real-time temperature variation during the system is operating. Close-loop water cooling circuits are used in acceleration structures, such as bunching cavity and three linear acceleration sections. Unsteady operating temperature can cause energy variations of the electron beam [1]. Therefore, it is necessary to develop a temperature monitoring system to monitor the operating temperature for these thermal-sensitive acceleration structures.

Secondly, the motivation of developing this temperature monitoring system is using a Siemens S7 PLC system, which is same as the original TPS Linac control system. There are many commercialized tools can be selected to monitor the temperature in this case. However, it is a good opportunity to study Siemens PLC program as a case study. This study is not only developing a thermal monitoring system with Siemens S7 PLC program, but also integrating with EPICS for an additional diagnostic function in TPS Linac [2]. The red dot block in Figure 1 shows the systematic diagram for both PLC program and EPICS. By completing this study with Siemens PLC program, it can help to understand TPS Linac control system and enhance the ability of trouble-shooting.
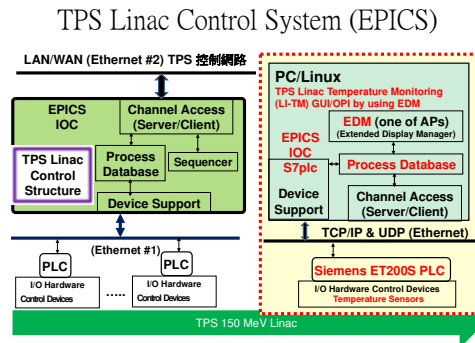
---

† email address: clchen@nsrrc.org.tw

Figure 1: Network diagram for TPS Linac control system.

THERMOCOUPLES

There are many types of thermocouples, each with its own unique characteristics in terms of temperature range, durability, chemical resistance and application compatibility [3]. Type K thermocouple is selected as the temperature sensor in this study, because it is the most common type of thermocouple with low cost and proper temperature range. A thermocouple is an electrical sensor consisting of two different conductors forming electrical junctions at different temperatures [4]. The circuit layout between thermocouple and thermal meter is shown in Figure 2. This block diagram illustrates the connection between thermocouple and the thermal meter. The overall circuit consists of three parts: a thermocouple, a junction box and thermal meter. The junction box is a terminal block for connecting a thermocouple with an extension cable to the thermal meter.
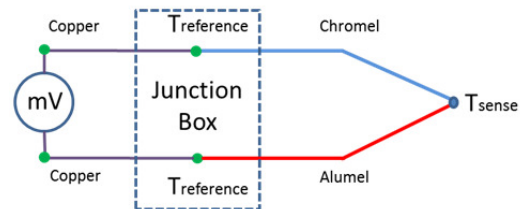

Figure 2: Standard circuit layout for thermocouple application [4].

The sense temperature (T_{sense}) can be obtained by the following equation:

$$E(T_{sense}) = V + E(T_{reference}) \qquad (1)$$

Where

E(T) is a characteristic function of the thermocouple;

V is the measured voltage;

$T_{reference}$ is the reference junctions' temperature.

So the above equation shows that there are three parameters, (E(T), V and $T_{reference}$) should be obtained in order to find the sensing temperature (T_{sense}). Most commercial thermal meters are hidden from the end users about the

reference junction temperature ($T_{reference}$), voltmeter, and equation solver. By establishing a thermal monitoring system with Siemens PLC thermal modules, the reference junctions' temperature ($T_{reference}$) is very important for obtaining a correct sensing temperature. To obtain the correct sensing temperature is not only sufficient to measure voltage. The temperature at the reference junctions ($T_{reference}$) must be known. This is the key for establishing a correct temperature monitoring platform. A PT100 is installed inside the terminal junction block for obtaining an accurate reference temperature. Figure 3 shows the terminal junction block with a PT100 sensor. This PT100 is used to measure the temperature at the junction box to compensate for any thermal variations [5].

Figure 3: Junction Box with a PT100 senor.

There are ten (10) thermocouples which are mounted on a bunching cavity and three linear acceleration sections. One thermocouple is on the bunching cavity and three ones are on upstream, middle and downstream of each linear acceleration section. So there are 10 in total. Figure 4 shows the photo of the K-type thermocouple's tip with a kapton tape for providing a good electrical insulation at low thermal gradients. A red rubber cork is used to mount the k-type thermocouple tightly on the linac section in Figure 5, and Figure 6 shows ten thermocouples' locations.

Figure 4: K-type thermocouple with a kapton tape for electrical insulation at low thermal gradients.

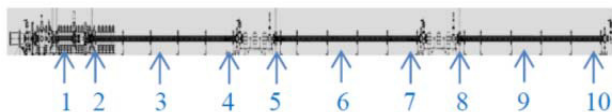Figure 5: A K-type thermocouple is mounted on the linac section with a red rubber cork.

Figure 6: Locations for 10 thermocouples.

PLC MODULES

There are many temperature measurement tools in the market, the computer interface between the hardware and programming software must be taken into account. The compatible controlling software is a very important issue with the Linac system. In TPS Linac controlling system, EPICS is used as the main controlling frame. All controlling logics were built with Siemens PLC controllers to connect to EPICS for user interface. By the existing Siemens PLC controllers, the temperature monitoring system is constrained with the same type PLC. However, it is a good opportunity to learn and understand both Siemens hardware and its PLC program codes for the thermal measurements. First of all, a Siemens PLC controller is chosen as the main temperature monitoring system. "Totally Integrated Automation Selection Tool", so called as TIA, is used to select a proper Siemens PLC set for temperature measurements. The TIA Selection Tool offers wizards for selecting the required devices and modules for meeting the needs for the measurement. There are also configuration wizards for selecting modules and accessories as well as for verifying that the functionality is in order. It is a very convenient tool for setting the PLC module configuration properly. Figure 7 shows the device graphic of Siemens ET200S. This PLC configuration is used to monitor TPS Linac system in this report. The main component is Siemens CPU controller IM151-8, which is installed in the slot of 1. A power module (PM-E 24..48 VDC) is a basic module for supplying DC voltage in Slot 2. A 2-channel RTD (Resistance Temperature Detector) thermal module is installed in Slot 3 for reference temperature. Then there are 5 sets of 4-channel thermocouple module and one set of 2-channel thermocouple module are installed in Slot 4~9. In this configuration, there are 22 thermocouples can be used in the system. One digital input (DI) and one digital output (DO) module are installed in the last two slots 10 and 11, respectively. DI and DO modules are used for other software training purposes.
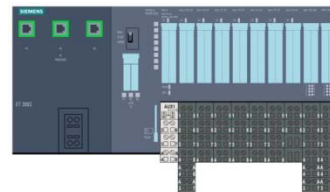

Figure 7: Temperature monitoring configuration with Siemens ET200S.

STEP 7 PROGRAMMING

The main block is called OB1 in Siemens Step-7. OB1 is "main Program" block for continuous scanning of program codes. OB1 stands for organization block (OB). In the temperature measurement setup, OB1 codes are simple and can be separated into 4 parts. They are:

1. TCP/IP communication to control system
2. Reset initial communication start
3. Calculation for thermocouples and PT100
4. Check digital input/output (DI/DO) for train-

07 Accelerator Technology

T31 Subsystems, Technology and Components, Other

ing purpose.

These four parts are written into 4 networks. Each network calls its own function block, such as FB81, FC11 and FC12. These function blocks implement the communication connections, measure the thermocouples' temperature, and record all the temperatures in an assigned location.

All temperature data, which are measured from 10 K-type thermocouples and two PT100 RTD, should be recorded from PLC. A date block is used for storing all measured data. This data block is named as DB11. DB11 contain only numeric values for temperatures. The other user program, such as EPICS, LabVIEW or other controlling programs, can access the data in DB11 with proper Ethernet IP address and data block addresses. The following table (Table 1) contains the thermocouple name, its PLC hardware address, and saved block address.

Table 1: Hardware Name, PLC Address and Saved Block Address for Each Temperature Measuring Point

Name	Read Address	Save Address
Buncher Temp	PIW288	DB11.DBW12
Linac 1_1 (up)	PIW290	DB11.DBW14
Linac 1_2 (middle)	PIW292	DB11.DBW16
Linac 1_3 (down)	PIW294	DB11.DBW18
Linac 2_1 (up)	PIW304	DB11.DBW20
Linac 2_2 (middle)	PIW306	DB11.DBW22
Linac 2_3 (down)	PIW308	DB11.DBW24
Linac 3_1 (up)	PIW320	DB11.DBW26
Linac 3_2 (middle)	PIW322	DB11.DBW28
Linac 3_3 (down)	PIW324	DB11.DBW30
PT100_TC1 (refer Temp)	PIW272	DB11.DBW32
PT100_TC2 (outside temp)	PIW274	DB11.DBW34

GRAPHIC USER INTERFACE (GUI)

A graphic user interface is established to allow user to read the actual temperatures in the system near the PLC rack. A 4.3-inch touch panel monitor, made by Nahua, is used. It provides an easy Ethernet connection, sensitive touch operation, and a colourful compact design. In addition, its user-friendly and powerful software provides editors to implement a visible graphical interface features. All 12 temperature readings can be displayed in one screen. Each numerical indicator can be set to obtain the temperature value from Siemens' assigned address. This touch panel helps users to read the real-time temperature in the system.

RESULT AND DISCUSSIONS

This temperature monitoring system starts to operate with EPICS to record the temperature variations of TPS linac system and the temperature inside and outside of Linac Tunnel. This temperature monitoring system can be operated 24 hours a day, 7 days a week without any disruptions. This is one advantages of using PLC controller for providing a high reliability measuring tool. During a machine shut-down period for TPS maintaining purpose, the temperature variation of each temperature measuring point is recorded for 3 days under a normal air condition-

ing and the steady hot-water circulation. Table 2 shows the summary statistic results of over 2000 samples for each measuring point.

Table 2: Statistical Results for Temperature Sensors

Temp	1	2	3	4	5	6	7	8	9
Min	39.9	39.5	38.9	38.7	38.7	38.3	38.9	39.1	39.2
Max	40	39.6	39	38.8	38.9	38.5	39.1	39.2	39.3
Range	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1
Avg	39.9	39.6	38.9	38.7	38.8	38.4	39.0	39.2	39.2
σ	0.04	0.01	0.03	0.04	0.05	0.05	0.04	0.04	0.02

By taking over 2500 samples for each thermocouple within 3 days, Siemens PLC provides with a series of temperature data for statistical analysis. First of all, two PT100 RTDs show both temperatures inside and outside of linac tunnel. The room temperatures in these two areas are set to approximately 22°C. The temperature range is from 22.0°C to 22.4 °C max. This indicates that air conditioning is well controlled in TPS. Secondly, the temperatures in the buncher system and three acceleration sections are also controlled within a small variation (0.1~0.2 °C or $\pm$ 0.1°C). The statistical analysis shows linac system has an effective temperature controlling system. Both hot-water circulation coolers and the air conditioning can provide the linac system under a constant temperature with very small variation (<0.2°C or $\pm$ 0.1°C).

CONCLUSION

Together with K-type thermocouples with PT100 RTD reference sensor, Siemens thermal modules, Siemens Step-7 program, local user graphic interface and EPICS, this temperature monitoring system with Siemens PLC controller is a complete solution for real-time temperature monitoring. This function enhances the ability to trace the beam instability if any large temperature variations occur in the linac system. All temperature data can be saved as a database via EPICS system. This provides an easy access way for a long-term historical thermal data. This report also provides a good opportunity to familiar with Siemens PLC and its related programming codes. This helps to understand the fundamental controlling structure of TPS Linac system, which is operated with the same type of Siemens PLCs.

REFERENCES

[1] R. Dortwegt et al., "Improved Temperature Regulation of APS Linac RF Components," XIX Int'l Linear Accelerator Conference (Linac98), Chicago, IL, USA, August 23-28, 1999, pp. 1001-1003 (1999).

[2] H.P.Chang, C.L. Chen, K.L. Tsai, C.S. Fann, K.K. Lin, Y.S. Cheng and K.T. Hsu, " Study and Construction of the TPS LINAC Control System ", Internal report NSRRC-TR00261(2015), pp. 5-8.

[3] Type of Thermocouple, http://www.thermocoupleinfo.com

[4] Thermocouple, http://www.omega.co.uk

[5] "How to Prevent Temperature Measurement Errors When Installing Thermocouple Sensors and Transmitters" (PDF). acromag.com. Acromag. Retrieved 3 February 2017.