IOP Conference Series: Materials Science and Engineering

Design of the control system for the cryogenic distribution system of the European XFEL project

To cite this article: T Böckmann *et al* 2015 *IOP Conf. Ser.: Mater. Sci. Eng.* **101** 012173

Design of the control system for the cryogenic distribution system of the European XFEL project

T. Böckmann[1], J. Bolte[1], Y. Bozhko[1], M. Clausen[1], K. Escherich[1], O. Korth[1], B. Schoeneburg[1], A. Zhirnov[1]

[1]Deutsches Elektronen-Synchrotron (DESY), Notkestrasse 85, 22607 Hamburg, Germany

In order to produce pulsed electron beam with the energy of 17.5 GeV, the European X-ray Free Electron Laser (XFEL) linear accelerator is under construction. The XFEL accelerator will contain the linear accelerator (linac) and the injector. The XFEL cryogenic distribution system supplies the linac and the injector with cooling helium. The cryogenic supply of the linac is separated in parallel cryogenic sections called 'strings'.
Operation of the XFEL cryogenic distribution system is under the process control system for Experimental Physics and Industrial Control System (EPICS). A complementary component of EPICS is the Open Source software suit CSS (Control System Studio) providing an integrated engineering, maintenance and operating tools for EPICS as well as human machine interface. Cryogenic instrumentation used for operation and diagnostic is connected to PROFIBUS. More than 300 PROFIBUS nodes control the XFEL cryogenic system. DESY introduced the monitoring system based on Field Device Tool (FDT). FDT framework contains Data Tool Management (DTM) applications to examine the correct installation and configuration of all PROFIBUS nodes in real time.
This paper describes the control system for the XFEL cryogenic distribution system including all steps from engineering to the pre-service tests.

1. Introduction

The European X-ray Free Electron Laser (XFEL), which will be operated as research facility for multiple users, is currently under construction at DESY, Hamburg. The XFEL linear accelerator linac consists of 100 1.3GHz accelerator cryomodules subdivided into 9 strings. The XFEL Injector [1] contains two accelerator cryomodules, one 1.3GHz and the other 3.9GHz. The linac and the injector will be cooled by helium at 2K from the XFEL cryogenic distribution system consisting of distribution boxes, transfer lines, string connection boxes separating the strings, and feed and end caps. The components of the distribution system contain different instrumentation like e.g. temperature sensors, level meters, heaters, valves' positioners, etc. to be dealt by the control system. Basic ideas and principles of the DESY control system realized in the Cryomodule Test Bench (CMTB) [2] and the Accelerator Module Test Facility (AMTF) [3] were also implemented and further developed in the control system for the XFEL cryogenic distribution system.
Operation of the XFEL cryogenic distribution system is under the process control system for Experimental Physics and Industrial Control System EPICS. A complementary component of EPICS is the Open Source software suit CSS (Control System Studio) providing integrated engineering,

maintenance and operating tools for EPICS as well as human machine interface. CSS is used for all tasks e.g. projecting, programming and operating. It replaces the previous X-Window based tools of the EPICS software suite.
Cryogenic instrumentation used for operation and diagnostic is connected to PROFIBUS. More than 300 PROFIBUS nodes will control the XFEL cryogenic system. DESY introduced the monitoring system based on Field Device Tool (FDT). FDT framework contains Data Tool Management (DTM) applications to examine the correct installation and configuration of all PROFIBUS nodes in real time. All essential tools like the configuration tool for PROFIBUS, the configuration tool for EPICS databases, the programming tool for SNL (State Notation Language) programs, the configuration tool for alarm handling and the design tool for synaptic displays are available and integrated in CSS.

Each component of the XFEL cryogenic distribution system is equipped with its own control system structure which comprises individual EPICS IOCs and PROFIBUS links. This structure facilitates independent operations during commissioning and in the operation phase.

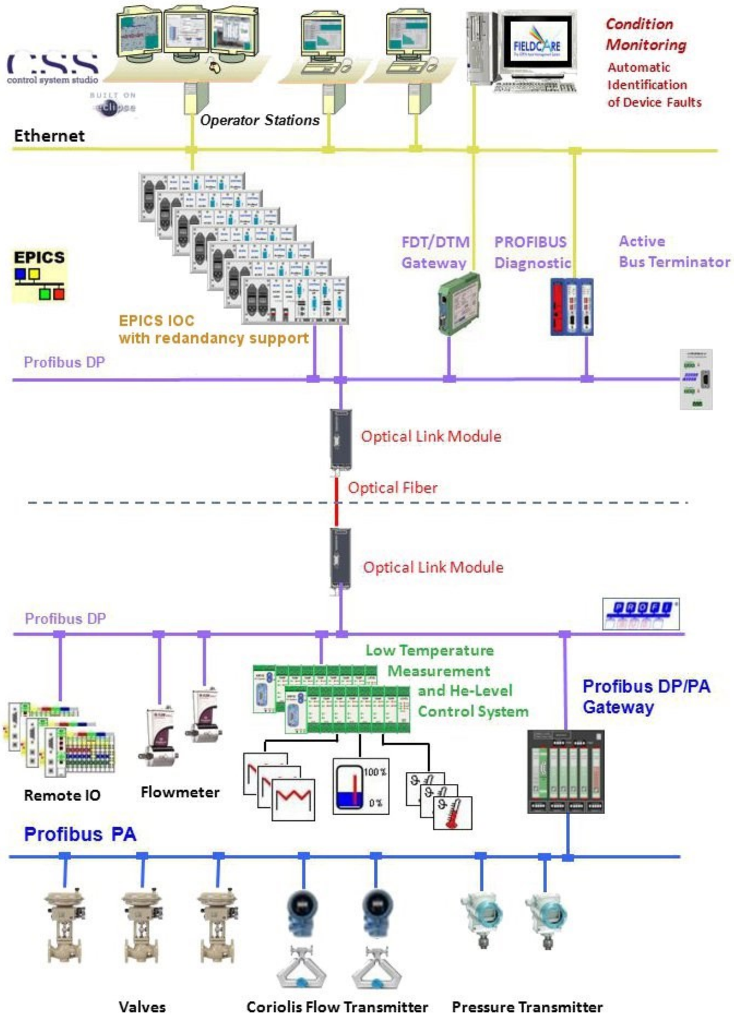


Figure 1: The EPICS based cryogenic control system uses distributed I/O. The selected field bus is PROFIBUS DP. All valves' positioners and most sensors are connected through PROFIBUS PA which also provides power. The in house developed low temperature measurement system is attached to PROFIBUS as well. Ethernet to PROFIBUS gateways provide access to the PROFIBUS components for the condition monitoring application.

The EPICS IOCs for the components of the cryogenic distribution system are installed in a dedicated computer room. Ethernet to PROFIBUS gateways provide access to the PROFIBUS components for the condition monitoring application and for PROFIBUS diagnostics. These are installed in the same location outside the XFEL tunnel.
The field devices are connected via fiber optical links with the IOC controllers. All valves' positioners and most sensors are connected through PROFIBUS PA which also provides power.

2. PROFIBUS Fieldbus

PROFIBUS is one of the most popular field buses for process control components in the world. Basically most of the intelligent sensors and actors are available with a PROFIBUS interface. PROFIBUS has the advantage that it is fully deterministic and therefore ideal for process controls. On the other hand it is very sensitive to malfunctioning components or misconfiguration. In order to fully separate the individual PROFIBUS lines not only logically but also electrically all of the lines are connected to the field by means of optical cables. This avoids potential grounding problems to the local subsystems or clusters of sensors and actors. These are connected by means of PROFIBUS DP / PA gateways to each other.
A PROFIBUS driver had to be written for the VxWorks operating system which is running on the IOCs. This is based on the source code written for Linux or Windows which is provided by the vendor of the hardware boards and guarantees long term independency from any new versions of the Windows operating system.

2.1 PROFIBUS Fieldbus configuration

Control System Studio CSS is the integrated environment tool for engineering, configuration and operation of the control system EPICS. This universal tool includes several configuration views for: PROFIBUS, process values (PVs), alarm PVs, edit state notation language programs (SNL), trend plotting and synaptic displays.

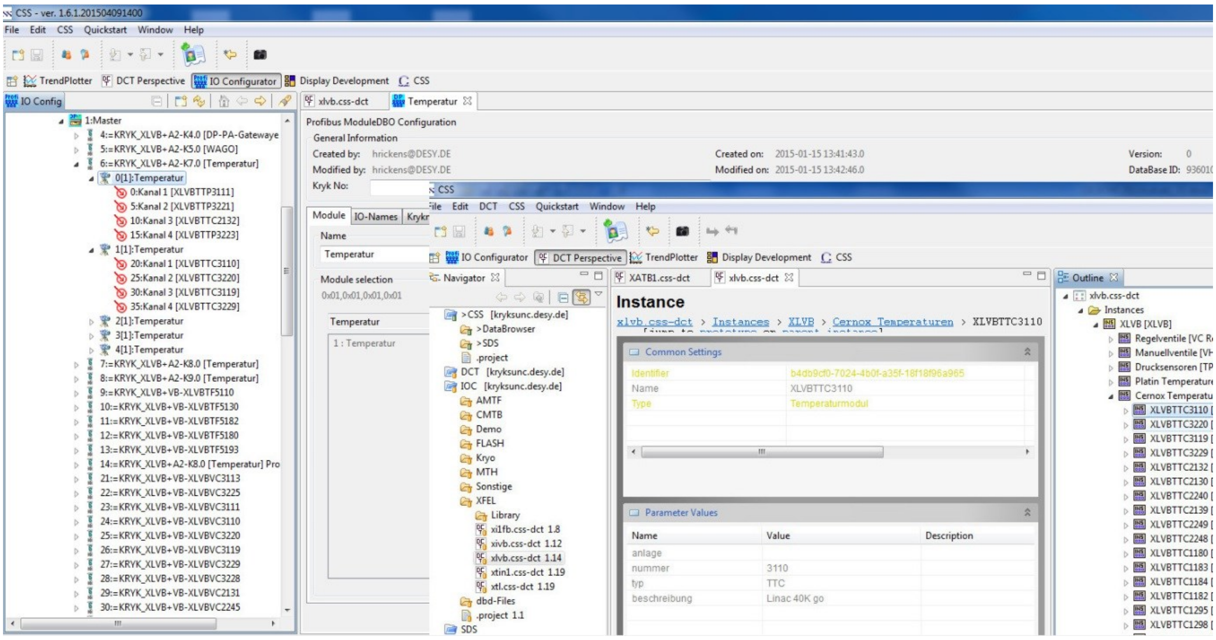
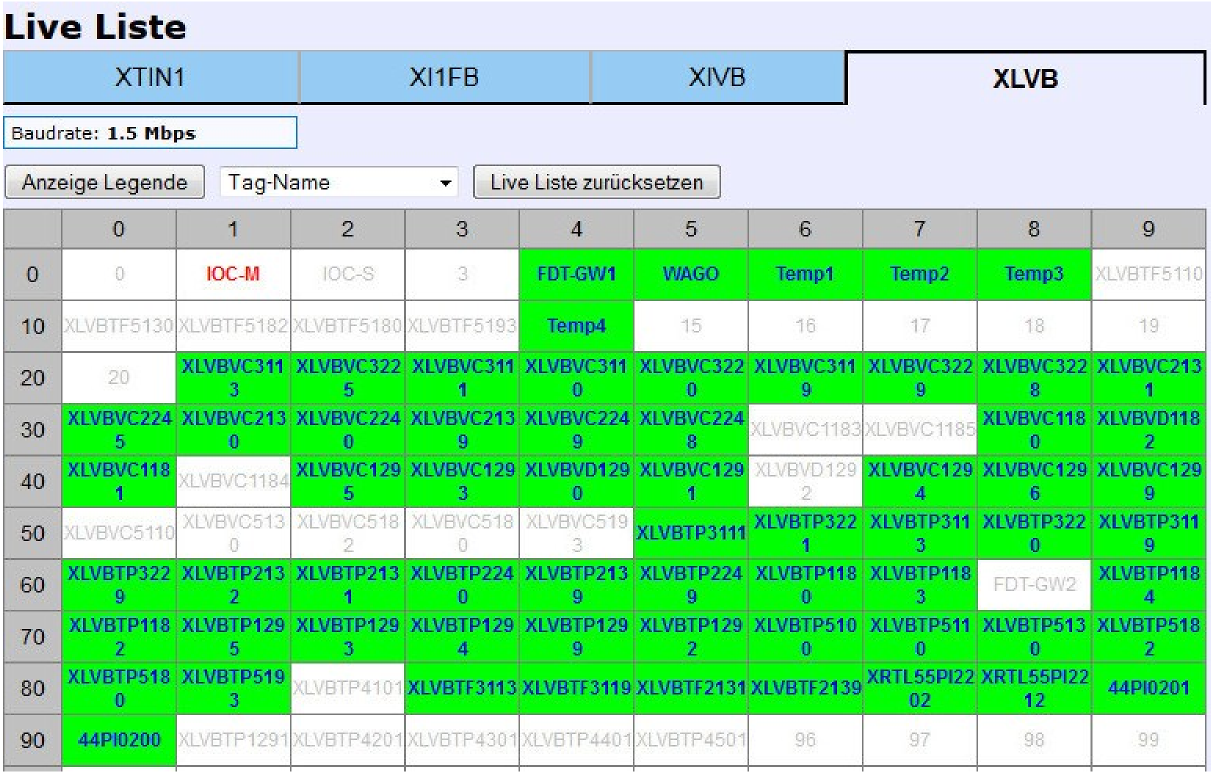


Figure 2: Screenshot of the PROFIBUS and PV configuration tools in Control System Studio (CSS).

IOP Conf. Series: Materials Science and Engineering **101** (2015) 012173 doi:10.1088/1757-899X/101/1/012173

After IO declaration in the CSS IO-Configurator Tool it will be possible to startup the PROFIBUS field devices. With the Web- Interface based diagnostic devices it is possible to examine the successful startup and operation of all field devices.

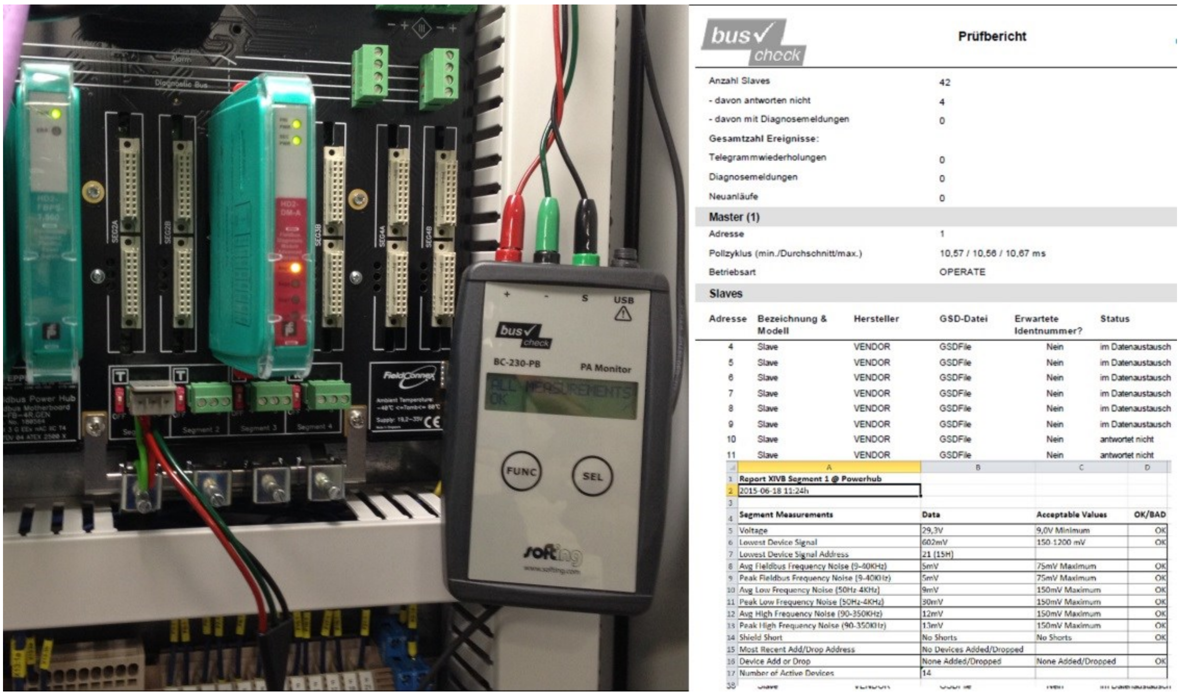


	0	1	2	3	4	5	6	7	8	9
0	0	IOC-M	IOC-S	3	FDT-GW1	WAGO	Temp1	Temp2	Temp3	XLVBTF5110
10	XLVBTF5130	XLVBTF5182	XLVBTF5180	XLVBTF5193	Temp4	15	16	17	18	19
20	20	XLVBVC3113	XLVBVC3225	XLVBVC3111	XLVBVC3110	XLVBVC3220	XLVBVC3119	XLVBVC3229	XLVBVC3228	XLVBVC2131
30	XLVBVC2245	XLVBVC2130	XLVBVC2240	XLVBVC2139	XLVBVC2249	XLVBVC2248	XLVBVC1183	XLVBVC1185	XLVBVC1180	XLVBVD1182
40	XLVBVC1181	XLVBVC1184	XLVBVC1295	XLVBVC1293	XLVBVD1290	XLVBVC1291	XLVBVD1292	XLVBVC1294	XLVBVC1296	XLVBVC1299
50	XLVBVC5110	XLVBVC5130	XLVBVC5182	XLVBVC5180	XLVBVC5193	XLVBTP3111	XLVBTP3221	XLVBTP3113	XLVBTP3220	XLVBTP3119
60	XLVBTP3229	XLVBTP2132	XLVBTP2131	XLVBTP2240	XLVBTP2139	XLVBTP2249	XLVBTP1180	XLVBTP1183	FDT-GW2	XLVBTP1184
70	XLVBTP1182	XLVBTP1295	XLVBTP1293	XLVBTP1294	XLVBTP1299	XLVBTP1292	XLVBTP5100	XLVBTP5110	XLVBTP5130	XLVBTP5182
80	XLVBTP5180	XLVBTP5193	XLVBTP4101	XLVBTF3113	XLVBTF3119	XLVBTF2131	XLVBTF2139	XRTL55PI2202	XRTL55PI2212	44PI0201
90	44PI0200	XLVBTP1291	XLVBTP4201	XLVBTP4301	XLVBTP4401	XLVBTP4501	96	97	98	99

Figure 3: At the first glance: State of PROFIBUS devices including Tag names.

The Figure 3 shows that some devices are missing at present. The other devices are in "data exchange" mode. They have no configuration and no parameter errors.

To verify the installation of the PROFIBUS DESY is using a PROFIBUS tester. There are several PROFIBUS testers available on the market. The bus tester checks the bus voltage, the signal noise, the signal level and short circuits of the cables against ground. The correct installation of the cables' shields will be checked too. The examination of a PROFIBUS segment takes a few minutes and the tester generates a test report automatically.



Prüfbericht

Anzahl Slaves	42
- davon antworten nicht	4
- davon mit Diagnosemeldungen	0
Gesamtzahl Ereignisse:	
Telegrammwiederholungen	0
Diagnosemeldungen	0
Neuanläufe	0
Master (1)	
Adresse	1
Pollzyklus (min./Durchschnitt/max.)	10,57 / 10,56 / 10,67 ms
Betriebsart	OPERATE

Slaves

Adresse	Bezeichnung & Modell	Hersteller	GSD-Datei	Erwartete Identnummer?	Status
4	Slave	VENDOR	GSDFile	Nein	im Datenaustausch
5	Slave	VENDOR	GSDFile	Nein	im Datenaustausch
6	Slave	VENDOR	GSDFile	Nein	im Datenaustausch
7	Slave	VENDOR	GSDFile	Nein	im Datenaustausch
8	Slave	VENDOR	GSDFile	Nein	im Datenaustausch
9	Slave	VENDOR	GSDFile	Nein	im Datenaustausch
10	Slave	VENDOR	GSDFile	Nein	antwortet nicht
11	Slave	VENDOR	GSDFile	Nein	antwortet nicht

Report XIVB Segment 1 @ Powerhub
2015-06-18 11:24h

Segment Measurements	Data	Acceptable Values	OK/BAD
Voltage	29,3V	9,0V Minimum	OK
Lowest Device Signal	602mV	150-1200 mV	OK
Lowest Device Signal Address	21 (15H)		
Avg Fieldbus Frequency Noise (9-40KHz)	5mV	75mV Maximum	OK
Peak Fieldbus Frequency Noise (9-40KHz)	5mV	75mV Maximum	OK
Avg Low Frequency Noise (50Hz-4KHz)	9mV	150mV Maximum	OK
Peak Low Frequency Noise (50Hz-4KHz)	30mV	150mV Maximum	OK
Avg High Frequency Noise (90-350KHz)	12mV	150mV Maximum	OK
Peak High Frequency Noise (90-350KHz)	13mV	150mV Maximum	OK
Shield Short	No Shorts	No Shorts	OK
Most Recent Add/Drop Address	No Devices Added/Dropped		
Device Add or Drop	None Added/Dropped	None Added/Dropped	OK
Number of Active Devices	14		

Figure 4: PROFIBUS PA segment checker and test reports

3. Low Temperature Measurements and liquid Helium Level Monitor with Integrated heater Interlock

A dedicated temperature measurements system integrated into the cryogenic controls has been developed in house (see FIGURE 5). Since both resistance and voltage measurements are supported by the system it allows to work with a number of different types of temperature sensors like e.g. CERNOX, TVO, PT100/1000, thermocouples, silicon diodes, etc. The measuring ranges are 0Ω to 200kΩ and 0V to 1.17V. For measuring resistances the system chooses an optimal current automatically achieving thus the accuracy of 0.02% for the range 33kΩ÷200kΩ and 0.01% for the range 0Ω÷33kΩ. Such accuracy makes possible using the system for the process controls and for precise measurements of cryogenic heat loads as well. The accuracy for voltage measurements is 0.02%±2µV. The system contains also an integrated protection to prevent sensitive temperature sensors like e.g. CERNOX from high currents.

Figure 5: Dedicated low temperature readout system and liquid helium level monitor

DESY has also developed a liquid helium level monitor based on using liquid helium level sensors of superconducting type such as e.g. 4.5K and 2K sensors from American Magnetics Inc. The energizing current can vary from 10 to 100mA. In order to reduce liquid helium losses the sensor is energized only for duration of sampling; sampling rate is 1Hz. The upper limits of the measured voltage and resistance are 120V and 2500Ω respectively – this allows the use very long liquid helium sensors. The monitor also contains an integrated sensor vacuum burnout protection.

The liquid helium level monitor is also designed so as to provide protection for the heater located in the same liquid helium bath (see FIGURE 6) against burning through. The protection is based on use of a thermocouple of type E or K integrated into the heater and on the value of liquid helium level in the bath. The monitor enables energizing the heater providing the heater temperature is below of a threshold and the level of liquid helium is sufficient. The thermocouple is directly wired to the monitor. Only thermocouples of floating type are allowed. The monitor provides also 0÷2.5V voltage for analog power supplies of the heater.

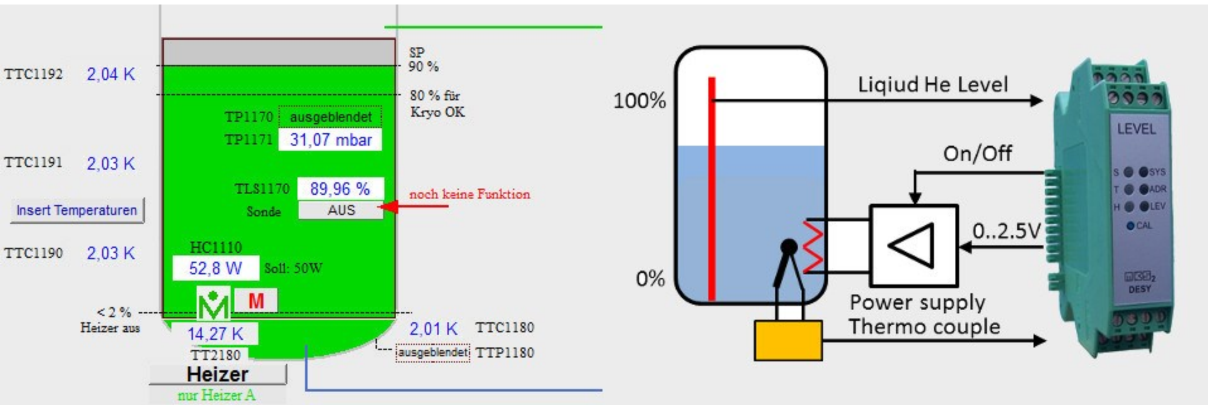


Figure 6: Typical installation of Helium vessel with LHe level sensor and heater

4. Pre-service tests of temperature sensors

Before each component of the XFEL cryogenic distribution system is connected to the DESY controls, all instrumentation belonging to the component shall be thoroughly tested. The tests begin at the manufacturer premises (Factory Acceptance Tests FAT), and then repeated at DESY after the

IOP Conf. Series: Materials Science and Engineering **101** (2015) 012173 doi:10.1088/1757-899X/101/1/012173

component is delivered to DESY and after completion of mounting works. Considering also the total number of the temperature sensors in the XFEL cryogenic distribution system of 900 (mostly TVO and PT1000), this has triggered creation of a system intended for fast and reliable tests of temperature sensors.

The temperature sensors are wired to vacuum feedthroughs (27 pins Fischer plugs) using 4 wires technique – maximally 6 temperature sensors can be wired to one plug. The earlier developed by DESY test box providing the measuring current 10nA with manual switching between different sensors within a plug was replaced by a set consisting of 3 e.bloxx A5CR modules (each for 2 temperature sensors) combined with an USB interface from Gantner Instruments (see FIGURE 7). The set makes possible readout with the following digitizing of all 6 sensors connected to the plug at a heat. This facilitates and speeds up testing works and results in higher accuracy.

Figure 7: Test boxes for temperature measurements. Left side the simple box and on the right side the Gantner box.

Software also provided by Gantner Instruments runs at a dedicated Laptop connected by USB to the measuring set. The resistance readings are transferred manually into an Excel sheet (an automatic way for the transfer is under development) which contains integrated polynomials for all temperature sensors connected to the plug and serves finally as a test protocol. The values of resistance are then recalculated into temperatures. These are compared each with a reference temperature normally defined as an ambient temperature since the pre-service tests are carried at room temperature. Large deviation with the reference temperature exceeding a pre-defined threshold triggers appearance of an alarm in the Excel sheet (see FIGURE 8). Such pre-service tests based on measuring temperature instead of resistance help to detect errors related to polynomials as well as those related to the temperature sensor proper and its installation. This makes possible reparation or replacement of the sensor at enough early stage. The checked polynomials are then transferred to the EPICS database.

68	TAG-Name	Sensor ID	Connector	Tsoll	Rist	Tist	Tdiff	Tdiff	Result
69				[K]	[Ω]	[K]	[K]	[%]	
70	XLVBTTC1295A	CCSA2N794	XT07	295,50	998	295,58	-0,08	-0,03	OK
71	XLVBTTC1295B	CCSA2N795		295,50	1045,7	275,64	19,86	6,72	ERROR
72	XLVBTTC1298A	CCSA2N495		295,50	1008	296,76	-1,26	-0,43	OK
73	XLVBTTC1298B	CCSA2N435		295,50	978,4	296,70	-1,20	-0,41	OK
74	XLVBTTC1182A	CCSA2N796		295,50	1010,9	295,82	-0,32	-0,11	OK
75	XLVBTTC1182B	CCSA2N797		295,50	1040,6	295,44	0,06	0,02	OK

Figure 8: Excel sheet for calculating temperature on the basis of measured resistance

5. Summary

The European XFEL is currently in the installation phase. Most parts of the XFEL cryogenic distribution system are already delivered. The integration into the EPICS control system is in progress. Control-System-Studio (CSS) provides the tools to configure the PROFIBUS field bus and the nodes with their I/O. It also supports creation and testing of EPICS database including the individual process variables (PVs). After the remaining cryogenic components will be delivered to DESY they will be connected to PROFIBUS using the pre-configured EPICS databases. This will speed up commissioning. The installed diagnostic tools on each PROFIBUS segment help to identify software and hardware problems. The most frequent faults are incorrect polarity of bus cables, missing / fault addresses and missing bus terminations. In all these cases the diagnostic tools generate error messages with a clear textual explanation. This way the examination of a PROFIBUS segment is reduced to just a few minutes. In addition the diagnostic tools provide an automatic generation of the test reports.
The developed by DESY software and hardware tools make possible quick and reliable check of the instrumentation of incoming components and their following integration into the DESY control system.

References

[1] Pyata E, Belova L, Boeckmann T, Kholopov M, Konstantinov V, Kulikov V, Sellmann D, Zhirnov A, Zolotukhina N, XFEL Injector-1 cryogenic equipment 2014 *ICEC25 Proceedings* Twente 868-873.

[2] Bozhko Y., Engling C., Gadwinkel E., Jensch K., Petersen B., Sellmann D., Zolotov A. “XFEL Cryomodule Test Bench”, Proceedings of ICEC21, (2006), Volume 1, 125-128

[3] Bozhko, Y., Petersen, B., Schnautz, T., Sellmann, D., Wang, X.L., Zhirnov, A., Zolotov, A., “Cryogenics of European XFEL Accelerator Module Test Facility,“ Proceedings of ICEC23, Wroclaw, 2010, pp. 911-918