Use of PROFIBUS for cryogenic instrumentation at XFEL

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Abstract. The European X-ray Free Electron Laser (XFEL) is a research facility and since December 2016 under commissioning at DESY in Hamburg. The XFEL superconducting accelerator is 1.5 km long and contains 96 superconducting accelerator modules. The control system EPICS (Experimental Physics and Industrial Control System) is used to control and operate the XFEL cryogenic system consisting of the XFEL refrigerator, cryogenic distribution systems and the XFEL accelerator. The PROFIBUS fieldbus technology is the key technology of the cryogenic instrumentation and the link to the control system. More than 650 PROFIBUS nodes are implemented in the different parts of the XFEL cryogenic facilities. The presentation will give an overview of PROFIBUS installation in these facilities regarding engineering, possibilities of diagnostics, commissioning and the first operating experience.

1. Introduction

The European X-ray Free Electron Laser (XFEL), currently under commissioning at DESY, Hamburg will be operated as a research facility for multiple users. The XFEL linear accelerator linac consists of 96 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 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 mastered by the control system. Basic ideas and principles of the DESY control system realized in the Cryo Module 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 managed by the process control system for Experimental Physics and Industrial Control System EPICS [4]. A complementary component of EPICS is the Open Source software suite 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 as e.g. projecting, programming and operating. It replaces the previous X-Window based tools DM2K of the EPICS software suite.

Cryogenic instrumentation used for operation and diagnostic is connected to PROFIBUS. More than 650 PROFIBUS nodes will control the XFEL cryogenic system. DESY introduced the monitoring system based on Field Device Tool (FDT). FDT framework contains Device Type Manager (DTM) applications to examine 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 synoptic 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 operation [5].

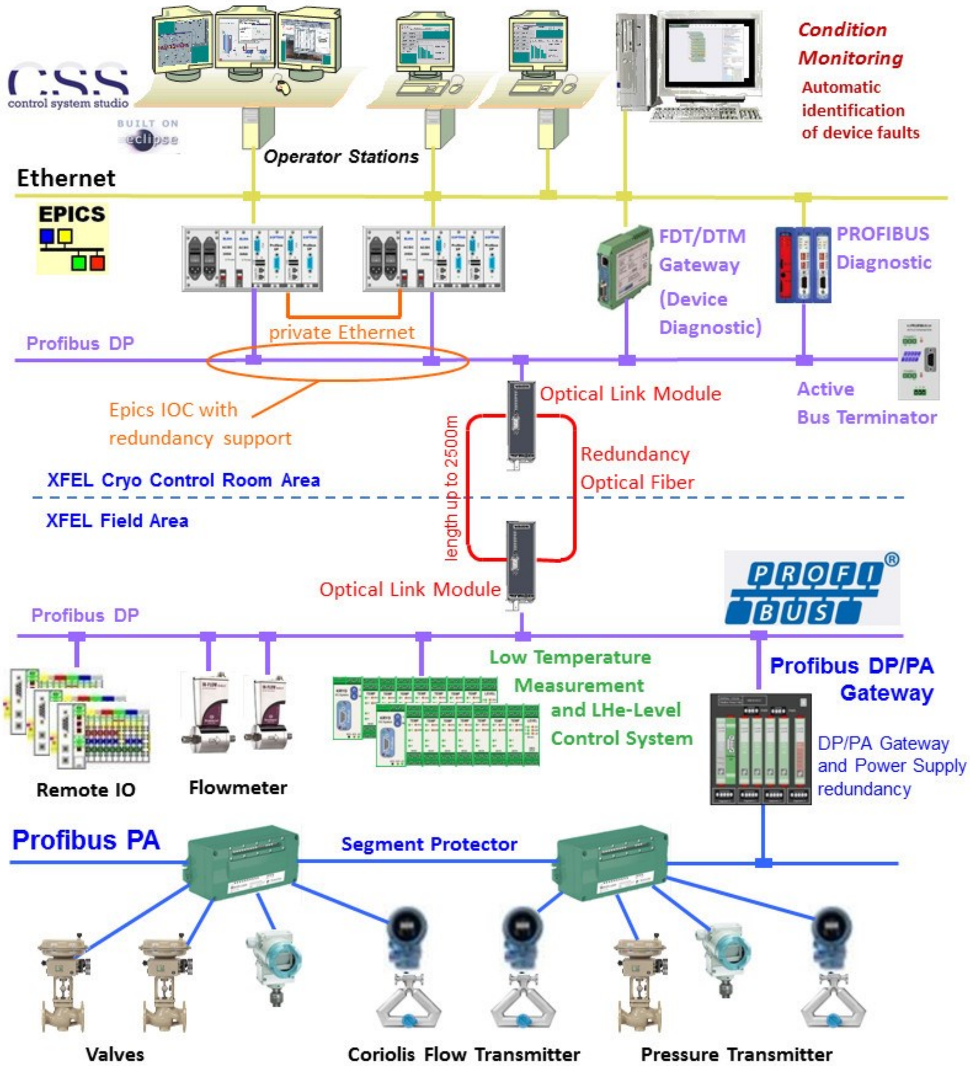

Figure 1. Control system overview. The EPICS based cryogenic control system uses distributed I/O. The selected field bus is PROFIBUS DP. All valves, actuators and most of the sensors are connected through PROFIBUS PA which also provides power to the sensors. Ethernet to PROFIBUS gateways provide access to the PROFIBUS components for condition monitoring.

2. PROFIBUS fieldbus

2.1. PROFIBUS network

PROFIBUS [6] is a widely-used fieldbus in industrial applications. 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 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 fiber lines with length up to 2.5 km. 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.

2.2. PROFIBUS driver for VxWorks

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 version of the Windows operating system.

2.3. PROFIBUS installation

The XFEL refrigerating plant shall operate continuously throughout the year with an availability of more than 99%. This requires that errors in the control system must not cause breaks or downtime of the cryogenic system resulting in loss of experimental time for XFEL end users. Therefore all installed components like power supplies, segment couplers, optical link modules and optical fiber lines are designed redundantly. The PROFIBUS field devices are connected by segment protectors. That save undisturbed data transfer in case of error and allow working at field devices during the operation if necessary.

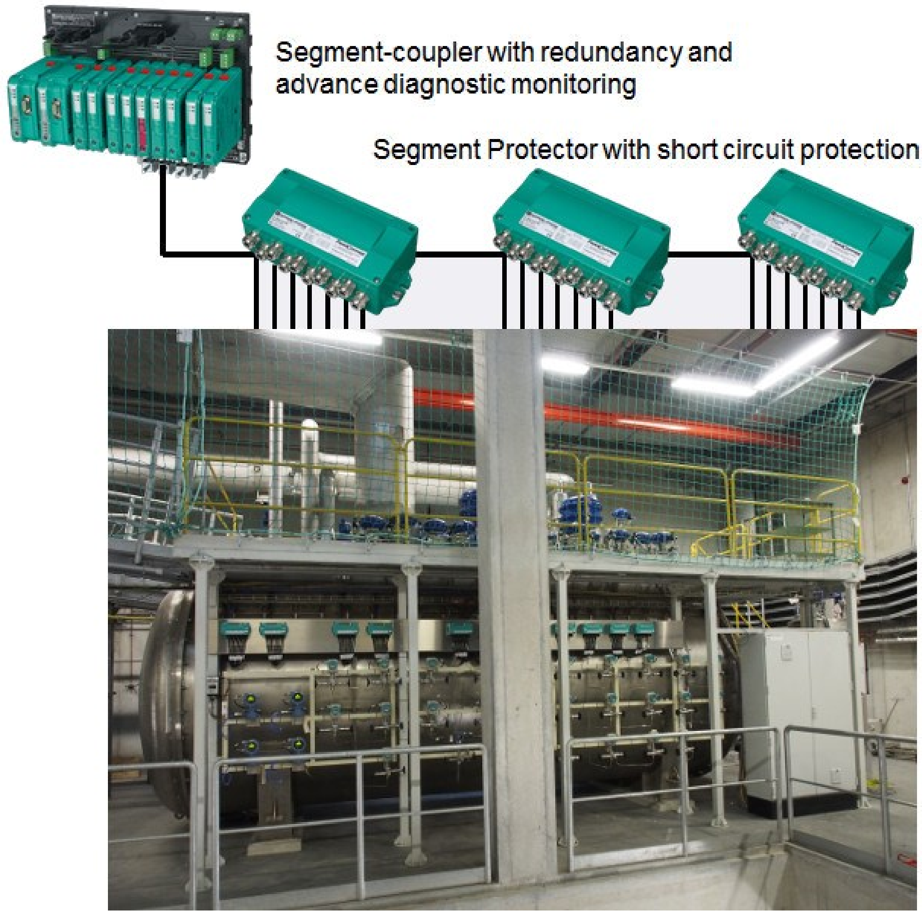

Figure 2. XFEL Distribution box XLVB and PROFIBUS field installation with redundancy segment-coupler and segment protector for field device connection.

Figure 3. XFEL tunnel control cabinet below concrete shielding.

Figure 4. XFEL tunnel field devices inside of the control cabinets.

2.4. PROFIBUS network length and cycle time

PROFIBUS DP can be used with baud rates up to 12Mbit/s. In the cryogenic plants at DESY the baud rate of 1.5 Mbit/s is established. This guarantees very reliable data transfer by copper cables with the lengths up to 200m. Table 1 shows a typical PROFIBUS DP cycle time at a PROFIBUS segment (refrigerator plant no. 2) with 100m length and 57 PROFIBUS participants. The cycle time of this segment averages to 17.9ms and can amount maximally to 30.3ms.

Table 1. Event and time periods at a PROFIBUS DP segment.

Event / Time Period	Last Minute	Last Period 24h	History 520.5h
Drop-outs	0	0	0
Internal Diagnostics	0	0	1
External Diagnostics	0	1681	24281
Error Frames	0	0	0
Max. Retries per Bus Cycle	0	0	0
Total Retries	0	0	0
Bus Cycle Time Min/Mean/Max [ms]	17.90/17.90/17.90	17.65/17.90/30.06	17.63/17.90/30.31
Last SNMP Request		-	
		Delete Measuring Data	

51 participants of this network are PROFIBUS PA devices and shared between 3 PROFIBUS PA segments with 20, 17 and 14 nodes. The PROFIBUS PA baud rate is fixed to 31.25 kbit/s. For these segments the typical cycle times amount respectively to 376ms, 333ms and 291ms. In consequence of this result it can be confirmed that PROFIBUS DP has an adequate bus cycle time. The data exchange rate is certain by PROFIBUS PA. The scan rate of the most process values at DESY is 1s.

Table 2. PROFIBUS network distribution at XFEL.

Facility	Number of PROFIBUS Segments DP / PA	Maximum Segment Length	Number of PROFIBUS DP Devices	Number of PROFIBUS PA Devices
Refrigerator KS1	4/5	250m	35	42
Refrigerator KS3	4/5	250m	35	42
Purifier TTR36	2/1	100m	7	29
Distribution Box DB54	2/5	100m	13	53
Coldbox CB 44	2/2	1000m	15	42
Valve Box XLVB	2/4	1000m	12	75
Valve Box XIVB	2/4	1200m	10	35
Injector1 XTIN1	2/2	1500m	6	5
LINAC XTL	12/12	2500m	61	113

Almost 1000 PROFIBUS devices are currently in use at DESY's cryogenic plants in different network parts.

3. PROFIBUS fieldbus integration

Control System Studio CSS is the integrated environment tool for engineering, configuration and operation of the control system EPICS. It is based on Java and Eclipse technology. 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.

The PROFIBUS fieldbus integration is achieved through import of the PROFIBUS devices description file (GSD) into the CSS configuration tool. The GSD file describes the cycle data exchange of elementary field devices. GSD files are created in ASCII plain text format to ensure independence from any operation system. Complex device descriptions like Electronic Device Description (EDD) or Device Type Manager (DTM) are currently not supported.

The assignment of fieldbus process values to the EPICS process values (PV) is featured by the CSS configuration tool.

4. PROFIBUS commissioning, condition monitoring and asset-management

4.1. PROFIBUS diagnostic

For fast commissioning of all PROFIBUS components it is helpful to use a diagnostic tool like Softing's Netinspector [7] or Procentec's Combricks [8]. It will show at the first glance whether the bus system works correctly and all participants are accessible, or whether there are configuration and/or parametrisation errors. In many commercial control systems a basic PROFIBUS diagnostic tool is integrated. The DESY PROFIBUS driver has been implemented the basic PROFIBUS functionality. PROFIBUS bus management functionality is not implemented currently. Therefore, DESY used separate diagnostic devices for each PROFIBUS DP segment.

4.2. PROFIBUS device diagnostic

Complex field devices like an intelligent pneumatic controller or pressure transmitter support a lot of parameters and additional status messages nowadays. Therefore, it is possible to analyse failure of field devices remotely. This will avoid or minimize service times in the plant. In many plants with 4-20mA field devices a technician always needs to access the plant for service. This is a big disadvantage. In many cases an access to the plant will not always be possible.

The access to the field devices can be realised by e.g. HART protocol with a handheld tool or a Process Device Manager (PDM) and Electronic Device Description or over a Field Device Tool (FDT) with Device Type Manager (DTM). By using PROFIBUS the FDT/DTM technology is the preferred method because the technical preconditions are already fulfilled. Only a FDT/DTM link (gateway) is necessary. Most manufactures support the FDT/DTM technology and deliver the DTM software free of charge for their field devices. FDT/DTM technology is not limited to PROFIBUS. HART protocol, Foundation Fieldbus (FF) and many others are supported too. But in each case access to the communication system will be needed. DESY installed a FDT/DTM link (Gateway) for each PROFIBUS segment. In case of PROFIBUS this is possible without any difficulty.

The free of charge tool PACTware (Process Automation Configurations Tool) [9] can handle all relevant tasks during commissioning and operation. Beyond that, PACTware will be helpful to administrate the field devices. So, it allows to sample all relevant information about the field devices in a clear representation. On the other hand PACTware does not support any further data interfaces. All information can be shown in a view or print out. PACTware can be used as an asset-management system for small applications.

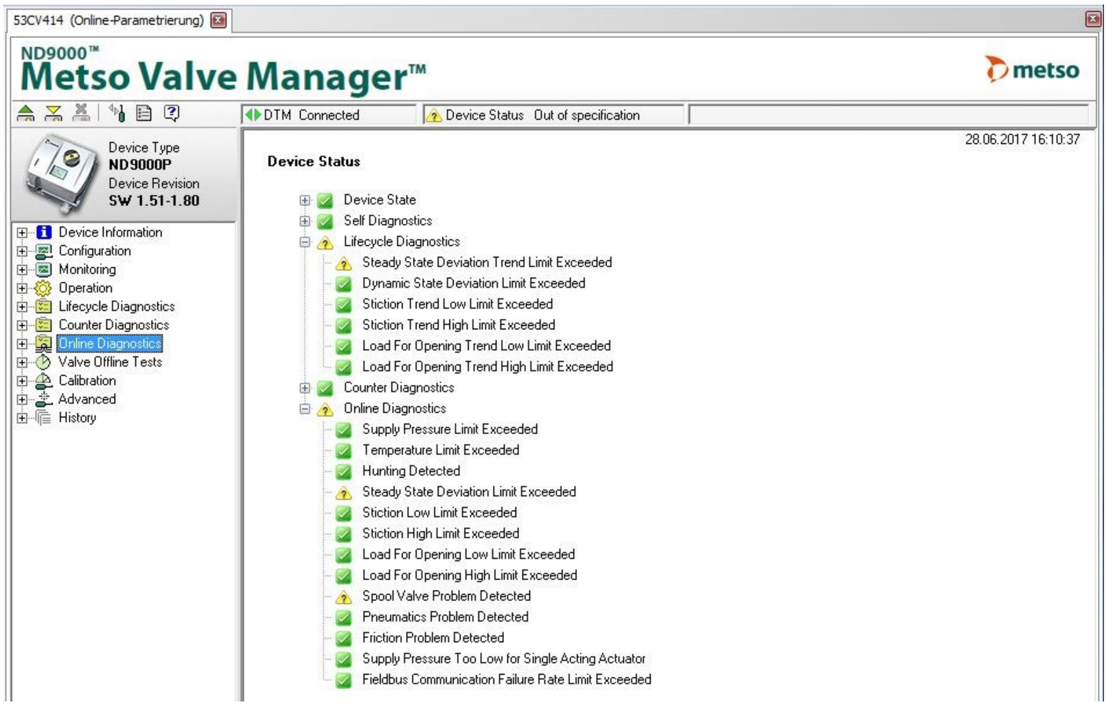

Figure 5. Valve controller with additional error messages. Controller reported spool valve problem. But the controller works without disturbance currently.

A goal is the operating of the refrigerator and the cryogenic distribution systems 24/7h throughout the year without failures. This results in a requirement to identify and solve potential problems in advance to prevent any system from downtimes.

PACTware is not able to identify field device failure automatically. For this purpose a condition monitoring system is necessary. The condition monitoring system is based on FDT/DTM technology and scans periodically all field devices for status information. This asynchronous process runs parallel to the process data exchange with low priority. Therefore, it is ensured that the process data exchange will not be disturbed. A clear representation shows at first glance the status of all field devices in the plant. All this information will be collected and saved in a database. Thereby it is possible to generate clear structured reports and generated work instructions for the next maintenance period. This is a requirement for preventive maintenance.

Unfortunately DTMs are not available for all field devices. The new Field Device Integration (FDI) standard shall solve this problem. FDI brings the Electronic Device Description EDD standard and the DTM standard together. FDI/DTM packages provide hereby as a container for the EDD ASCII files. For using FDI a FDT framework version 2.0 is necessary. In addition a version control for EDD and DTM is an inherent part of the FDI tool. A FDT framework 2.0 will be available in PACTware version 5.

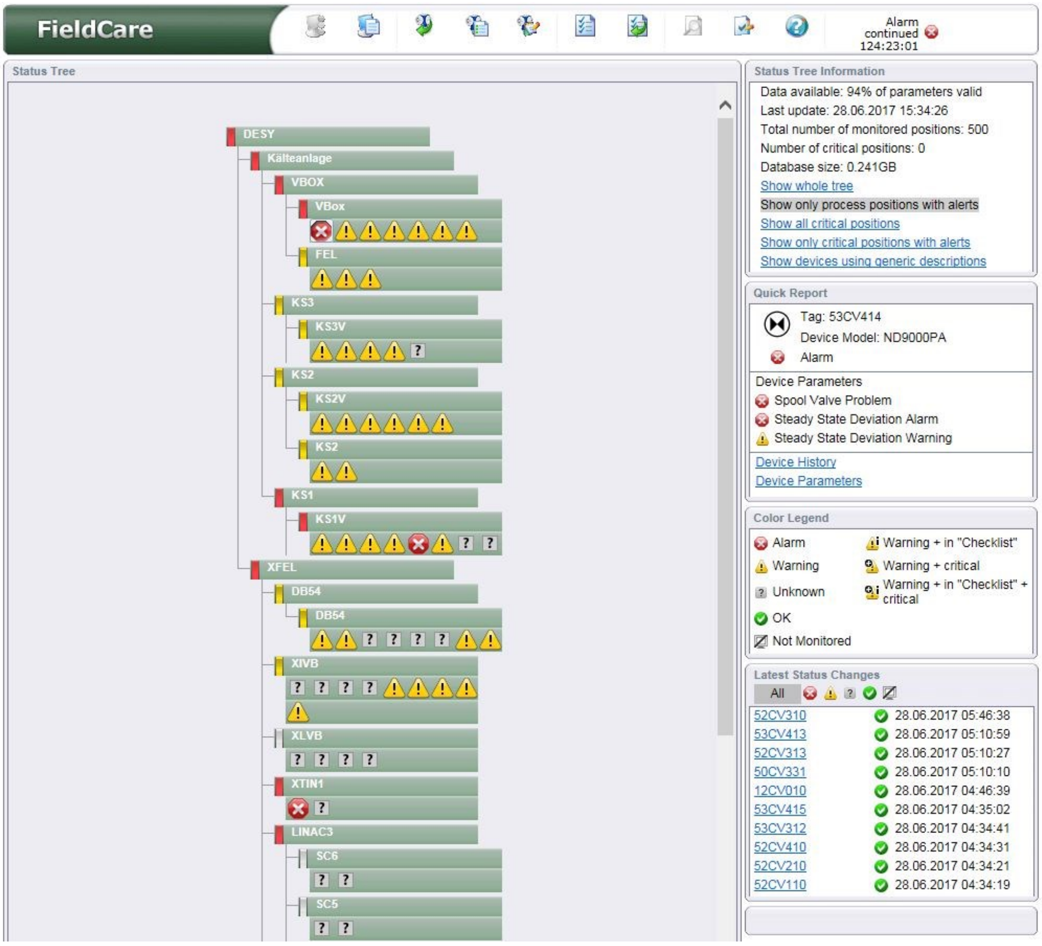

Figure 6. The condition monitoring shows at first glance the status information of all field devices.

4.3. Field Device Documentation

Complex field devices such as intelligent pneumatic controller or pressure transmitter support a lot of parameters. The access to the field devices can be realised by e.g. HART protocol with a handheld tool, a control system or an asset-management tool like PACTware or Fieldcare . With this asset management tools it is possible to configure the devices of a plant in an easy, fast and efficient way. Such tools are very helpful for:

- Planning
- Commissioning
- Operation
- Diagnosis
- Field Device Documentation

Figure 7. Typical view of field device documentation in older plants.

Figure 8. Field device documentation with Asset-Management like PACTware.

Using an Asset-Management tool like PACTware or Fieldcare situations as shown in figure 7 will be avoid. Figure 8 shows the solution with PACTware. Many tasks can be done from the office comfortably.

5. Summary

Using PROFIBUS DP and PROFIBUS PA for controlling and monitoring the cryogenic plants for years has been proved to be advantageous. Already the planning of the plants is very easy and possible without special tools. The documentation can be done easily in EXCEL or VISIO. The handling during installation and commissioning is easy as well. PROFIBUS has excellent possibilities of diagnostic methods. The PROFIBUS network protocol is easy and clear to understand. However, the biggest advantage and essential matter for DESY is the reliability of the PROFIBUS. After correct installation the system is running stable and without any disturbance.

The decision for a fieldbus like PROFIBUS has shown that the technology is technically mature, reliable and available for many years. Therefore, the willingness to use fieldbus based systems a question of the internal organisation.

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

[4] Boeckmann T, Clausen M, Korth O, Schoeneburg B “Concept, implementation and commisioning of the automatic system for the accelerator module test facility” Proceeding of CEC/ICMC 2013, AIP Conf Proc. 1573

[5] Böckmann T, Bolte J, Bozhko Y, Clausen M, Escherich K, Korth O, Schoeneburg B, Zhirnov A “Design of the control system for the cryogenic distribution system of the European XFEL project” Proceeding of CEC/ICMC 2015, IOP Conf Ser.: Mater. Sci. Eng. 101 0121173

[6] PROFIBUS / PROFINET International Organisation

[7] Softing Industrial Automation GmbH

[8] Procentec GmbH

[9] PACTware Consortium e.V.