ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-THPHA143

SYNCHRONOUS MOTION WITH S7-1500 PLCS IN NEUTRON INSTRUMENTS

H. Kleines, JCNS-2, Forschungszentrum Jülich, Jülich, Germany

Abstract

Control systems of neutron instruments are responsible for the movement of a variety of mechanical axes. In the TANGO based control systems developed by Forschungszentrum Jülich for neutron instruments, Siemens S7-300 PLCs with single axis stepper motor controllers from Siemens or Phytron have been used for this purpose in the past. Synchronous coordinated movement of several axes has been implemented with the FM357-2, a dedicated multi-axis modules for the S7-300 with NC functionality.

In future, the recent S7-1500 PLC family shall be used for motion tasks. With the S7-1500, stepper motor control is possible with low-cost fast digital outputs, so called PTOs (pulse trade outputs). The integrated motion functions of the S7-1500 directly support synchronous movement. The function block interface defined by PLCopen serves as a homogenous programming interface which is independent of a specific motion controller.

For the single crystal diffractometer HEiDi at the research reactor FRM-II a prototype for the replacement of a S7-300 with FM357-2 has been implemented based on a S7-1500 PLC and a PTO module.

INTRODUCTION

Stepper motor and servo controllers are typically implemented as dedicated hardware modules. Due to the increase in computing power, these functionalities also can be implemented by PLC CPUs based on low cost fast digital (so called PTOs: pulse trade outputs) and analogue outputs, requiring external stepper or servo drivers. The hot single crystal diffractometer HEiDi [1], which is operated by the Institute of Crystallography, RWTH Aachen University, and JCNS, Forschungszentrum Jülich, has been equipped with the multi-axis function module FM357-2 for the synchronous movement of the 4-axes-diffractometer unit during measurement. It is intended to replace the old S7-300 with the FM357-2 module at HEiDi by an S7-1500 System with the technology module TM PTO 4 (with 8 pulse trade outputs). The next sections give an overview the instrument HEiDi as well as the so-called “Jülich-Munich Standard”, since the overall control system software and hardware architecture of HEiDi conforms to this standard. After an introduction into the S7-1500 motion functionality the implementation of a test system for the coordinated movement of axes is described and first measurement results are presented.

THE “JÜLICH-MUNICH STANDARD”

The “Jülich-Munich standard” [2] is a framework for the selection of technologies and components at each level of the control system. The definition of this framework was motivated by synergy effects and the reduction of spare parts on the shelf. A guiding principle for the framework was to minimize the development efforts and to acquire as much from the market as possible. A key component of the framework is the consistent use of industrial technologies like PLCs, fieldbus systems or decentral periphery in the front end. Main motivations are:

- low prices induced by mass market
- inherent robustness
- long term availability and support from manufacturer
- powerful development tools

A control system according to the Jülich-Munich Standard is organized hierarchically into the following levels:

Field level: The field level is the lowest level, at which devices that are not freely programmable reside, like motor controllers, SSI controllers, PID controllers, analogue and digital I/O modules, or measurement equipment. For all industrial type of I/O modules PROFIBUS DP or PROFINET based decentral periphery is recommended. Siemens ET200S is the preferred one. The ET200S modules 1STEP and 1STEP-DRIVE are the predominantly used stepper motor controllers.

Control level: The control level resides on top of the process level. Devices at the control level are freely programmable. They must meet real time requirements and guarantee robust operation in a harsh environment. At the control level Siemens S7 PLCs are used, because they dominate the European market.

Process communication: Process communication covers the communication of devices at the field and control level with supervisory controllers or computers. For lab equipment GPIB and proprietary RS232/RS485 connections are unavoidable. For industrial automation equipment PROFIBUS DP and PROFINET are the recommended choices. They are the dominating fieldbus systems in Europe and naturally supported by S7 PLCs and many other devices. A major reason for their success is the technological and functional scalability based on a common core as well as the programming model, which easily maps to PLC operation.

Experiment Computer: For economic reasons, all experiment computers should be PCs. Linux, being well established in the scientific community, is the only supported operating system. CentOS is the preferred distribution at JCNS. Direct device access is typically implemented on industrial PCs, mainly CompactPCI systems. CompactPCI allows deploying a variety of existing software in a mechanically more robust platform that fits into 19” racks.

Middleware: Since the framework aims at an inherently distributed system, software support for the transparent distribution of services between systems is required. For

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-THPHA143

this purpose TACO [3] originally has been selected as the middleware system. TACO is a client-server framework developed for beam line control at the ESRF in Grenoble. In a TACO environment each device or hardware module is controlled by a TACO server. The server offers a set of device-specific functions, which can be accessed by TACO clients via a RPC-based mechanism over a TCP/IP network. To make its functions available to clients, the device server registers itself with the so called manager process and the data base server. The manager in combination with the data base server operates as a name server, which is consulted by clients to get the actual location of a device server. TACO includes a simple database for sharing of configuration data and operational variables between clients and servers. During the last few years, TACO has been replaced by TANGO [4] at most JCNS instruments. TANGO is a successor of TACO based on CORBA and ZeroMQ. Contrary to TACO, it is consistently object-oriented and removes many of the deficits TACO had. As an example, it provides generic multi-threading, data caching and proper event handling. Additionally, it comes with many standard tools not available in TACO, e.g. alarm system, logging system, code generators for device servers, process data base, graphical editor for the configuration data base, start up tool,

Application level: On the client side originally a high degree of freedom was allowed ranging from python based pure scripting applications to more static GUI-applications in C++. At most JCNS instruments these applications have been replaced by the standardized measurement program NICOS [5] during the last few years. NICOS offers scripting in python and in a simpler command language as well as a configurable GUI for graphical user operation. Functionalities comprise electronic logbook, history plots, detector data plots,…..

THE HOT SINGLE CRYSTAL DIFFRACTOMETER HEIDI

The instrument HEiDi, located at the reactor hall of the reactor FRM II in Garching, is designed for detailed studies on structural and magnetic properties of single crystals using thermal and epithermal neutrons [6]. As shown in Fig. 1, HEiDi has a classical setup with monochromator, analyser and a ^{3}He detector tube. Core of the instrument is the 4-circle diffractometer, consisting of an Eulerian cradle for the sample and the detector arm. Additional motion axes comprise several apertures and filters.

Over the span of about 15 years RWTH Aachen, Technical University Munich and Forschungszentum Jülich have implemented subsystems of HEiDi. As a consequence its control architecture is not as consistent as it could be and in future some efforts to improve this are required. E.g. at the moment some HEiDi components are controlled by TACO and some are controlled by TANGO. The measurement program is dif4n, a dedicated software for single crystal crystallography. Some motors are controlled via Phytron MCC-2 devices, connected via serial interface to the computer with the TACO-Servers.

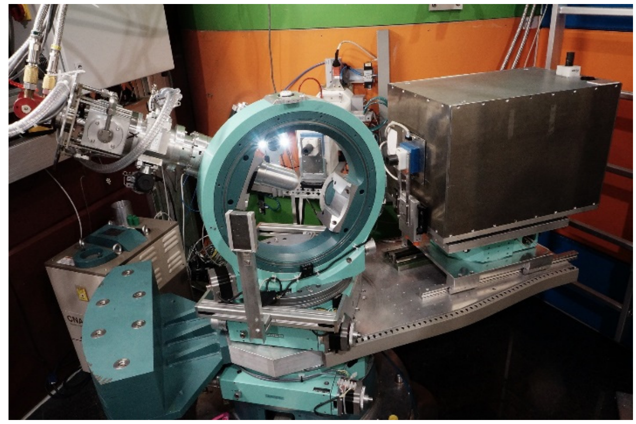

Figure 1: Photo of the HEiDi instrument.

Other motors are controlled by 1STEP-DRIVE devices, connected to a S7-300 PLC. An additional S7-300 PLC equipped with an FM357-2 function module controls the four axes of the 4-circle diffractometer. The FM357 is a multi-axis module for up to 4 servo and stepper drives (with SSI or incremental encoders) supporting complex traversing profiles with high-precision interpolation and synchronization of axis combinations. Via the pulse/direction interface it is connected to Phytron CCD stepper drivers.

It had been selected for the implementation of a synchronous movement during measurement and the generation of signals for the synchronisation with the detector. Since it was phased out by Siemens in 2015, a midterm replacement is required. It is intended to use a S7-1500 PLC with integrated motion control for this purpose and use this PLC also for the overall unification of motor control at HEiDi.

S7-1500 MOTION CONTROL

The motion product portfolio of Siemens is very complex ranging from decentral drive based motion (e.g. SINAMICS) to high end SIMOTION systems and dedicated systems like SNUMERIK NC controllers.

Since Siemens motion products are mainly directed to high-end servo applications whereas neutron scattering applications predominantly employ stepper motors, JCNS implemented its own motion software on S7-300 PLCs connected to central or decentral motor controllers from Siemens or other companies. The motion software directly accesses the register interfaces of these controllers, which is always very specific. With the recent PLC lines S7-1200 and S7-1500, the situation has changed since both come with a homogenous motion control functionality implemented in software due to the increased CPU speed, which offers also a good support for stepper motors [7, 8]. The variant S7-1500T provides additional hardware support for motion. Motion functionality and number of supported axes depends on the type (and price) of the PLC CPU. As an example, the S7-1200 cannot do any axis synchronisation, whereas the S7-1500 can do only electronic gearing and the S7-1500T support full CAM functionality with up to 128 synchronous positioning axes. Interfacing to drives can be done via fast digital

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-THPHA143

IOs (pulse train outputs), analogue IOs, dedicated technology modules or decentral PROFIdrive devices.

Configuration, programming and testing is independent of the type of drive or interface since it is based on software technology objects, like “speed axis”, “positioning axis”, “synchronous axis” or “cam”. Synchronous position measurements by activating an input are implemented with the help of the technology object “measuring input” and the technology object “cam track” allows the definition of a track of positions that activate an output in a synchronous way.

Programming is done in a standardized and homogenous way on base of the function blocks for motion control defined by PLCopen [9].

IMPLEMENTATION OF THE TEST SYSTEM

For the implementation and the examination of the motion capabilities of the S7-1500 with regard to synchronous movement, a 3-axis table based on linear actuators form ISEL was used as test mechanics, as shown in Fig. 2. The linear actuators do not have any position encoders. Instead they are equipped with reference points.

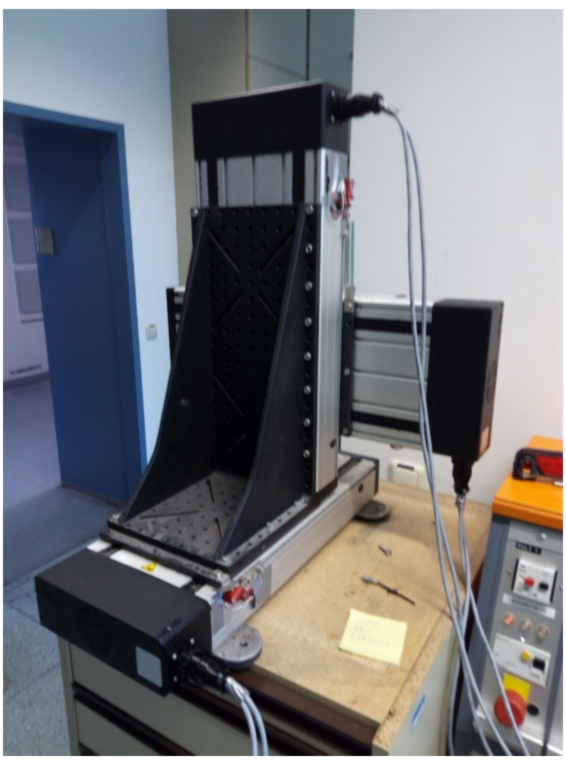

Figure 2: Triple axis test mechanics.

For the interfacing existing to the Phytron CCD stepper drivers the S7-1500 technology module TM PTO 4 has been selected. It is a pulse train output module with 8 RS422 outputs that can be used for the step/direction interface of 4 stepper axes with a frequency up to 1 MHz, and additional digital IOs for reference points, drive ready signals, etc. Unfortunately, the RS422 interface did not work in the first version of TM PTO 4. Only HTL (24V) was possible, which complicated the cabling a lot due to the required resistors. A fully functional version of the module with RS422 is announced for October 2018. The CPU 1516-3 PN/DP was selected for the PLC and the electronics for the lab test system was assembled in a contact isolated box, as shown in Fig. 3.

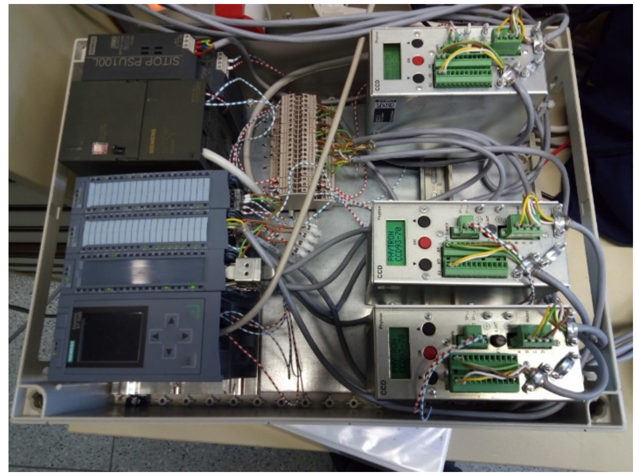

Figure 3: Electronics of test system.

The implemented software relies on gearing with the MC_GearIn function block, which means that the speed for the synchronous axis x and y is proportional to the lead axis z:

$v_x = k_x * v_z$; k_x *rational number e/d*

with e,d integer and $1 < e,\ d < 2^{**}31$

For each positioning a new k_x has to be computed according to the simple equation

$k_x := (x_{target} - x_{real}) / (z_{target} - z_{real})$

and MC_GearIn has to be called in order to sychnronize the axes again (analogous for axis y; the indices *target* and *real* describe the destination and the actual positon of the corresponding axis).

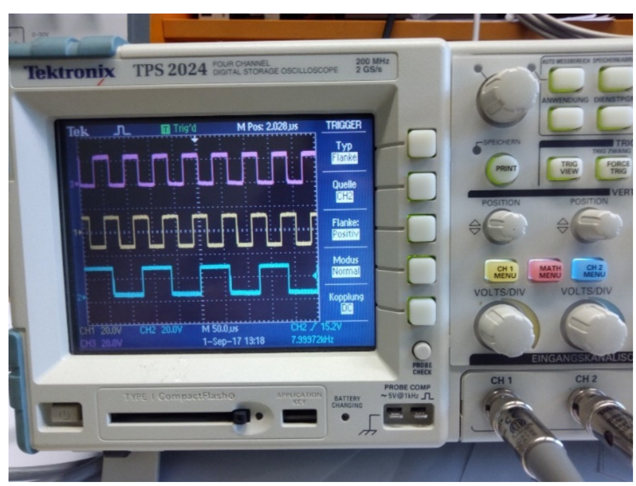

Figure 4. Oscilloscope picture of the step signals of all axes. The middle graph corresponds to the lead axis. The top and bottom graphs correspond to synchronous axes with identical and half speed, respectively.

ISBN: 978-3-95450-193-9 doi:10.18429/JACoW-ICALEPCS2017-THPHA143

Some optimization can be done by the selection of lead axis (always the one with the biggest distance) and by upscaling e and d in order to reduce truncation and rounding errors. But during the tests no rounding errors could be observed.

The standardized communication protocol developed by JCNS based on PROFIBUS and PROFINET defines an abstract controller/axis model, which allows the movement of individual axes or the synchronous movement of several axis grouped to a controller.

In order to examine the quality of the synchronization, the step signals of all axes were measured with an oscilloscope. Fig. 4 shows that these signals have a constant phase delay during movement, proving that the axes are moving synchronously.

CONCLUSION AND OUTLOOK

A test system has been successfully implemented showing that synchronous movement of several axes is easily possible with the integrated motion control functionality of the Siemens S7-1500 PLC family. As a next step, the system will be integrated into the HEiDi instrument at the FRMII by emulating the existing software interfaces.

In a second step, the existing TACO solution at HEiDi will be replaced by a TANGO implementation and a synchronisation mechanism with the detector based on cam tracks will be implemented.

The PLCopen programming interface in combination with a homogenous parametrization and test tool allows access to different types of stepper motor controllers, DC motor controllers, servo motor controllers and frequency converters in a consistent, device-independent and efficient way. Therefore future motion implementations of JCNS at FRM-II will be based on S7-1500 motion. The new TM-StepDrive module announced by the company Phytron for the ET 200SP decentral periphery system will be used as standard stepper motor solution with integrated stepper driver. This module will be supported by S7-1500 motion via the PROFIdrive interface.

REFERENCES

[1] Heinz Maier-Leibnitz Zentrum. (2015). HEiDi: Single crystal diffractometer at hot source. Journal of large-scale research facilities, 1, A7. `http://dx.doi.org/10.17815/jlsrf-1-20`

[2] H. Kleines *et al.*, Implementation of the Control and Data Acquisition Systems for Neutron Scattering Experiments at the new "Jülich Center for Neutron Science" according to the "Jülich-Munich Standard", Proceedings of the ICALEPCS 2005, Geneva, 2005.

[3] A.Götz, W.-D. Klotz, E. Taurel, J. Meyer, J.-L. Pons, M.C. Dominguez (ESRF),TACO manual version 2.1, `http://heanet.dl.sourceforge.net/project/taco/manual/2.1/TACO-2.1.pdf`

[4] Official TANGO homepage, `http://www.tango-controls.org`

[5] T. Unruh, "Instrument Control at the FRM-II using TACO and NICOS", Proceedings of the Nobugs 2002, Gaithersburg, 2002.

[6] M. Meven, G. Heger, HEIDI, new single-crystal diffractometer at the hot source of FRM II, Acta crystallographica / A 60, s113 (2004-00-).

[7] S7-1200 Motion Control V6.0 im TIA Portal V14 Funktionshandbuch, 09/2016, A5E03790550-AE

[8] S7-1500 Motion Control V3.0 im TIA Portal V14 Funktionshandbuch, 09/2016, A5E03879255-AD

[9] Technical Specification, PLCopen - Technical Committee 2 - Task Force, Function blocks for motion control (Formerly Part 1 and Part 2), Version 2.0, März 2011, PLCopen Organisation