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INDUSTRIAL STEPPING MOTORS INTEGRATION IN THE UNICOS-CPC FRAMEWORK

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Abstract

A large number of movable devices are present in the field of accelerators and must often be integrated in a control system. Typical examples of these systems are phase shifters and magnetic dipoles among others. The standard industrial control system UNICOS-CPC (UNified Industrial COntrol System for Continuous Process Control) provides a set of generic device types which matches the majority of the industrial equipment employed in process control. This new development extends it with additional device types for precise positioning equipment based on stepping motors.

The paper focuses on how the integration on UNICOS was fulfilled, the potential use of the solution and the automatic integration with the CERN real-time FESA (FrontEnd Software Architecture) framework. Finally, it illustrates a couple of use cases that already incorporate the solution: the CTF3 facility, the two-beam acceleration scheme envisioned for CLIC (Compact Linear Collider) and the EuroCirCol project for the measurements of the beam screen prototype for the FCC-hh (Future Circular Collider proton-proton).

INTRODUCTION

A stepping motor is an electric device capable of positioning objects in discrete regular steps with great accuracy and reliability. It can be controlled from several types of hardware including: industrial computers, specific electronics or, as in this publication proposed case, PLCs. A large number of movable devices are present in the field of accelerators and must often be integrated in a control system. This paper proposes integration through a standard device within the UNICOS-CPC (UNified Industrial COntrol System for Continuous Process Control) framework [1].

At CERN there were several legacy installations which were using control solutions based on standard PLCs with a wide variety of technical approaches. Our engineers were frequently called for support on those installations and thus a standard for stepping-motor integration in the UNICOS framework was proposed.

Another requirement was the integration of such devices to the standard accelerator control systems at CERN which are based on the FESA (Front-End Software Architecture) framework [2].

In this paper, we will go through the steps needed to include the stepping motor device as a new field device type in the UNICOS framework, its integration on the control systems and its application in real installations.

HARDWARE ARQUITECTURE

The selected solution is based on PLC hardware architecture with Siemens components. A distributed station *ET200S* is connected to a *S7-300* series Siemens PLC. The specific controller *1STEP-5V*, placed in the *ET200S*, is an electronics card with its own custom logic and is in charge of producing the signals to control the motor. It has a dedicated input where a reference switch is connected. As this input has a faster scan cycle than the normal digital inputs of the PLC, this enables increased precision in the detection of the reference position. In some installations, the end switches limiting the movement of the device are also connected to this same input. Pulses emitted by the card and signals indicating the turning direction are sent to the power module, which decodes them and gives the motor the electrical power to turn.

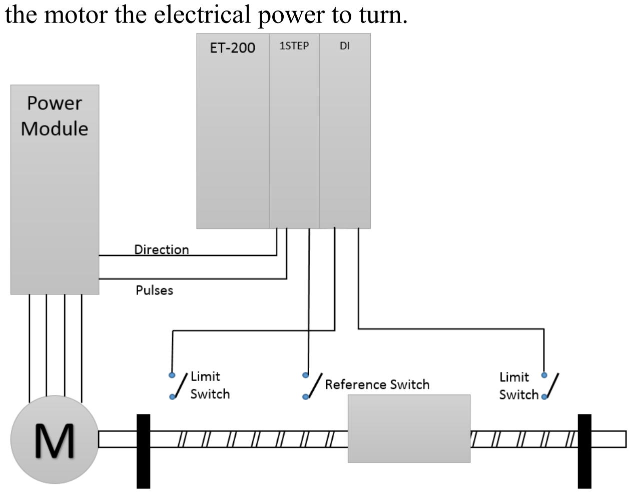

Figure 1: Hardware scheme of a typical installation.

The wiring of the setup depends on the desired mode of operation and the instrumentation installed. The recommended and fundamental configuration is based on using two end switches and a reference switch in between. The end switches are connected to digital inputs of the PLC I/O card. The reference switch is connected to the specific input of the controller card. Another possible configuration uses only two end switches, taking one of them as reference and connecting both of them to the controller card. In this configuration there is no need for digital input cards, making the final set simpler, but this is only possible with the second generation of controller cards.

INTEGRATION IN THE UNICOS-CPC FRAMEWORK

The first step to integrate the object in to the UNICOS-CPC framework was designing the device according to the UNICOS device model. This needs a device type

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classification, a definition of its interface and, finally, the internal logic specification. The device was classified as a field object within the generic device types of UNICOS-CPC [1]

To satisfy the generic field device type requirements, the new stepping motor device type must have:

1. Auto requests coming from the control logic implemented on the PLC, typically from a higher hierarchy device.
2. Manual requests coming from an operator through the HMI (Human Machine Interface) of the SCADA (Supervisory Control and Data Acquisition).
3. Local requests coming from field placed equipment (i.e. industrial touch panels)
4. Parametrizations to customize the behaviour of the instantiated device with the user configuration.
5. Interlocks to put the object in an inoperable state.
6. Input and output signals from the lower levels of the automation pyramid, as digital or analog inputs.
7. State feedback of the motor to be sent to the SCADA or the others devices in the project.
8. Commands or orders to devices on lower hierarchical levels.

This device type interface is defined in the Type Constructor Tool (TCT), which is a component of the suite of offline tools of the UNICOS framework.

The exchange of information with the specific Siemens hardware module is realised through four double words, two for reading the status of the motor (Figure. 2). *FbByte* 1 and *FbByte2* are bit patterns contain information about the state of the card and CtrlByte1 and CtrlByte2, also bit patters, to send the commands to the motor

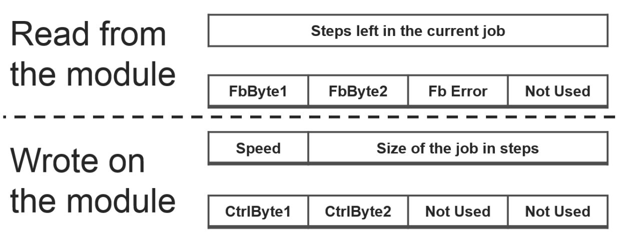


Figure 2: Interface with the 1STEP module.

The card offers several working modes, but in the designed device type only two are available:

1. **Reference Search**. In this mode the controller performs an algorithm aimed to search for the reference switch. Initially the position of the movable part is unknown, the controller will slowly move it until the reference switch is detetected. The reference switch is a lever placed in a known position.
2. **Positioning**. This is the normal operational mode in which the motor executes positioning duties. It works with relative positions, so the logic of the object calculates the number of steps needed to go from the current position to the required one.

The device type internal behaviour has been designed as a Harel state machine [3] which reduces the numer of transitions to represent a system by using the cocept of hierarchy (Fig. 3). This state machine deals with all the transitions between UNICOS working states and the set of intrinsic modes in which device could be. Figure 3 shows the simplified state machine for the stepping motor device type.

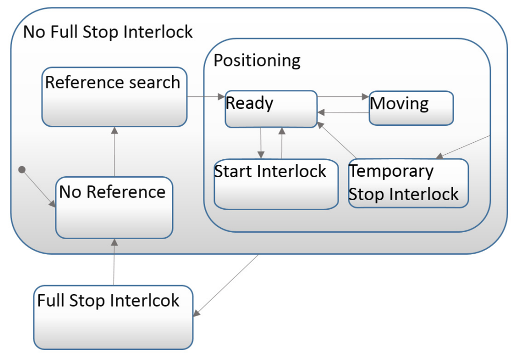
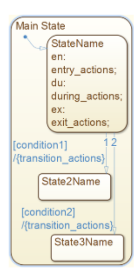


Figure 3: Simplified state machine.

Note that behind the state named "Reference search" there are 19 different sub-states. This led to a strict conversion of the code from the state machine to SCL (Structure Code Language) a high-level PLC programming language particularly suitable for programming complex algorithms. SCL corresponds to the textual high-level language ST (Structured Text) defined in the standard IEC 61131-3

Figure 4 shows an example with the structure of code created when translating the chart to SCL code.

For each macro-state, a *case* sentence is defined, constants for each state were defined to make the code easier to understand. There is also a Boolean variable for each state indicating if it is the first cycle on it to properly execute its initialisation. Then the possible transitions are evaluated ordered by their priority and if any of them is validated, the new state is set and the exit actions executed.




```
CASE StateIndex OF
    StateName:
    IF first_time_in_state THEN
        entry_actions;
        first_time_in_state := FALSE;
    ELSE
        during_actions;
    END_IF;
    IF condition1 THEN
        StateIndex := State2Name;
    ELSIF condition 2 THEN
        StateIndex := State3Name;
    END_IF;
```

```
IF StateIndex = State2Name THEN
    transition_actions;
END_IF;
IF StateIndex = State3Name THEN
    transition_actions;
END_IF;

IF StateIndex <> StateName THEN
    exit_actions;
    first_time_in_state := TRUE;
END_IF;
```

Figure 4: SCL code generated from the chart.

The integration in the UNICOS-CPC framework also requires: (1) definition of default parameters and creation of the specification templates that allow the control engineers to instantiate stepping motors in new projects, (2)

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modification of the generation tool and the Siemens S7 plugin in UAB (Unicos Application Builder) to include the new field object [4], (3) definition and design of the exchange data from the PLC and the SCADA, (4) TIA portal touch panel counterpart device type and (5) WinCC OA SCADA counterpart device type.

When including a new UNICOS compliant device on a WinCC OA SCADA, all the visualization logic and operator command options must be designed. The visualization includes a faceplate, a full representation of the device status and the means to interact with the device (Fig. 5).

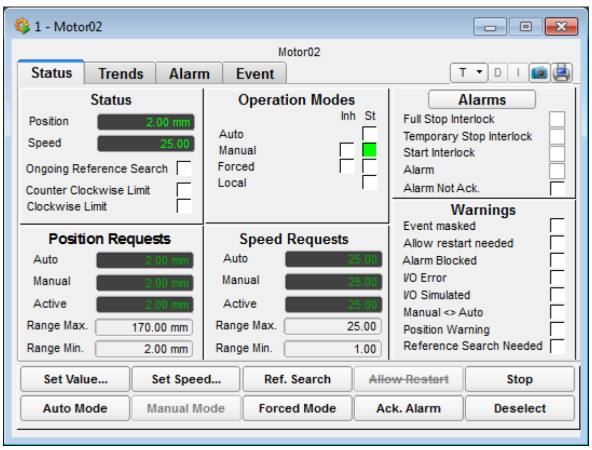

Figure 5: Faceplate of a stepping motor in WinCC OA.

Also a minimal, but meaningful, graphical representation of the device is required: the 'widget'. This is included in general views of the process or synoptics. Last, but not least, all scripts for the automatic importation and exportation of the devices are required. With these features, project engineers do not need to develop anything when deploying applications but just import their devices instances in the SCADA.

INTEGRATION WITH FESA

As already mentioned, many facilities where stepping motors are deployed have a control system based on the CERN standard for the accelerator controls. A FESA device is the way that the current CERN accelerator control system models a physical device, providing a software interface to control and monitor the hardware behind. SILECS (Software Infrastructure for Low-level Equipment Controllers) is an offline tool which procude the binding between the FESA device and the physical device, in this case the stepping motor instance deployed in the PLC.

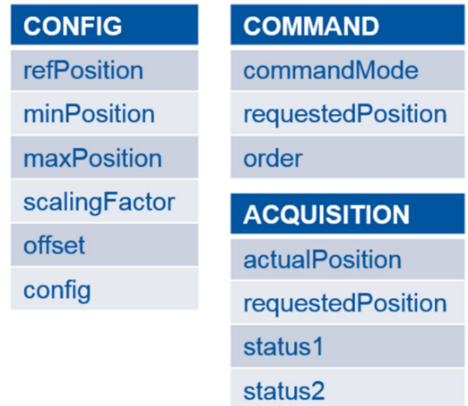

Figure 6: Front-end PLC interface.

After defining the interface, SILECS generates the source code to insert in the PLC. These blocks contain the shared database allowing the exchange of information between the PLC and the FEC. In this kind of communication, the PLC maintains a passive role, with the FEC in charge of reading and writing the data. A template for UNICOS-CPC was included in the generation tool (UAB) to automatically generate the PLC code to connect the inputs and outputs of the objects with the shared database.

USE CASE 1: CTF3 AND CLEX FACILTY

The objective of the CTF3 (Clic Test Facility) experiment at CERN is to demonstrate the feasibility of a linear collider positron-electron of CLIC type at the level of the multi TeV [5]. For this purpose, part of the LEP (Large Electron-Positron Collider) preinjector was reused to create a test-bench for a deeper study of the possible difficulties to overcome in the construction of such a machine. Several stepping motors were used in this facility to position different hardware, like phase shifters, attenuators or collimators.

The operators in the control room of the experiment interact with the motors through what is known as a "Knob" (Fig. 7), which is a standardized component available in the HMI of the supervisory applications and which can be linked to any device property of a FESA-based device. Integrating the UNICOS device within the accelerator controls environment provides coherence to the control system and allows the operator smooth operation with a logical abstraction of the way the stepping motor is designed.

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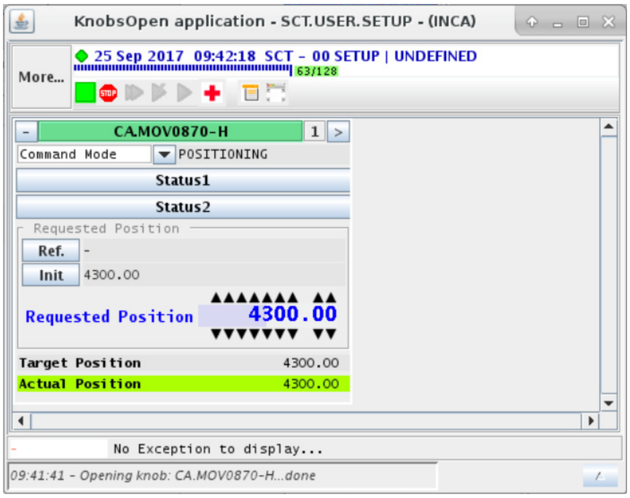

Figure 7: Knob to Control a stepping motor through FESA.

Currently, two distinct projects run in the experiment. One controls 4 attenuators and 3 phase-shifters in the CTF3 and the other controls 2 platforms for the positioning of part of the beam-pipe and its quadrupoles.

The wiring of the motors and associated sensors in these projects was quite heterogeneous, therefore additional requirements were taken into account to adapt the baseline of the device type to support all the cases. The motors of the platform positioners did not have reference switches, so the complete algorithm of the reference search was emulated with the end switches and a digital output of the PLC.

The phase-shifters constitutes a very special case They have mechanical encoders providing a continuous positional feedback. This obviates the requirement for a reference search. Another specific associated object for the UNICOS-CPC framework was developed to model this device: the encoder.

USE CASE 2: EUROCIRCOL PROJECT AT THE ANKA FACILITES

Eurcircol is a conceptual design study for a post-LHC research infrastructure based on an energy-frontier 100 TeV circular Hadron Collider [6]. For the validation of several parameters in a prototype of its beam screen a setup was installed in the ANKA (Angströmquelle Karlsruhe) synchrotron ring.

The beam screen will be irradiated with synchrotron radiation comparable to that expected at the future collider. To modulate the amount of radiation applied to the beam-screen, a collimator system consisting of four slits, two in the vertical axis and two in the horizontal, was placed in one of the front-ends of the ANKA accelerator (Fig. 8). These four slits are controlled by four independent stepping-motors. The platform, housing a beamscreen, is also movable with two motors to test different angles of incidence of the photon beam.

The availability of the device in UNICOS-CPC allowed rapid prototyping and commissioning of the control system which already included a PLC for the vacuum control system based also on UNICOS-CPC. The system requirements included the ability to create a square gap in a defined position of a given size and place the beamscreen in the correct angle to be irradiated. New parameters were defined for the vertical and the horizontal axis of the collimator and for the displacement of the beamscreen. These specific parameters are independently provided through the SCADA system. Also, during the design phase, the zero position of the slits was unknown, therefore a configurable offset was also required. These were new features to be introduced in the stepping motor device type.

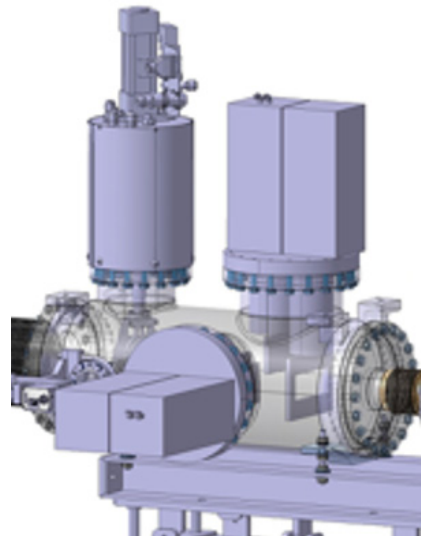

Figure 8: Representation with the four slits forming the collimator.

A set of alarms was configured to prevent the motors from moving if the reference was lost, if the gap size and position are out of bounds or if slits are about to collide.

The positions and speeds of each motor are logged in the SCADA database to be analysed offline with the additional data gathered by other systems in the experiment.

CONCLUSIONS

The development of the stepping motor in the UNICOS-CPC framework extends the functionality of the framework to control movable devices in the motion domain.

Supporting various architectures and configurations increased the complexity of the development of the new device type, but provided the flexibility required to adapt to different installations. This new device constitutes a UNICOS standardized solution which uses off-the-shelf simple PLC-based hardware. The integration with the CERN accelerator controls is ensured and all the components are generated automatically from an offline specification.

Most of the installations using stepping motors controlled by PLCs represented a high cost in terms of maintenance and operation. Revamping many of these installations, as the CTF3, allowed the team to better

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maintain those projects and extend the capabilities of the projects in terms of usability and diagnostics, both provided by the UNICOS standard.

The solution allows the engineering of new projects with a minimal cost. No further development is needed when deploying the projects as developers need only to instantiate their physical assets (stepping motors) in the form of new device instances. Only basic knowledge in automation is required to follow the procedure to add new devices. This was proven in the ANKA project, where PLC developers with limited experience in the field of motion were able to integrate the majority of the existing motors and make corrections in the specification of the devices with no development effort.

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