Advanced Proportional Servo Valve Control with Customized Control Code using White Space

Dr.-Ing. Peter Lauer
Eaton Hydraulics LLC, Software and Electronic Controls, 7945 Wallace Road, 55344 Eden Prairie, MN, petermlauer@eaton.com

Abstract
An industrial control valve has been designed by Eaton (AxisPro® valve). The servo performance valve has onboard electronics that features external and internal sensor interfaces, advanced control modes and network capability. Advanced control modes are implement in the valves firmware. With the help of the white space it is possilbe to execute custom code directly on the valve that interact with these controls. Small OEM applications, like rubber moulding machines, benefit from the combination of build in controls and custom code, to provide adaptations for their special machines.

KEYWORDS: Servo Valve Control, White Space, IEC 61131-3, Distributed Control, Rubber Moulding Injection Process, Cia DS 408 Device Profile

1. Valve Architecture and Software Overview
The valve is a standard zero lap spool and sleeve design, direct acting in a CETOP 3 and CETOP 5 configuration. A fast solenoid with digital electronic control and position feedback gives state of the art hydraulic performance. There is a sensor interface with internal pressure sensors on the P, A, B and T port, oil temperature and external sensor interfaces for pressure, position and speed sensors. The software can close the outer loop with pressure, speed, position control and a PQ control. Setup and calibration is done via CANbus using the ProFx graphical user interface. The product uses the industrial standard of the CANbus, CANopen for the connection to the machine controller. With these options many typical hydraulics applications can be solved just with the Axispro valve by itself, without any external control hardware, see Figure 1. In a 2 stage configuration it uses a CETOP 3 pilot with a CETOP 5 to CETOP 10 mainstage body.

The controller structure for the implemented PID controllers follows the Profile Fluid Power Technology VDMA proposal /1/. The CANOPEN DS408 /2/ further defines the
address and data types for the parameters. It features cylinder position control (DPC Digital position control), pressure or force control with one or two pressure sensors (DFC digital force control) and a combined PQ control, typical in press or molding applications.

**OEM Machine**
- Plastic injection moulding
- Rubber moulding
- Blow moulding

**Figure 1:** Advanced Servo Valve Control Structure with White Space

2. **White Space Interface Design and Options**

The term white space is used to describe the ability for the user of the valve to execute their own software. In addition to changing parameters, setting up control loops, there is the ability to execute custom code on the valve. As a standardized platform to support custom code we chose the IEC 61131-3 PLC programming language. This standard is widely accepted and assures that users of the white space do not need to learn a new programming language. Commercial implementations also provide the user interface for the code development suite and maintain it for all current PC operating systems, **Figure 2** shows the screen outline. A version of the IEC 61131-3
PLC development environment pre-packaged with libraries for Eaton products is available and called ‘ProFX control’.

![Image](image.png)

**Figure 2: Environment for IEC 61131-3 PLC Software Development**

In the white space the user can create code that has access to all usual PLC functions, like timers and variables, and can access all the valve functions:

- Analog sensor inputs (4mA to 20mA inputs)
- Digital sensor inputs (speed sensor and SSI sensor)
- Internal sensors (LVDT, electronic and oil temperature)
- Valve command input and monitor output (4mA to 20mA and +/-10V)
- Internal pressure sensors (P, A, B, T ports)
- Network access (CANopen Master and slave)
- Memory access (Flash, EEPROM, RAM)
- Drive functions, Control Modes, Set Points, Feedbacks

Central to the organization of the data access is the CANopen object dictionary in **Figure 3**. With having full access to the internal valve and controller function, the white space is ideal for sequencing, executing automated functions in a NC machine operation.
3. Rubber moulding application

In this application, a high dynamic proportional valve, often with a special ‘PQ’ spool, controls the injection cylinder see Figure 4. The rubber will be liquefied in the screw chamber, than with a precisely defined velocity profile, the rubber material will be injected into the mould. When the rubber cools down a pressure profile ensures best tolerances of the part.

The build-in control modes for position and pressure can close the loop for pressure and position. The problem is, that for the injection cycle, the build-in position controller only offers one speed. In our application 4 different injection speeds, depending on the position of the injection cylinder are needed.

**Figure 3**: Data Architecture for equal access via CANbus, White Space and Firmware
The situation for the pressure control is similar. Because pressure spikes can happen during the injection process, the switch over from position control to pressure control should be only possible in the last portion of the injection cylinder stroke. Then the pressure should be controlled with a predefined pressure over time profile and then transition into a hold pressure profile. The standard pressure controller offers only on pressure.

The plasticising part of the process, when the injection cylinder retracted to it filled with plastic material again, need a specific back pressure control.

3.1. Implementation

A relative small IEC 61131-3 PLC application has been develop to implement the injection function on the valve. In the beginning the valve is initialized and waits for the start command from the machine control Figure 5. To begin the injection cycle, the IEC 61131-3 PLC program sets up the position controller to move to the final position, the ramp time is calculated so that the cylinder accelerates to the first speed setting in the speed profile. After the cylinder starts to move, the state machine step monitors the actual cylinder position. As soon as the actual position is greater that P2, the speed is set to the S2, the second speed in the profile from Figure 5. Then the state machine jumps to the next steps and waits for the cylinder to pass position P3. This process is repeated until the last step in the velocity profile, where the transition to pressure
control is enabled. The cylinder fills the mould until the pressure rises to the point to start the pressure hold cycle.

![State Machine Rubber Moulding Process](image)

**Figure 5:** State Machine Rubber Moulding Process

Where the injection cycle was transitioning by the cylinder position, the hold pressure phases are defined by a time duration. When the first hold time is passed, the state machine move to the next phase and sets the pressure controller command to the next pressure. This is repeated for all phases of the hold pressure cycle. After that the injection cycle is completed. The injection cylinder has to be refilled with material, plasticising it from the extruder. To support that the cylinder is returned to the origin position, driven by the force of the extruder screw. The valve supports this by keeping a constant back pressure on the cylinder to allow for consistent filling of the injection cylinder. The IEC 61131-3 PLC software sets the pressure control mode and applies the relative low back pressure. It constantly monitors the cylinder position, once it is back to the original position, the valve is closed, ending the cycle and waiting for the next injection process to start.
3.2. Communication with the machine controller

There are two methods possible for communicating with the upper level controller, the machine control, or PLC. For the first method uses a set of free network variables. The range from CANopen parameter index 2087 to index2086 can be written from the controller and are used to store command, like stop, go, reset to the state machine. A second range of CANopen parameters from index 2087 to 208D can be written by the white space and provide information about the current status of the state machine. Sensor data can always be streamed via custom PDOs or simply accessed as data from the object dictionary. In this method IEC 61131-3 PLC does not use its own CANbus CANopen stack, it simply accesses the CANbus via the object dictionary of the valve, which runs its own CANopen stack in the firmware.

In the second method, the white space uses its own stack and all the data is shared with the network is held in its own object dictionary linked to a custom EDS file. It does not conform to DS408 anymore, the injection axis becomes its own profile. This takes extra work to design and implement, but allows to encapsulate the valve and control function from the network. This can lead to a simpler and easier to use network interface.

3.3. Visualisation

It is possible to create a visualisation inside of the IEC 61131-3 PLC development environment. The performance of the injection function can be debugged and optimized, see Figure 6 for a screen shot.

![Figure 6: Visualisation in Development Environment](image-url)
It is only available during the development process, when the PC is connected for programming and debugging. If the visualization is helpful in the production environment, it can be ported to a HMI (human machine interface) and be part of the machine control interface. As an alternative the user interface of the valve (ProFX configure) can be used for calibration and data logging, Figure 7.

![Figure 7: Access Control Data in Valve User Interface](image)

4. Results

The software written for this paper on the intended use on a rubber moulding machine took about 2 weeks. The code size was 120 lines of code, the task was set to a 5ms loop time, execution time was about 120us. This was sufficient, since all the control loops were executed in the firmware at a rate of 1ms. The data was taken on a small hydraulic axis simulator. For the presentation the results on the actual customer machine will be available and shared.

5. References

/1/ Profile Fluid Power Technology Version 1.5 VDMA Frankfurt 2001

/2/ CiA Standard DS 408 CANopen Device profile fluid power technology V1.5.2 2005

/3/ Eaton AxisPro User Manual April 2013