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CHALLENGES OF AUTOMATING THE PHOTOCATHODE FABRICATION PROCESS AT CERN

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Abstract

The CERN Photoemission Laboratory was founded in 1989 with the goal of studying laser-driven electron sources, for producing high-brightness electron beams within the framework of the Compact Linear Collider (CLIC) study. To produce these photocathodes, two processes run in parallel. The first process, which is slow and asynchronous, controls and monitors the evaporation of photoemissive material. For this first step several power supplies are controlled to evaporate different metals through the Joule effect, with the power maintained constant in time and the thickness deposited monitored. The second process is synchronized with a laser trigger ranging from 0.1 to 50Hz, where the photocurrent and laser energy are measured to calculate the Quantum Efficiency.

The control system for these processes has recently been renovated to benefit from the modularity of a PXI-based real-time environment using the standard CERN MiddleWare communication layer (CMW). This paper describes the challenges of the fabrication process as well as the flexibility introduced by using a PXI system.

INTRODUCTION

The CERN Photoemission Laboratory [1] was built with the goal to study and supply the CLIC Test Facilities (CTF 1 and 2) [2] with electron bunches of a few ps in time with a high electrical charge in the range up to 100 nC.

The CERN Photoemission Laboratory apparatus is divided in three parts:

- The Preparation Chamber where the fabrication of our photocathodes (the electron source) is done
- A DC Gun coupled with a beam measurement line for the characterisation of the cathode properties with a real, powerful, electron beam.
- A laser which is used to illuminate the electron sources during the fabrication and characterisation phases.

In the middle of the years 1990, after a few years of R&D, and the validation of the Cs-Te deposition technology, the laboratory received an important upgrade which enable the possibility to supply the CTF, our first client, with electron sources.

FABRICATION PROCESS

Physical Process Involved

The fabrication of the photocathode (Fig: 1) is the process of coating a substrate, the Cu photocathode plug, with a mixture of alkali metals and another element, tellurium or antimony. During this process the cathode is illuminated with a laser. A photoemission reaction occurs and produces an electron current, collected and measured to quantify the cathode's performance. The goal is to maximize the photocurrent and the quantum efficiency of the cathode while ensuring a very good source lifetime.

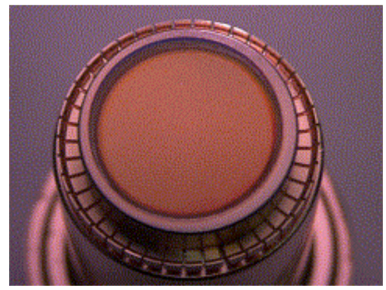

Figure 1: Cs-Te coating visible on the photocathode head.

In order to optimize the process, the system needs to be able to control several power supplies used to heat the evaporators and monitors the applied electrical power, temperature, laser energy, intensity produced by the photoelectron current, thickness of the coatings and vacuum pressure.

Instrumentation

- The Inficon XTM/2 deposition monitor is dedicated to monitor the alkali coating.
- The Inficon XTC/2 deposition controller is used to monitor the thickness of the tellurium coating.
- The Inficon XTC/3S is a spare deposition controller
- The TPG300 is a vacuum gauge controller to monitor the pressure in the vacuum vessel.
- The VIONIC 159 is the vacuum gauge controller for hot cathode gauge.
- The Heidenhain ND 780 is a positioning ruler, as a milling machine gives the position of the evaporator arm and the cathode arm in um.
- The Radiometer RM6600a is used as Joulemeter to monitor the laser energy when the light hits the cathode.
- Power supplies (Delta Elektronika + CERN made electronics) heat the evaporator (Cs or Te) by the Joule effect (control and instrumentation)
- Temperature monitoring with thermocouple and dedicated electronics
- Photocurrent acquisition with a precise laser synchronous timing system and fast sample/hold electronics.

CHALLENGES

Photocathode fabrication in laboratories like CERN is not reproducible because installations were designed for R&D and not for industrial production. Furthermore, with

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each fabrication we often change parts of the process for learning purposes. Lots of parameters can affect the final result and we need to have a good knowledge and control of each of them:

- Deposition Flow Rate of Cs or Te (called Stoichiometric Ratio Control)
- Caesium availability in the evaporator
- Vacuum Quality
- Temperature (Alkalic Antimony Cathode only)
- Mechanical positioning of the Evaporators (ruler)

We learned how to upgrade the mechanical engineering aspects of the project to reach reproducible results and a fully automated process is now mandatory to assist the operator in controlling the process. All the tools are now available to start a real automatic process.

AUTOMATION

Architecture

The user should be able to monitor and control the main parameters with a refresh rate of approximately 1 Hz and plot them as a function of time. The entire process can take more than half a day and should not be stopped. Some intelligent devices like the laser energy meter or the thickness monitors communicate via GPIB or RS-232 The other devices are controlled by analog signals (between +/-10 V) and digital signals. To separate the GUI and the real-time process, a standard 3 tier design (Fig. 2) has been chosen. The communication between the real-time task and the GUI is done using the CERN Controls Middleware framework (CMW) [3]. Each equipment is abstracted by a dedicated software module.

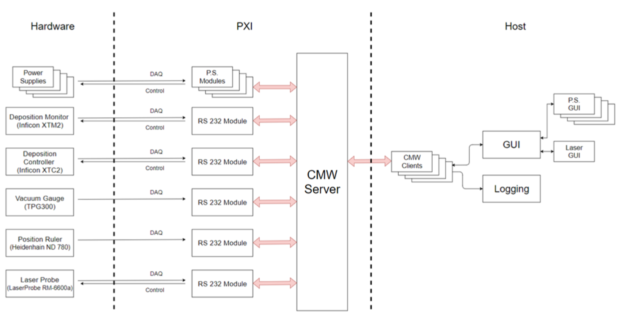

Figure 2: Automation software architecture.

The software is implemented using the Actor Framework [4], which abstracts the communication between the different modules, thereby increasing development efficiency. This framework is object-oriented, which allows us to add several layers of abstraction. Each serial device is a child of the RS-232 module class (Fig. 3).

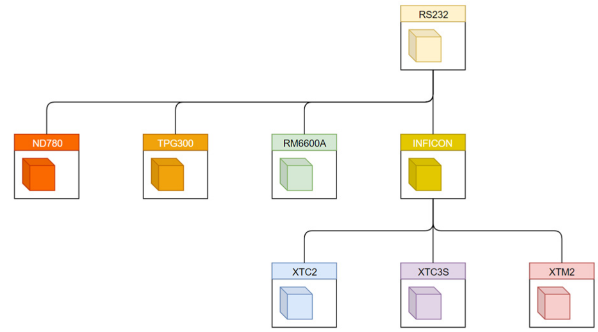

Figure 3: Class hierarchy of the RS-232 module.

Each serial device has maximum 3 features:

- Live streaming of the current data
- Getting the current settings
- Reacting to user commands

The RS-232 devices class abstracts all these features and has a common communication interface with the main module. The INFICON devices, being similar to each other, share a common parent. The addition of a new device and the maintenance of the current ones benefit from this implementation.

The most challenging part of the real-time software was the power supply implementation (Fig. 4).

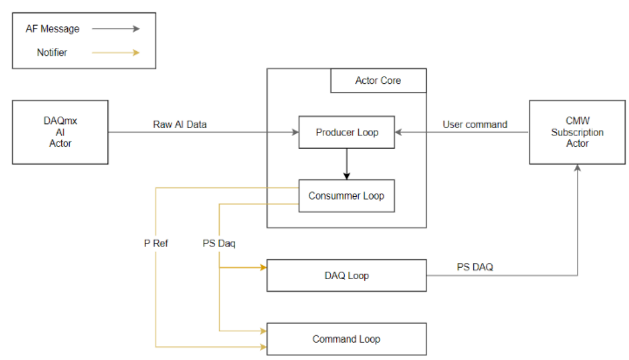

Figure 4: Power supply internal communication actor.

Each power supply is handmade at CERN and therefore has its own behaviour. To regulate the power supplies, an adaptive controller could also have been implemented but the idea was discarded due to a lack of time and the difficulty to make a system identification.

The actor framework's main drawback on LabVIEW real-time targets, is that each actor is re-entrant. This means they cannot be debugged using standard LabVIEW tools. To cope with this limitation, the RADE-logger [5] was heavily used to track errors. To be able to test the actor framework properly on real-time targets, additional support modules had to be developed, adding overhead compared to standard OOP LabVIEW implementations. In hindsight, using the Actor Framework on a real-time target might not have been the best design choice for this project, however it proved both scalable and adequate for the job.

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Hardware Chosen for the Automation

The process doesn't require high speed acquisition or control, however it does require stability during a long run. To benefit from a Real-Time OS, a timing input and a robust CPU, the PXI controller NI PXIe-8821 with a PXIe-1082 chassis, was used. To communicate with the serial devices, a PXIe-8430/8 was used. To communicate with power supplies, a PXIe-4302 for the analog inputs, a PXIe-6738 for the analog outputs, and a PXIe-6535 for the digital inputs and outputs were used (Fig. 5).

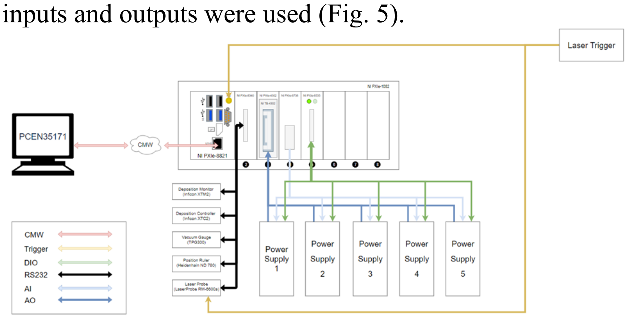

Figure 5: Automation hardware architecture.

Power Supply Control

In the application, the power supplies are controlled for power, but physically in the hardware, only the current parameter is controlled at the power supply. We use the voltage of the evaporator to compute the power of the evaporator as shown in Eq. (1).

$$P_{Evaporator} = U_{Evaporator} * I_{Power\ Supply} \quad (1)$$

This power must be regulated in real time within a few hundreds of ms via the application. Up to five power supply values can be regulated in parallel.

Continuous Process

The power supply feedback is made with a 100ms cycle to comply with the control system design. Therefore, the analog and digitals inputs are acquired at 10 Hz. They following the power supply current, voltage and states and also the temperature of the fabrication bench as shown in Fig. 6.

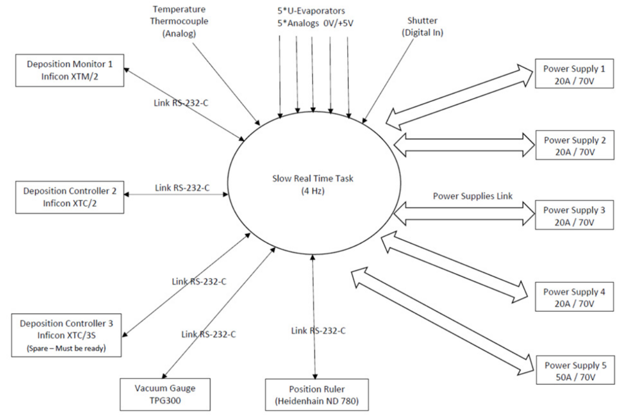

Figure 6: Slow process communication layer.

Several devices are connected to the control system using RS-232. As the fabrication of the photocathodes is a relatively slow process, it is sufficient for the feedback of the deposition of the different metals to be followed on the timescale of one second. The use of serial communication is therefore acceptable. The readings of the different devices are made at 4 Hz. 10 to 20 seconds are needed to get a proper deposition, and within this time we can pass from a good to a bad cathode. A precise quantity of matter needs to be deposited to maximize the quantum efficiency (QE), which is given by Eq. (2) [6].

$$QE = K \frac{Laser_{Energy}}{U_{Electrode}} \quad (2)$$

Where K is a coefficient.

Triggered Process

The electrode voltage and the laser energy are monitored at 10Hz. This value allows us to compute the quantum efficiency that the operator will maximise to improve the quality of the photocathode. The acquisition of the radiometer, measuring the laser energy, and the electrode voltage are synchronized using the TTL trigger from the laser as shown in Figure 7.

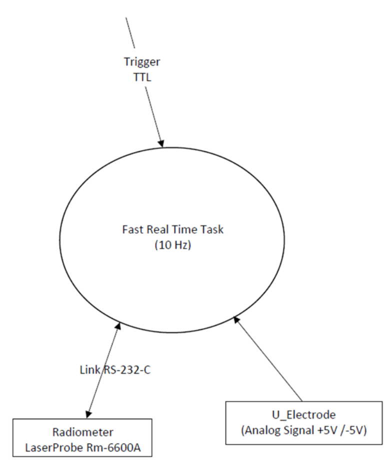

Figure 7: Fast process communication layer.

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RESULTS

To optimize the stoichiometric ratio of the Cs-Te (Cs2Te) alloy, you need to optimize the flow rate of the Caesium vapor. This optimization is a function of the (not constant) tellurium vapor flow and of the level of quantum efficiency. This is done by fine tuning the evaporator power.

This allows the QE to achieve record values greater than 20% (Fig. 8) but the process remains delicate. The key to achieve this is the monitoring of parameters such as photocurrent, laser energy, deposited thickness and a good control of the power.

The high quantum efficiency allows us to produce a cathode with longer lifetime (between weeks and months depending on the electrical charge produced and the frequency of use) addressing what is probably the main issue of these cathodes.

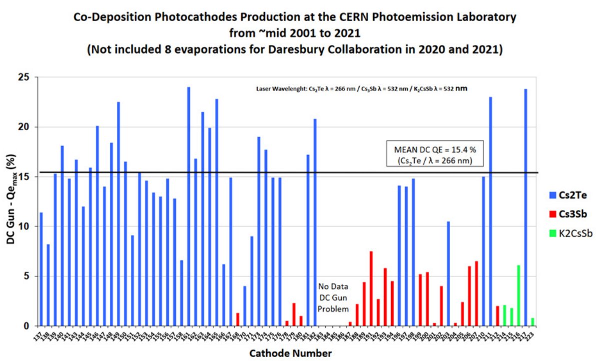

Figure 8: Quantum efficiency result.

Even if the process is not very fast, it requires both a flexible and deterministic control solution. The NI PXI systems provide both things. Moreover, the PXI platform opens the possibility to add additional cards and/or more mathematical processes in the future.

FUTURE IMPROVEMENTS

To improve the quantum efficiency, and further automate the solution, we need a deeper understanding of the physical process itself. This could be done via increased monitoring and perhaps, using machine learning, further optimising the process itself.

In general, adaptive controllers could be implemented after proper system identification. Interlock monitoring on the mechanical pieces could be added. The motors of the cathode holders and the vertical arms holding the evaporators could be controlled automatically. This will still require a deeper understanding of the manual process itself which today relies entirely on the experience of the operator.

CONCLUSION

Even though an operator is still required to monitor and control the photocathode fabrication process, the automation of various tasks such as the evaporator control, the synchronization of each device and the reproducibility introduced by this new implementation allows CERN to be technologically ready for full automation of this process in the future. In addition, the accuracy of the power regulation as well as the availability of the data gives us more flexibility in the automation.

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