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HIGH LEVEL CONTROL SYSTEM CODE WITH AUTOMATIC PARAMETRIC CHARACTERIZATION CAPABILITIES

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Abstract

Several degree of freedom have been introduced in the design of the proton source (named PS-ESS) and in the Low Energy Beam Transport line (LEBT) developed at INFN-LNS for the European Spallation Source (ESS) project. The beam commissioning was focused on the most important working parameters in order to optimize the beam production performance taking into account the ESS accelerator requirements. The development of a MATLAB custom code able to interact with the EPICS control system framework was needed to optimize the short time available for the beam commissioning. The code was used as an additional high level control system layer able to change all source parameters and read all beam diagnostics output data. More than four hundred of thousand configurations have been explored in a wide range of working parameters. The capability to connect Matlab to EPICS enabled also the developing of a genetic algorithm optimization code able to automatic tune the source towards a precise current value and stability. A dedicated graphical tool was developed for the data analysis. Unexpected benefit come out from this approach that will be shown in this paper.

ION SOURCE PARAMETERS FLEXIBILITY

The proton source [1-2] developed at INFN-LNS for the European Spallation Source [3] is a Microwave Discharge Ion Source (MDIS) working at 2.45 GHz. The most important parameters having a direct effect in the plasma production are the magnetic field, the microwave power and the gas inlet pressure. The magnetic field is provided by a three coils magnetic system packaged with XC10 steel to increase the flexibility in the magnetic field production. Three are the parameters the user can select to change the produced magnetic field: the amount of current flowing in each coil (named Injection, Middle and Extraction). Starting from this set of current values the magnetic field profile inside the plasma chamber is evaluated with a magneto static simulation and the strength in three points close to the three coils is extracted. The amount of microwave power provided by the magnetron can be selected by the user and the adsorbed power can be monitored. The microwave injection line consists also of a four stubs (two couples) tuning unit that is used to match the impendence of the plasma chamber and increase the microwave to plasma coupling. This device show to the user two parameters that are the positions of the X stubs couple and the Y stubs couples. The pressure inside the plasma chamber is driven by the amount of gas (pure Hydrogen) that is injected in the plasma chamber.

The main parameter that change the beam transport in the LEBT [4-5] are the magnetic field of two focusing solenoids and four steerers. The beam transport is strongly affected by the space charge of the beam that is neutralized by a gas addition in the LEBT. Two type of gas can be selected in our installation, Hydrogen and Nitrogen. Both in the source and in the LEBT the gas adduction is regulated by a dedicated mass flow controller able to regulate and measure with high precision and repeatability the amount of gas injected. The used ranges for the parameters of the source and of the LEBT are shown in the tables 1 and 2. Others parameters that increase the source flexibility but that were not connected with the software layer described in this paper are present but not here reported.

Table 1: Main Source Parameters

Parameter	Minimum value	Maximum value
Microwave power	100 W	1200 W
X stubs	0	10000
Y stubs	0	10000
Coil Injection	0 A	400 A
Coil Middle	0 A	400 A
Coil Extraction	0 A	400 A
H_2 gas flow	0.2 SCCM	10 SCCM

Table 2: Main LEBT Parameters

Parameter	Minimum value	Maximum value
Solenoid 1	0 A	400 A
Steerer Vertical 1	0 A	50 A
Steerer Horizontal 1	0 A	50 A
Solenoid 2	0 A	400 A
Steerer Vertical 2	0 A	50 A
Steerer Horizontal 2	0 A	50 A
H_2 gas flow	0.2 SCCM	10 SCCM
N_2 gas flow	0.2 SCCM	10 SCCM

CONTROL SYSTEM

The control system developed by ESS and CEA is based on EPICS and the graphical interface was developed with Control System Studio. The graphical interface uses two screens one for the parameters setup and one for the beam diagnostics measurements. The most important parameters of the source and the LEBT are shown in two tabs shown in the Figure 1 and 2. A detailed view of all working parameters of each used device is shown in different tabs here

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not reported. In the beam diagnostic interface there is a section with the Faraday Cup (FC) measurement shown in Figure 3, and beam current monitor section that show the measurement done with two AC Current Transformers (ACCT) shown in Figure 4. This sections show the actual beam characteristics for each beam pulse produced and a trend diagram that shows average, maximum and minimum current for the last ten thousand produced pulses. Doppler shift measurement unit and Emittance measurement unit section are also present but not here reported.

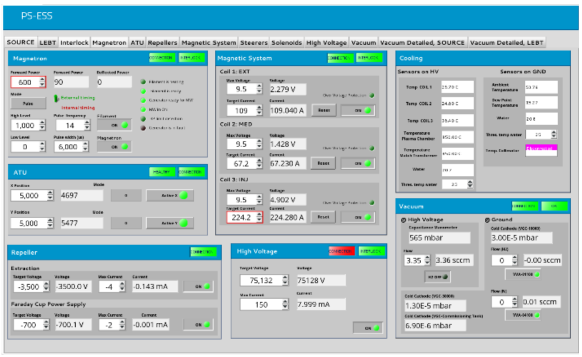

Figure 1: Source parameters main interface.

Figure 2: LEBT parameters main interface.

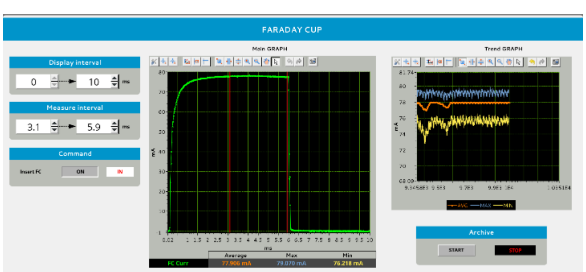

Figure 3: Faraday Cup interface.

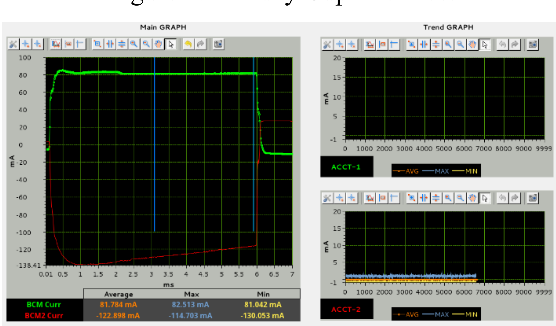

Figure 4: AC current transformers interface.

MATLAB CHANNEL ACCESS TO EPICS

The Matlab Channel Access (MCA) to Epics was installed in a windows based machine using the instructions that can be found on the link:

`https://github.com/EPICSTools/mca/blob/master/README_WIN7.txt`

The installation required: 7zip; Make; Perl; Matlab; Microsoft Windows SDK v7.1; Visual Studio 2012 Professional; EPICS base; C/C++ Compiler; MCA.

At the end of the installation, Matlab is able to interact with EPICS by using three functions:

- **pvhandle=mcaopen(pvname);** acronym of Matlab channel access open, that open the link to the process variable on the host epics environment of the source control system.
- **pvvalue=mcaget(pvhandle);** acronym of Matlab channel access get, that provide the value of the process variable in the epics environment.
- **[]=mcaput(pvhandle,value);** acronym of Matlab channel access put, that insert a value in the process variable of the epics environment.

With only this three functions it is possible to change the parameters of the source and read the output of all measurement equipment.

To obtain reliable and reproducible results the only need is wait, after the setup of a new operating point on the source, an adequate amount of time to permit the source stabilization in the new configuration. After this time the measurement output of the new source configuration is acquired. Few seconds are typically needed to wait the response of the power supplies connected with inductive load. When the microwave tuning unit is used in automatic mode, it is important to wait the time needed to find the new optimum stubs positions.

OPTIMIZATION WITH A GENETIC ALGORITHM

The capabilities offered by the MCA enabled the possibility to write a code able to change the source parameters and measure the source performance. Therefore, our efforts have been focused in the devel-opment of a genetic algorithm optimization tool. After different trials we succeeded in the development of a tool able to drive the source to a configuration pro-ducing the desired beam current and quality. However, we observed that this tool do not provide to a potential user a clear comprehension of the source behaviour. In particular, the size of the stability island and any even-tual dangerous configuration close to the operating one were not shown. To get a better understanding how the source parameters affect the source perfor-mance a study of its response by varying each of them in a wide range has been carried out. This systematic exploration of more than 400.000 configurations, permitted to identify the regions where the source work well and the forbidden regions where the source does not match the operating requirements and the potential dangerous configurations.

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WIDE PARAMETRIZED SOURCE CHARACTERIZATION

For the characterization of the source performances the list of the source parameters with their respective ranges is shown in table 1. Our attention was focused at the beginning in the identification of the most critical parameters affecting the source performance taking also into account the ESS requirements. The source produces a pulsed beam 6 ms long with a repetition rate of 14 Hz. For a reliable and reproducible analysis one hundred pulses for each configuration under test were acquired. For each pulse the measurements of almost all diagnostic equipment plus some live processed data were stored. The most important measurements were provided by an acquisition card that digitalize the Faraday Cup and the two ACCT beam response with a sample rate of 1 MHz. Some parameters that describe the variation between the hundred pulses of each configuration and the average pulse shape are evaluated in a live mode and stored. One of the most critical parameters extracted from all the acquired pulses for each source configuration is the beam ripple parameter. This parameter is a mathematical function we defined for the description of the beam stability. All the analysis done was driven by the necessity to have a tool clearly showing the operational points satisfying the ESS requirements. In particular, the two most relevant parameters are the stability of the current during the duration of the pulse, and the stability of the average current produced in the pulse sequence. The total amount of data collected for each source configuration is composed by 3 different type of pulse shape at 1 MHz of sample rate and 26 parameters that describe the beam pulse shape and the stability between consecutive pulses.

The large amount of data collected required the developing of a dedicated interface able to show the different output parameters versus the source parameters used. An example of the developed interface is shown in the figure 5 where four graphs are used to identify the trend of the performance versus the source parameters. In the top left part there is the average current produced on the FC. In the top right there is the average current captured by the ACCT located in the high voltage cable of the platform. In the bottom left part of the interface there is the trend of the ripple parameter. In the bottom right part there is the ACCT current after applying a filter of the configuration that satisfy at least half of the stability requirement needed by the ESS accelerator. Marked with an asterisk there are the maximum performance of the first two maps and the configuration that fully satisfy the ESS requirement for the other two maps. For a physical understanding of the results the configurations are indexed using the magnitude of the field produce instead of the amount of current used in the three coils of the source, Injection, Middle, Extraction.

CONCLUSION

The most important aspects making this approach possible are: the capability to connect Matlab to EPICS and the reliability and repeatability of the source. This is evident by looking to the results shown in the figure 5. Each pixel represents a different source configuration, going from top to down the configurations are consecutive, while going from left to right the configuration are not consecutive and the source behaviour shows a clear trend that is not affected by the different tens of configurations tested in between. This is a clear proof that identify the truthfulness and the repeatability of the acquired information.

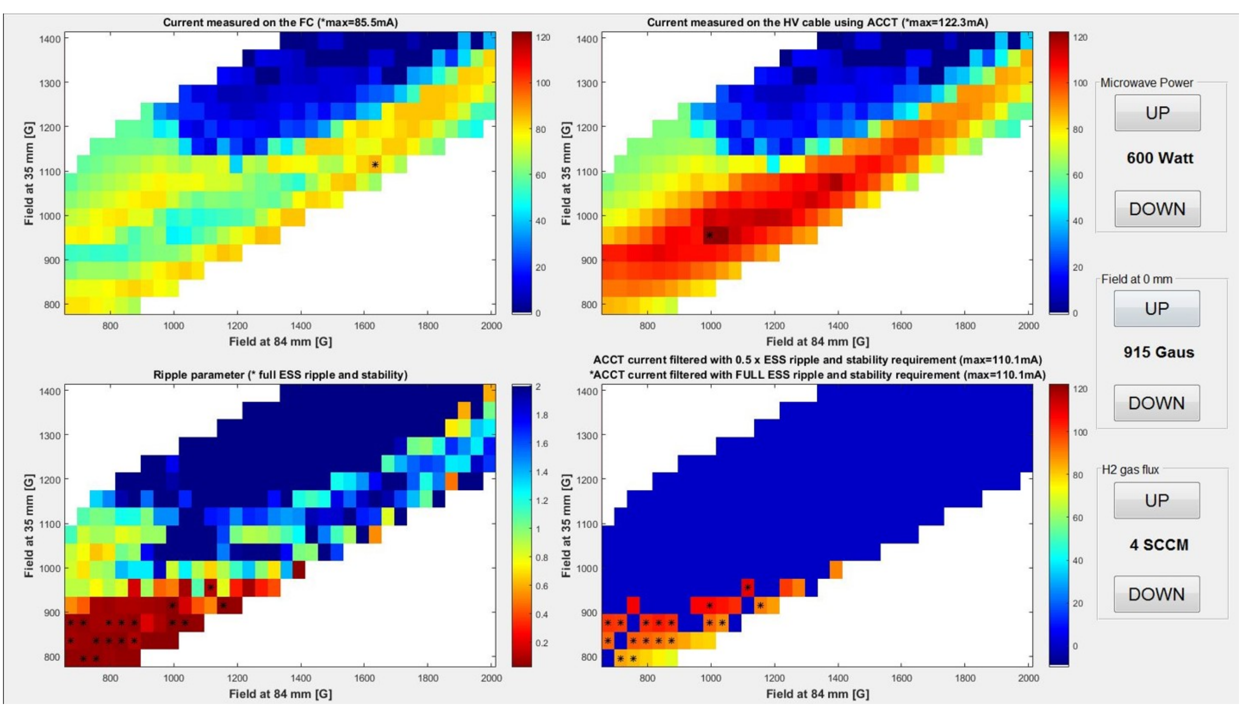

Figure 5: Interface developed for the navigation of the wide range of source parameters tested.

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The benefits of the used approach are evident. The time needed for the characterization were minimized with respect what would have been necessary for an operator that can change manually the source parameters and write a report for each configuration tested. The analysis was also quantitative and free from human approximated judgement. The commissioning was done 24 hours per day. The man power was redirected to the data analysis effort.

At the end of the commissioning the most important result was the clearly identification of several sets of source parameters fully satisfying the ESS requirements.

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