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Particle Accelerator Focus Automation

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The *Laboratório de Aceleradores e Tecnologias de Radiação* (LATR) at the *Campus Tecnológico e Nuclear*, of *Instituto Superior Técnico* (IST) has a horizontal electrostatic particle accelerator based on the Van de Graaff machine which is used for research in the area of material characterization. This machine produces alfa (He^+) and proton (H^+) beams of some µA currents up to 2 MeV/q energies. Beam focusing is obtained using a cylindrical lens of the Einzel type, assembled near the high voltage terminal. This paper describes the developed system that automatically focuses the ion beam, using a personal computer running the LabVIEW software, a multifunction input/output board and signal conditioning circuits. The focusing procedure consists of a scanning method to find the lens bias voltage which maximizes the beam current measured on a beam stopper target, which is used as feedback for the scanning cycle. This system, as part of a wider start up and shut down automation system built for this particle accelerator, brings great advantages to the operation of the accelerator by turning it faster and easier to operate, requiring less human presence, and adding the possibility of total remote control in safe conditions.

Keywords: Particle accelerator, LabVIEW, beam focus, ion source.

1. Introduction

There have been some efforts in research facilities around the world to automate the operation of their particle accelerators in order to increase their ease of use [1-4].

At LATR a horizontal electrostatic particle accelerator based on the Van de Graaff machine is used (Fig. 1) for research in the area of material characterization.

This type of particle accelerator uses an electrostatic charging belt to generate a voltage potential at a high voltage terminal. The positive ions are produced by energizing the low-pressure Hydrogen or Helium gas contained in a small glass chamber (ion source) placed at the high voltage terminal, with the help of a radiofrequency (RF) signal and a 0 to 2 kV voltage applied directly at one end of the ion source which controls the amount of ions coming out of the source (extraction voltage), both generated at the terminal. The ions are then accelerated by the potential difference between the terminal and the ground through a tube (accelerator tube) maintained at very low pressure (about 10^{-6} mbar).

The accelerator tube is composed of a series of 60 ring shape electrodes separated from each other by insulating glass rings. Between each electrode is a resistor of 1 GΩ, forming a cascade of 60 GΩ (Fig. 2). The aim of this assembly is to have a constant voltage drop along the tube from terminal to ground to improve high voltage stability.

As the ions are all of positive charge, the ion beam has the tendency to spread, thus the need to have a focusing system. The focusing is achieved with the help of an electrostatic lens placed just after the ion source.

Fig.1. Photograph of the particle accelerator installed at the LATR-IST.

The lens effect is obtained by biasing the second electrode after the source with a negative voltage relative to the terminal, so the potential difference between the second and first and third electrodes creates a sequence of electric fields that act on the ion beam as an Einzel lens.

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Furthermore, the correct value of voltage to use depends on the energy of the beam, that is, on the composition of the beam and the velocity of its ions. The correct focus voltage to use depends thus on the user settings of the desired beam energy but also on other non-ideal aspects like the variability of gas pressure used in the ion source or the mechanical hysteresis of the device that produces the focus voltage, which is basically a potentiometer with a motor positioned cursor [5,6].

All these procedures require the setting up and monitoring of different controls and parameters. The proper turn on and turn off procedure is intricate and traditionally done by an experienced technician. Those procedures require the technician that is operating the machine to adjust the focus control voltage, while reading the beam current, in order to maximize the value of that current.

One of the difficulties in carrying out the focusing procedure by hand is related to the nonlinear relation between the control dial and the voltage applied to the lens due to the hysteresis of the mechanical gear control of the voltage supply (Fig. 4).

This paper describes the procedure required to automatically achieve the best focus possible under those variable conditions. The system developed at LATR-IST uses a personal computer (PC) and LabVIEW software to monitor and control the particle accelerator [7]. It goes one step further than the previous systems since it has the added benefit of being able to automatically set the terminal voltage to the desired energy, strike up the ion source and focus the ion beam. It is also capable of shutting down the accelerator safely.

In this paper, the "control voltage" is the low voltage used to control the supply for high voltage applied to the electrostatic focusing lens and the "beam current" is the current measured on a beam stopper, which is a conductive target made of tantalum placed in the path of the ion beam. The automated procedure presented here is able to consistently achieve good beam focus in less than 30 seconds and can be used by non-experienced users.

2. Beam Focusing

A focused beam is obtained when the proper voltage is applied to the electrostatic lens (Fig. 2).

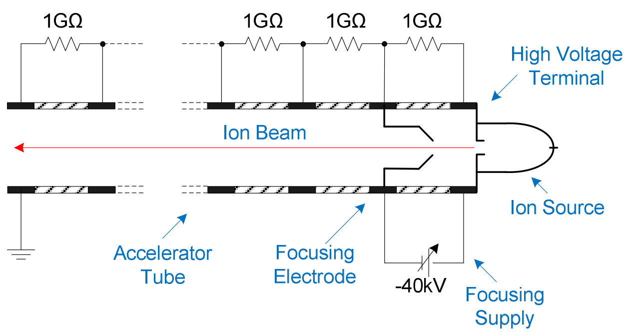

Fig. 2. Focusing assembly schematic.

This lens is composed of three cylindrical accelerator tube electrodes placed just after the ion source. The beam focus is achieved by setting the proper voltage in the middle electrode [8]. As the supply of this voltage is connected to the source potential, the voltage must be negative, so that the middle electrode can be biased with a voltage between the source and tube electrodes.

The maximum focusing voltage is -40 kV in the LATR-IST particle accelerator. The circuit that generates such high voltage is shown in Fig. 3. It uses a potentiometer connected between 110 Vac and terminal ground in order to produce a voltage which is input into a transformer which raises it up to 10 kVac.

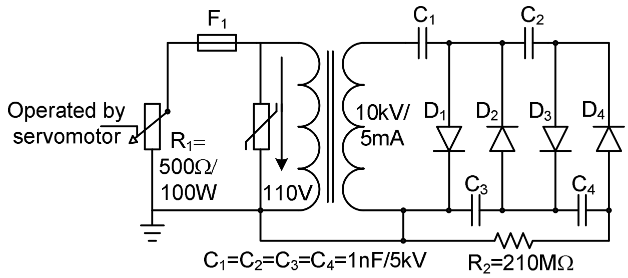

Fig. 3. Manufacturer's schematic showing the circuit used to produce the high voltage applied to the Einzel lens.

After that a Villard cascade voltage multiplier (or Cockroft-Walton multiplier) is used to quadruple and rectify the voltage up to -40 kV [9]. To be able to remotely control the high voltage produced, a DC servo-motor is used to transfer the rotation of a dial in the control console to the potentiometer inside the particle accelerator.

The rotational movement of the servo-motor is transformed into an axial movement of the potentiometer cursor using a screw and gear, as shown in Fig. 4. This mechanical arrangement has a hysteretic behavior as will be shown later.

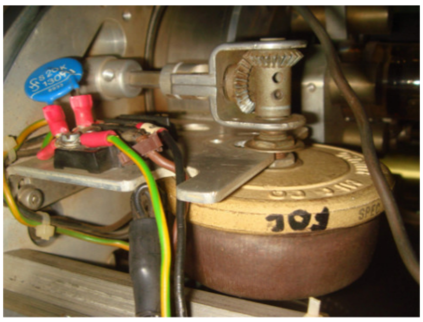

Fig. 4. Gear and potentiometer that controls the focusing voltage supply.

To check if the beam is focused, a measuring beam stopper is placed in the beam path. The more focused the beam is, the higher the current measured on the beam stopper. That current is used as an indicator of beam focus.

The degree of beam focus can be visually accessed by looking at a quartz viewer placed in the tantalum target since it emits a bluish light when the ions in the beam strike it. The beam stopper has a peep hole that is used just for that purpose as can be seen in Fig. 5 and Fig. 6 which correspond to a beam out of focus and a focused beam, respectively.

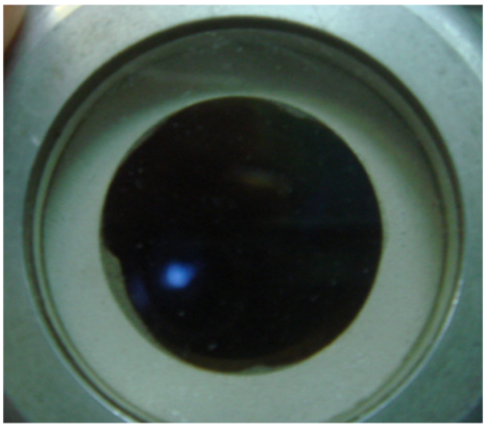

Fig. 5. Head on view of the light produced by the beam hitting the quartz viewer on the beam stopper when the beam is not in focus.

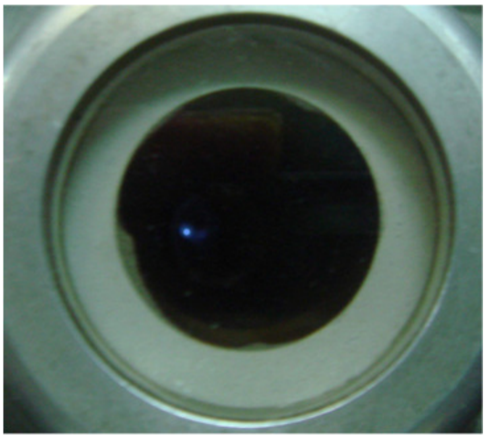

Fig. 6. Head on view of the light produced by the beam hitting the quartz viewer on the beam stopper when the ion beam is in focus.

3. CONTROL APPLICATION

An application developed using National Instruments LabVIEW was created to automatically control the particle accelerator operation. The operator can monitor and control all procedures using the developed interface and at any point the automated procedures can be interrupted so the operation can carry on manually.

The procedures were implemented using a computation model known as finite state machine. The particle accelerator operation state machine can be seen in Fig. 7. The states in the finite state machine are the phases that the particle accelerator goes through before being ready for use ("Machine Ready" state), namely, setting the terminal voltage (an intermediate value to be set before the final value can be reached), striking up the ion source, and focusing the beam. When any of these operations are not possible (there is no Hydrogen or Helium gas left in the gas bottles, for example), the machine reverts to the initial state ("Machine Off").

A state machine can be programmed in LabVIEW using a "Case" structure linked to an integer variable and placed inside an infinite while loop. Each iteration of the loop represents one state transition.

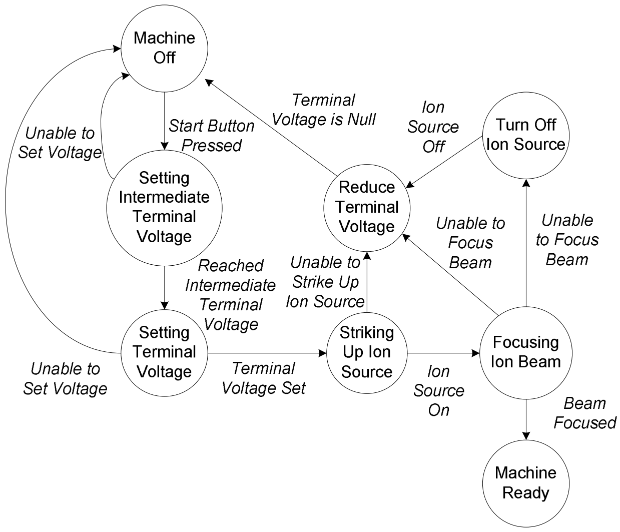

Fig. 7. Particle accelerator state machine.

The beam is focused when the current in the beam stopper is maximal. Beam focusing is done by slowly increasing the focus voltage and determining when it corresponds to the maximum beam current. When it decreases by 5% it is considered that the maximum beam current has been passed. In Fig. 8 the flowchart of the beam focusing procedure is presented.

This cycle can be repeated a number of times, as can be seen in Fig. 9, to refine the peak value. This is done by comparing the mean of the beam current taken over the last measurements with the previous mean.

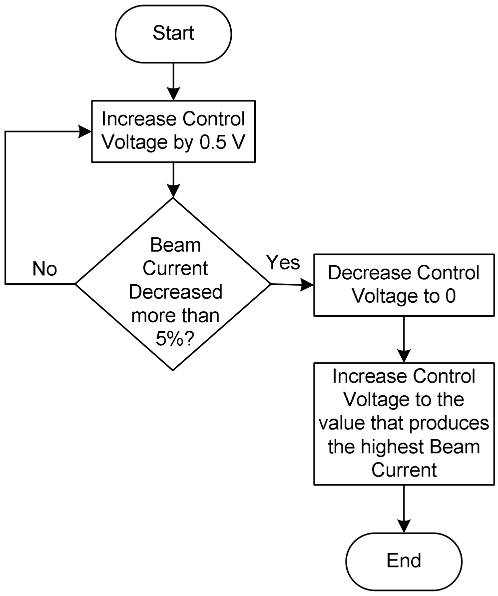

Fig. 8. Ion beam focus cycle flowchart.

The focus control voltage is increased in 0.5 V increments while the beam current is increasing. As soon as the beam current decreases by more than 5% from the maximum it is considered that the current maximum has been reached. Then, the focus control voltage is decreased to 0 in order to increase it to the value that was previously determined as leading to the maximal beam current. This resetting of the control voltage to 0 has to be done due to the hysteresis factor.

In Fig. 9 a chart is shown with the beam current as a function of the focus control voltage for a terminal voltage of 1.3 MV and extraction voltage of 500 V. Several passes were made by increasing the control voltage from 0 to 10 V and back to 0. An offset between increasing and decreasing of control voltage is clearly seen. This hysteresis behavior is due to mechanical gaps on the potentiometer control mechanism inside the particle accelerator as explained before.

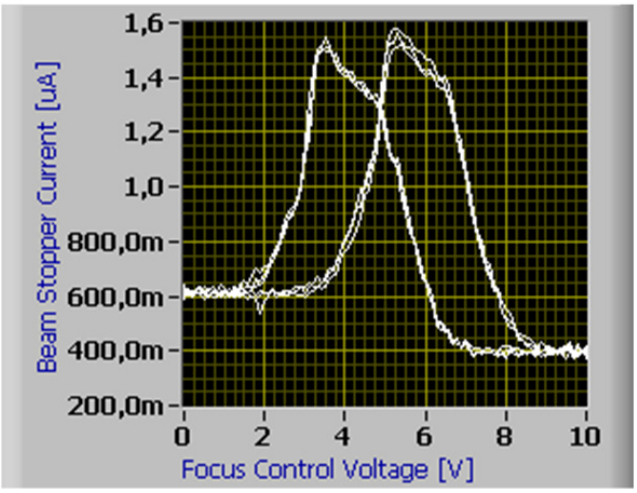

Fig. 9. Chart showing the relation between the beam current and the focus control voltage during focusing procedure, for a terminal voltage of 1.3 MV. Control voltage ascending values peak on the right and descending values peak on the left.

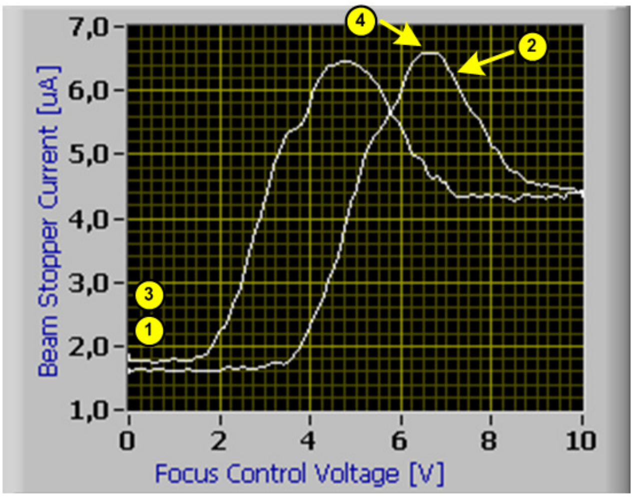

Fig. 10. Chart showing the beam current vs focusing control during focusing procedure, voltage for a terminal voltage of 2 MV. 1) voltage increase to find maximum current value; 2) current 5% below maximum peak is reached; 3) voltage set to 0 again; 4) voltage set to peak value.

This effect results in the peak obtained by ascending voltage values that appears on the right of the peak obtained by descending voltage values.

In Fig. 10 a chart is shown with beam current vs control voltage for a terminal voltage of 2 MV and an extraction voltage of 750 V. Only one increasing and one decreasing pass was carried out for better demonstration.

Two differences are noted. One is that the maximum value of the beam current is higher, which is explained by the higher extraction voltage applied. The second difference is that the maximum voltage occurs for a higher control voltage which is explained by the higher terminal voltage and consequently higher voltage applied on the focusing lens.

The focusing procedure is all done automatically according to the settings previously determined by the operator, including the number of cycles for current peak value refining.

4. Conclusions

The system developed to automatically focus the ion beam on a particle accelerator used at LATR-IST, based on a personal computer running LabVIEW, was presented. This system is able to automatically determine the proper voltage to apply to the focusing lens to achieve the best beam focus.

The main particularities of the ion beam generation and focusing control were highlighted, namely the control system's hysteresis, and were taken into account when designing the automation procedure.

The described ion beam focus system is part of a more extensive system which is able to set the terminal voltage to the desired value, strike up the ion source and focus the beam. All these procedures were automated, bringing great advantages to the operation of the particle accelerator by allowing it to be easily operated, with less human presence required and the possibility of total remote control in safe conditions.

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