Automation of a Particle Accelerator Operation Using LabVIEW

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Abstract – **In this paper we present an automatic system developed for the Lisbon's Technologic Nuclear Institute to control the operation of their particle accelerator. It is an accelerator based on a Van de Graaff machine. The system uses a personal computer running LabVIEW software which implements the procedures to automatically increase the terminal voltage, light-up the ion source and focus the particle beam.**

Index Terms – **Particle accelerator, LabVIEW, Beam focus, Ion source.**

I. INTRODUCTION

The Van de Graaff particle accelerator, installed at the Ion Beam Laboratory of the Technological Nuclear Institute is used for research in the area of material characterization. This machine is capable of producing Helium (He+) and Hydrogen (H+) ion beams with energies up to 3 MeV and current intensities of a few microamperes. It is like many others around the world dedicated to scientific research [1].

The complexity of a particle accelerator and the variety of parameters that can be adjusted to fit different research experiments carried out with it, benefit substantially if its operation can be done with the help of a computer. There are innumerous instruments and measurement systems that use a computer to control it and collect, process, represent and store the results. Many of them use National Instruments LabVIEW graphical programming language like the one described in [2].

This setup, using a personal computer and LabVIEW, has also been used with particle accelerators like the one in the Nuclear Structure Laboratory (University of Notre Dame) [3] which is also a Van de Graaff style particle accelerator. The application created allows manual operation of the particle accelerator both locally and remotely.

In Idaho Accelerator Center [4], they monitor various electronically isolated accelerator parameters with LabVIEW, such as: electron source gun filament voltage, magnetron current, beam current, vacuum pressure, radiation exposure, and accelerator cavity assembly temperature. The last three parameters have safety interlocks with user adjustable trip points. Through the personal computer (PC) they control manually the magnetron high voltage, electron source gun filament voltage, and RF tune, and can also deflect the electron beam across an off axis faraday cup to obtain beam energy profile information.

In this paper we describe a system that uses a PC and LabVIEW to monitor and control a Van de Graaff particle accelerator. It goes one step forward than previous systems known by the authors. It has the added benefit of being able to automatically set the terminal voltage to the desired value, light up the ion source, and focus the ion beam. It is also capable of shutting down the accelerator safely. All this 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. In the developed system all of those procedures are done without user intervention. This allows easier operation and the safe use of the particle accelerator by less experienced users.

II. VAN DE GRAAFF PARTICLE ACCELERATOR

The Van de Graaff particle accelerator in the Technologic Nuclear Institute is an horizontal electrostatic accelerator, Model AN-2500 Type-A, manufactured by High Voltage Engineering Europe (Fig. 1).

Fig. 1 – Photograph of the particle accelerator.

The accelerator is housed inside a tank electrically insulated with pressurized SF6 and N2. A radio frequency ion source is used to create a particle beam made of H or He ions which are accelerated by a Van de Graaff machine, focused using Einzel lenses and steered to three different lines using a magnetic field.

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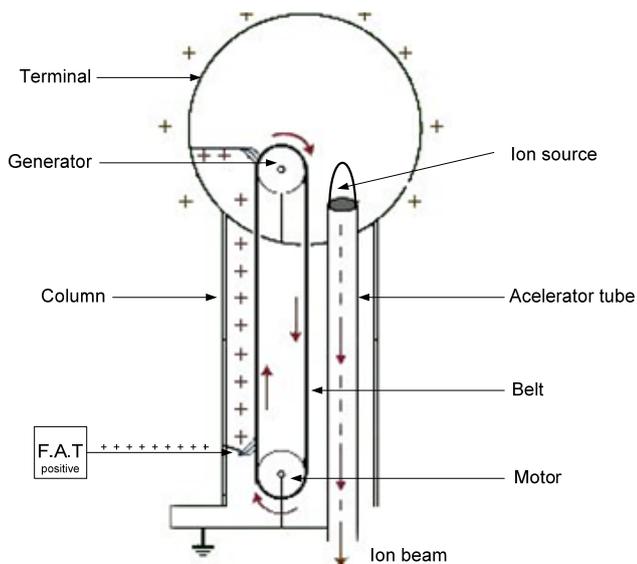
Fig. 2 – Schematic representation of a Van de Graaff accelerator.

We will now briefly explain the functioning of a Van de Graaff type particle accelerator (Fig. 2).

The accelerating voltage on the terminal is created with a rotating belt that physically transports electrons from one end to the other [3],[5]. They are deposited onto de belt in one end and removed from it on the other end. "Since the terminal is electrically isolated from the ground end of the accelerator, huge potential differences can be created. A potential gradient is created by using a chain of resistors that gradually step the voltage down from the terminal to ground. This gradient is attached to the electrodes that partition the insulating glass of the accelerator tube."

"A radio frequency (RF) ion sources is used to produce the ions. A small amount of a gas is released via a thermal-mechanical leak into a quartz plasma chamber. A RF oscillating voltage is applied to two bands on the chamber; this voltage causes the "naturally present electrons to oscillate in helical orbits through the gas, thus ionizing the gas atoms" [6]. An extracting voltage is applied to the back of the plasma chamber (anode) that collects the free electrons, and pushes the positively charged ions out of the ion source and into the accelerating tube. The accelerating tube ends at the tank base of the accelerator and the beam line that transports the charged particles to the target begins. This beam line contains a series of magnets that steer and focus the beam as it travels. There are also slits and cups that measure the shape and amount of beam present at various positions along the beam line. The whole system is kept under high vacuum to maintain the purity of the beam and to prevent unwanted interactions with foreign particles in the tube. The tank base is filled with a pressurized dielectric gas that allows the terminal to reach much higher voltages than it would in air by preventing electric breakdowns between the components in the column or the terminal and the tank. Sulfur hexafluoride (SF_6) and Freon ($CCl2F2$) are commonly used for this purpose [7]."

The operation of the particle accelerator is monitored and controlled through a console (Fig. 3). The console has a stabilizer which is in charge of keeping the terminal voltage steady. It also has controls and indicator to operate the particle accelerator.

Fig. 3 – Particle accelerator control console.

III. AUTOMATION SYSTEM

Before implementing the automatic control system, the particle accelerator was commanded only through the control console (Fig. 4).
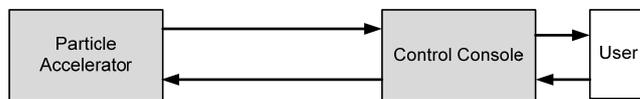

Fig. 4 – Block diagram of the particle accelerator operation before the automatic control system was implemented.

To automate the operation of the particle accelerator, we used the signals present in the control console instead of getting the signals directly from the accelerator. The main reason was that we wanted still to be able to control and monitor the particle accelerator manually through the console. The final system has a switch that allows the user to choose between manual operation and computer controlled operation.

This dual operational mode was implemented using relays controlled by a switch. Those relays were interposed on the electronic circuits of the console between the panel controls (selectors, switches and buttons) and the particle accelerator actuators so that the signals from the personal computer could be directed to those actuators. The signals that travelled in the other direction, that is, the signals from the sensors in the particle accelerator to the control console remained connected to the console and were connected in parallel to the computer (Fig. 5). That way, during automatic control of the particle accelerator by the computer, the information supplied by the particle accelerator was presented

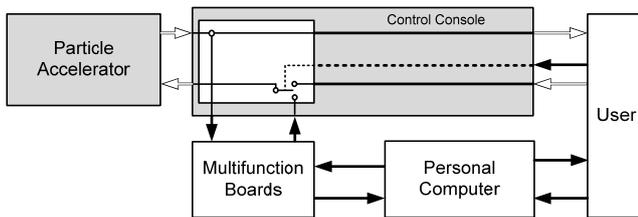simultaneously in the control console and in the computer monitor.

Fig. 5 – Block diagram of the particle accelerator operation after the automatic control system was implemented. The white arrows represent pre-existing information flow. The black arrows represent added information flow.

To carry out the automatic control system, a personal computer was equipped with two multifunction input/output boards from National Instruments, model PCI 6229. Those boards have both analog and digital inputs and outputs. Two of them were needed because of the number of signals present:

- 20 digital outputs
- 4 digital inputs
- 13 analog inputs
- 4 analog outputs

The digital outputs were needed to control on/off actuators like turning on and off the terminal voltage stabilizer in the control console or selecting the gas bottle to use for the ion source.

The digital inputs were needed to read the status of the particle accelerator. They correspond do the information presented using LEDs in the control console panel like the status of the drive motor (on or off).

The analog inputs were needed to read several analog currents and voltages in the particle accelerator like the slit currents which indicate the position and focus of the ion beam. Note that all the signals input into the multifunction boards are voltages between -10 V and 10 V. The conditioning of the different signals is done by the control console.

The analog outputs are used to control some variable actuators that control, for instance the amount of gas input in to the in source. Higher voltage means higher gas pressure.

IV. PROGRAMMING

We chose National Instruments LabVIEW to implement the control and monitoring application for the personal computer. It is a graphical programming language specially created for instrumentation and measurement.

In Fig. 6 we show the user interface of the application created. It has buttons to control the particle accelerator and indicators (numerical and graphical) to monitor the particle accelerator status. The application developed allows manual control of the particle accelerator as well as automated control. At any point during the automated procedures the user can interrupt the operation and carry on manually.
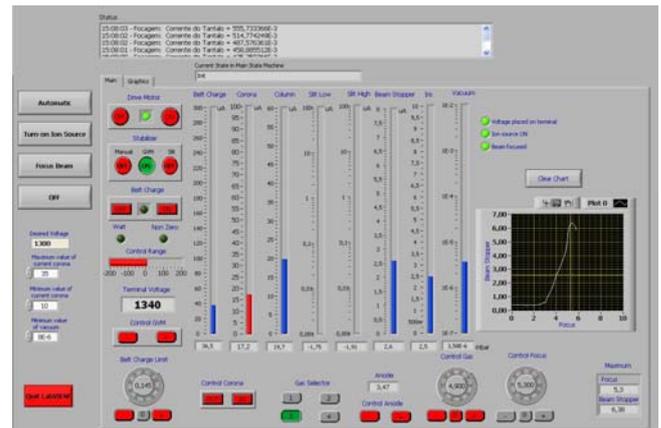

Fig. 6 – User interface of the control and monitoring application.

There are 4 main procedures that needed to be automated:
- Setting of the Terminal Voltage.
- Lighting up the Ion Source.
- Focusing the Ion Beam.
- Shutting down the particle accelerator.

The first 3 are required to power-up the accelerator, that is, to take it from a shut down state to a having a focused ion beam with a given energy (Fig. 7).
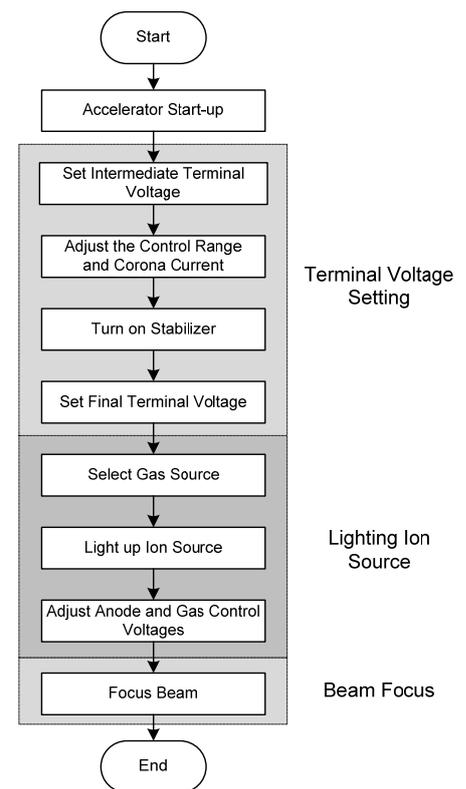

Fig. 7 – Flowchart of the particle accelerator power up.

In the following sections we describe some of these procedures.

The procedures were implemented using finite state machines. 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. A "shift register" in the loop is used to pass the value of the following state to the next iteration. That state then selects the proper case in the "Case" structure which contains the code to be executed in that state, including the determination of the state to follow according to the state variables (Fig. 8).
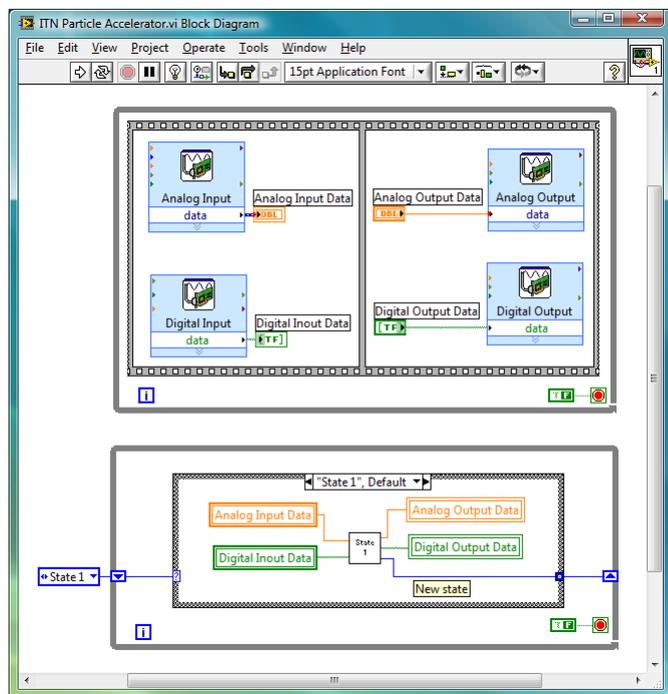

Fig. 8 – Example block diagram of the state machine and data input/output of the LabVIEW application.

In our case the state variables are the values of the sensors in the particle accelerator (corona current, tantalum current, gas pressure, terminal voltage, etc…). Those values are read from the multifunction board in another infinite while loop that runs parallel to the while loop of the state machine. In the same loop the actuator values set by the state machine are output to the multifunction board.

A. Setting the Terminal Voltage

The first step in automating the power-up procedure is to set the terminal voltage. This is the voltage used to accelerate the ions. The higher the voltage, the higher is the speed that the ions reach at the end of the accelerator tube. One of the requirements of a particle accelerator is that it is able to keep a constant terminal voltage during the experiment it is being used in. The control console has a stabilizer used to do just that. It has two operation modes called GVM and SLIT. The first one uses the value of the terminal voltage measured by a Generating Voltmeter (GVM) [8] for slow varying changes and by a Capacitive Pick-Up (CPU) [8] for fast varying changes. The second stabilizer mode (SLIT) uses the current in a slit through which the ion beam passes and the terminal voltage given by the CPU. A block diagram of the stabilizer is presented in Fig. 9.
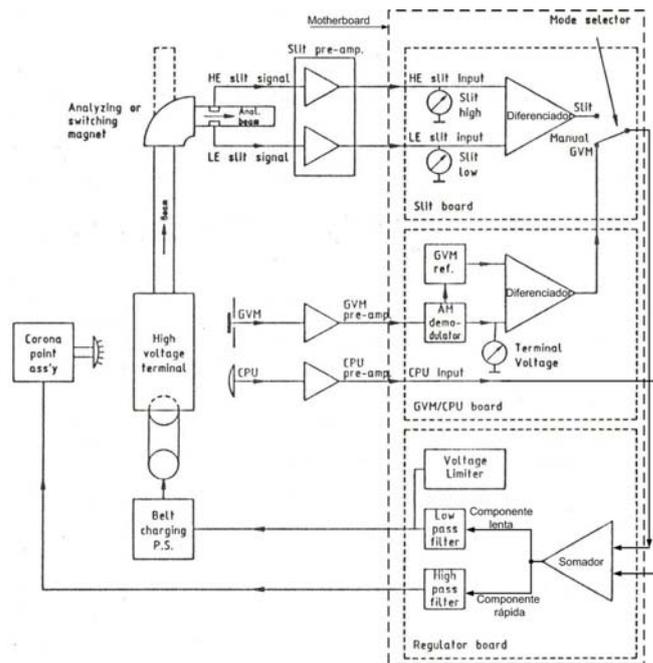

Fig. 9 – Block diagram of the particle accelerator and stabilizer.

Before the stabilizer can be turned on, the terminal voltage needs to be high enough and stable (intermediate terminal voltage). After that the stabilizer will keep it stable even when the required terminal voltage is increased, which is done by adjusting the GVM reference while keeping the Corona Current and Control Range indicator inside a given range. The corona current is controlled by positioning the corona closer or further away from the terminal and should be typically between 15 and 35 µA. The control range variable is controlled by adjusting the amount of electric charges deposited in the belt and should be between -100 and 100 during the terminal voltage increase and between 0 and 25 when the desired terminal voltage has been reached.

We automated this procedure using the flowchart in Fig. 10. The first step is to verify that the gas pressure inside the ion source is lower than 2e-5 mbar. After that the applications enters a cycle where it checks the corona current and control range, adjusting them if necessary and increases the GVM reference by an amount that is predetermined but which can be easily changed. The higher the step increase the faster the procedure will be but greater is the chance that the stabilizer loses its ability to maintain the terminal voltage stable. We choose to use a step increase of 50 keV. With this value we are able to reach the desired terminal voltage in a few minutes. After reaching that point the application keeps checking the corona current, control range variable and terminal voltage for another 4 cycles to make sure all the parameters are stable. Finally the belt charge is adjusted so that the control range variable is within the interval 0 to 25.
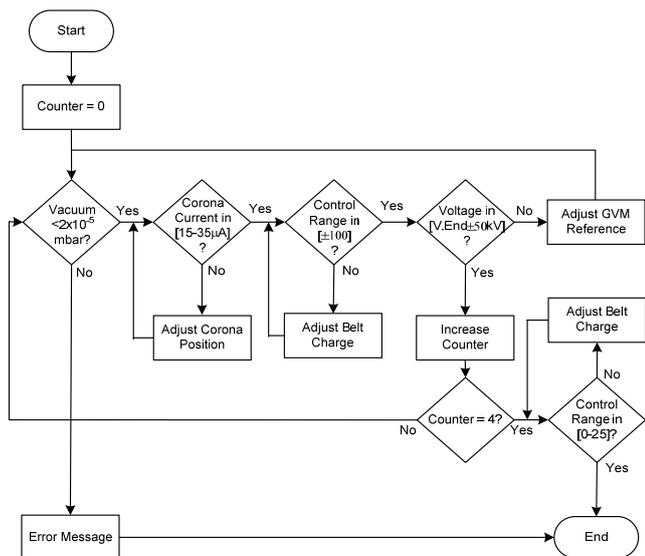
Fig. 10 – Setting the terminal voltage flowchart.

B. Lightning up ion source

To light up the ion source it is necessary to apply 2 kV to the ion source anode, and slowly increase the gas pressure inside the ion source until it lights up. This is checked through the value of the tantalum current which is the current that flows through a tantalum target which is placed in the way of the ion beam. When it is higher than 0,2 μA it means that the ion source is producing ions and that they are being accelerated toward the tantalum target (Fig. 11).
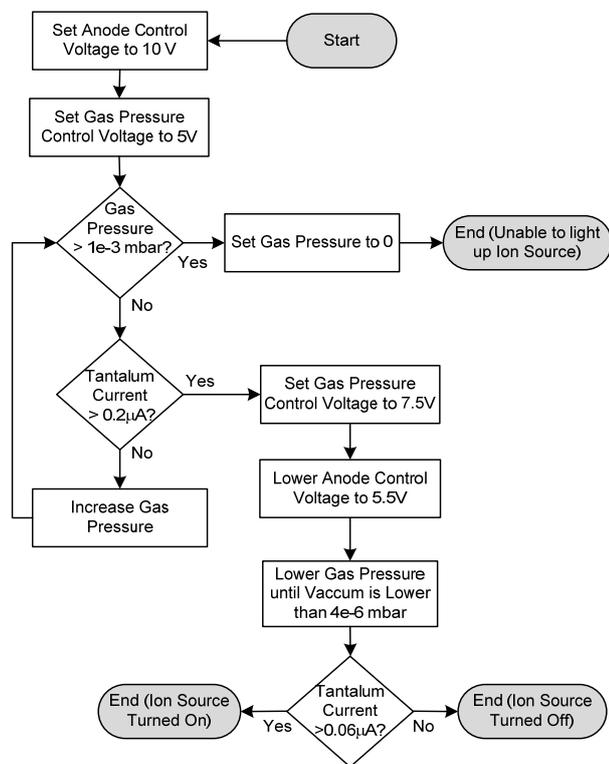

Fig. 11 – Ion source light up flowchart.

After the ion source is on, it is necessary to decrease the anode voltage and the gas pressure. Initially this is done rapidly to save gas and then slowly to prevent the ion source from going off until it reaches 4e-6 mbar. If the tantalum current is above 0.06 μA then the ion source is still on.

C. Beam focus

The ion beam is focused using an Einzel lense (Fig. 12) which uses an electric field to widen the ion beam and then narrow it to achieve focus.
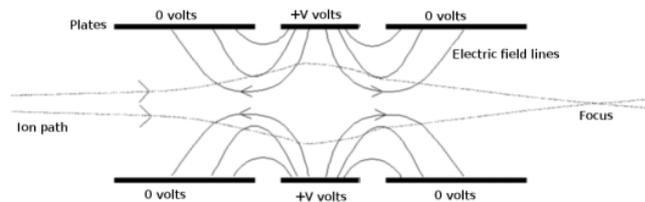

Fig. 12 – Einzel Lense.

To focus the beam, the correct value of voltage to apply to the plates of the Einzel lenses has to be determined. The beam is focus when the current in the tantalum target is maximum. Beam focusing is done by slowly increasing the focus voltage and determining when it corresponds to the maximum tantalum current. We have done that by comparing the mean of the tantalum current taken over the last 10 measurements with the previous mean. When it decreases 5% we consider that we have passed the maximum of tantalum current and decrease the focus voltage by 0.5 V (Fig. 13).
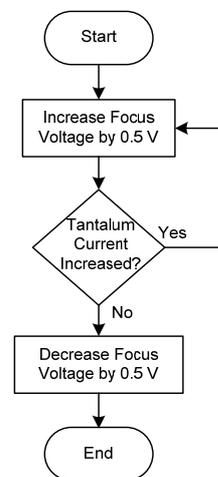

Fig. 13 – Ion beam focus flowchart.

In Fig. 14 we show the chart present in the computer screen showing the tantalum current as a function of focus voltage. The vertical straight line indicates the final value of the focus voltage.
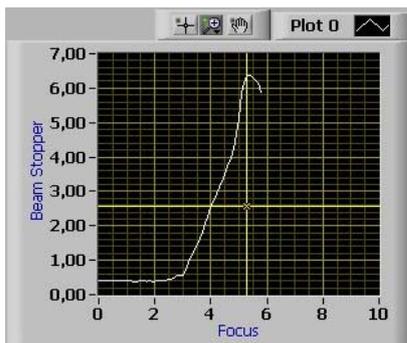
Fig. 14 – Chart presented in the user interface showing the tantalum current relative value (beam stopper) as a function of the focus voltage in volt.

V. CONCLUSIONS

In this paper we presented the automatic control system developed to automate the operation procedures of a Van de Graaff particle accelerator used by Lisbon's Technological and Nuclear Institute for scientific research.

This system allows less qualified users to operate the particle accelerate, eases operation of the accelerator by automatically performing the monotonous activities of setting up the particle beam and decreases the chance of incorrect operation of the accelerator that could lead to failure. It also allows the particle accelerator to be remotely controlled from another computer.

The system used a personal computer, two multifunction input/output boards, some custom made electronic interface modules and a LabVIEW application. The user interface presents to the user all accelerator variables for total control of the particle accelerator. In Fig. 15 we show the information presented to the user in the end of the focusing procedure. We see that the terminal voltage is 1.34 MeV which is within the chosen ±50 keV of the desired voltage of 1.3 MeV and a beam current of 2.6 µA (Beam Stopper indicator).

Fig. 15 – Illustration of the indicators available for the user to monitor the status of the particle accelerator.

The system has been thoroughly tested and proven to work consistently. In the event of a computer crash, the application developed is prepared to resume operation from a previous state.

The time it takes from power up to beam focus varies depending on the machine previous operating conditions from 10 to 20 minutes. This time can possibly be further reduced as a result of optimization of the procedures implemented.

In the future, other procedures could be implemented for automatic execution namely, beam deflection, terminal voltage sweep and others that the researchers find useful for their work.

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