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AUTOMATED CONDITIONING SYSTEM FOR SIEMENS NOVEL ELECTROSTATIC ACCELERATOR

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Abstract

Siemens has proposed a novel compact DC electrostatic tandem accelerator to produce protons of a few MeV and is currently commissioning a prototype at the Rutherford Appleton Laboratory. The geometry of the accelerator involves large surfaces which are exposed to high electric fields and therefore need long procedures for conditioning. An automated system for conditioning has been developed. It reacts quicker to breakdowns than a human operator could do, thus being more effective and also reduces the time spent by research staff on the conditioning.

INTRODUCTION

The novel electrostatic accelerator [1] proposed by Siemens, among other possible applications, aims to provide a simple and robust solution for the production of PET isotopes. It relies on a modified Cockcroft-Walton cascade voltage multiplier and promises to be smaller, cheaper and much easier to operate than a cyclotron.

The capacitances of the Cockcroft-Walton cascade are represented by two sets of concentric hemispherical metallic shells which are interconnected with the diodes of the CW setup. The highest electrostatic potential will be in the centre of the accelerator itself (so called terminal), which will be shielded by all subsequent sets of shells. A set of holes through the shells will act as beam tube. It will therefore be able to provide much higher gradients than conventional Cockcroft-Walton accelerators whilst keeping all the advantages. The accelerator will be operated with a negative ion source in tandem mode with a carbon stripper foil in its centre.

By its nature the accelerator involves large metallic surfaces which are constantly exposed to high electrostatic fields. High electrostatic voltages in vacuum usually involve a lot of conditioning. This is due to dirt and imperfections on the surfaces of the electrodes between which the fields are applied. Those dirty regions and imperfections cause the voltage to break down, however during the process of breakdown the dirt and imperfection may get partly or completely removed and subsequently the system is able to reach a higher voltage than before without breaking down. These processes are rather complex and some detailed investigations into the nature of them have been made by other researchers (e.g. see [2], [3], [4], [5], [6] and [7]).

However breakdowns during conditioning may not only have beneficial effects. The released energy can damage the diodes of the Cockcroft Walton circuit and the insulators between the metallic shells as well as the metallic surfaces themselves. If breakdowns are too violent, happen too frequently or even develop into sustained discharges then this may do permanent damage to the system and decrease its voltage holding capability. This effect is called deconditioning. In order to have a positive effect without the negative outcome of deconditioning the conditioning process needs to be done very carefully. This means limiting the number of discharges per time as well as the duration and intensity of single discharges. All prolonged discharges are to be avoided and discharges should be interrupted as soon as they have started. This can be done by decreasing the input voltage. After some time, when produced gas and ion clouds have had time to be pumped away, the voltage can be increased again. This procedure can take many hours, for this reason it is desirable to automate it. The following sections describe a software which I have developed for the conditioning of our various prototype test setups at the Rutherford Appleton Laboratory.

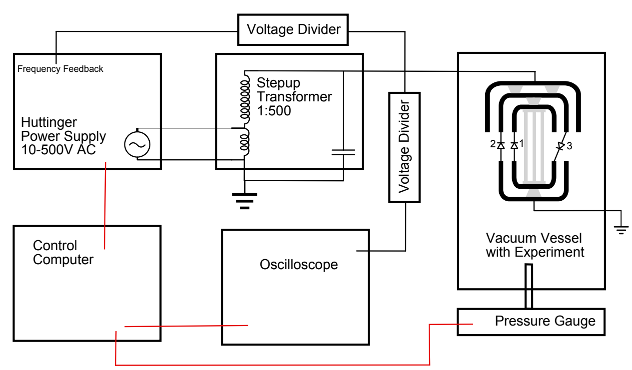

Figure 1: Schematic of the physical setup for the conditioning with the conditioning software. The computer controls the Huttinger AC Power Supply and reads feedback from that same power supply as well as from the pressure gauge and the voltage divider.

SETUP

The used test system comprises an off-the shelf induction heating AC power supply with several hundreds of volts output voltage and about 20 kW output power by the manufacturer Huttinger. It drives a resonant step up transformer with an output voltage of up to 100 kV, using feedback from the transformer output side. A separate voltage divider on the output side of the transformer is connected to a digital oscilloscope which uses one of its measurement functions to measure the Peak-to-Peak value of the sinusoidal output voltage of the transformer. The control computer reads this

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measurement from the oscilloscope. The transformer output voltage connects to the inside of a large vacuum vessel via a high voltage feedthrough with AC capability, which was designed and commissioned by our group (see [8]) . Inside the vacuum we placed test setups usually consisting of various metallic shells interconnected by diodes and spaced apart by insulators. The pressure inside the vacuum vessel is monitored by a pressure gauge. See Figure 1 for a schematic of the setup.

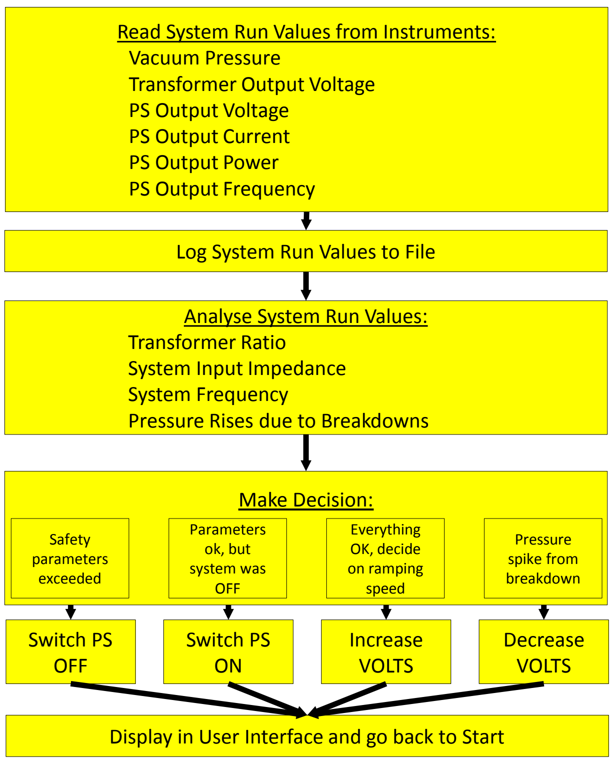

Figure 2: Simplified flow diagramme of the conditioning software, showing the main steps of each iteration.

SOFTWARE WORKING PRINCIPLE

A generic control system concept developed by Siemens (same as used for [9]) was used. It allows for the rapid implementation of software applications for frontend-controllers and/or standalone experimental setups which can use any of the physical or virtual devices in the system, which are represented by global software objects with thread safe access (LabVIEW OOP, see [10]). Although no real-time OS has been used, the response time of the application can be reduced to just the time needed for communicating with the devices whilst guaranteeing correct execution of all commands in a multi-threaded environment.

I developed a software application which gradually increases the Huttinger Power Supply voltage and thus the transformer output voltage which is the input voltage to the Cockcroft Walton test system inside the vacuum vessel. The value of the vacuum pressure is used as a feedback to detect breakdown, as every breakdown event creates some sort of gas or ion cloud and therefore increases the pressure. As soon as a breakdown is detected, the input voltage is decreased and kept constant at a lower voltage for some time. After a while the software starts increasing the voltage again. The software also monitors the parameters of the Huttinger Power Supply and the output voltage of the transformer and performs a number of system checks to make sure that everything is running correctly. If any of the monitored values cross a certain threshold the software stops the experiment. See Figure 2 for a flow diagramme of the software.

RAMPING UP THE VOLTAGE

The higher the voltage gets, the slowlier does it need to be increased. Therefore the software has three different speeds of increasing the voltage. The first one is after switching on the power supply and gets the voltage near to the threshold where breakdowns occur. Gradients of up to a few $kV\,s^{-1}$ are reasonable for this stage. This rather high ramping spead saves time, as a conditioning process often involves the safety switch of the power supply to switch the power supply off. After each safety switch-off the software needs to restart the power supply and ramp the voltage again. The second ramping speed is used for the last few kV before the current breakdown threshold is reached and is also used to go back to the breakdown threshold when the voltage was reduced as reaction to a breakdown. For this ramping phase a few hundreds of Volts up to $1\,kV\,s^{-1}$ are viable. The third phase is slowly increasing the voltage at the current breakdown threshold. Here low gradients of $50\,V\,s^{-1}$ and below are appropriate.

DETECTING BREAKDOWNS

For breakdown detection it is important for the software to react even to small pressure increases. The system pressure naturally oscillates slowly over time and normal operation of the system can increase the pressure as well, this too usually happens rather slowly. The system therefore calculates a base pressure and then immediately reacts if this pressure is exceeded too far. From experience with our experiment it is reasonable to set the threshold at 2×10^{-8} to 5×10^{-8} mbar. The base pressure is usually of the order of 3×10^{-7} mbar. The base pressure value is calculated from a histogramme of the last 100 pressure measurement with a channel width of 1×10^{-8} mbar for the histogramme. The highest pressure histogramme channel with more than 30 % of the measurements is taken for the base pressure. The mean of all values in that channel is used as the base pressure value. This ensures that quickly rising pressure values do not effect the base pressure calculation.

REACTION TO BREAKDOWN AND SAFETY SWITCH-OFF

Whenever a breakdown occurs and the pressure exceeds the threshold the software immediately decreases the input voltage by about 5 kV and then waits for the pressure to come down. If it does not come down within a few seconds the

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software decreases the voltage by another step. After the pressure has come below the threshold again, the software waits another few seconds and then slowly increases it at intermediate ramping rate up to the voltage where the breakdown occurred. Then it goes back to slow ramping rate. If the power supply is switched off either by the software itself or by its internal safety switches, the software waits for the system pressure to come below the threshold and then switches the power supply on at a rather low voltage. After that it ramps the voltage up to about 5 kV below the breakdown threshold. From there it continues ramping at an intermediate rate until the voltage is reached where the switch-off happened.

SAFETY CHECKS

During operation the software constantly monitors the transformer ratio, the system input impedance, the resonance frequency, the power supply output current and the system pressure. If any of these values are outside the limits specified for them, the software immediately switches the power supply off. After that it will restart it, however for safety reasons it will only do a limited number of restarts before it stops the experiment completely. Events where this happened during our experimental trials include carbonised components as well as a loose connection on the transformer resonance feedback and the safety precautions of the software have proved very beneficial.

USER INTERFACE AND USER INTERFERENCE

The software logs all the measured data to files but it also displays it in a graphical user interface (GUI), so that operators can watch and supervise the process. All operating parameters of the software (like pressure thresholds, safety limits, ramping speeds etc.) can be changed online in this GUI, which enables the user to optimise the process during operation and to tailor it to the current test setup inside the vacuum vessel. The user can also separately open the user interface of the Huttinger power supply and manually set voltages. For this purpose the software can be deactivated with the 'passive' button. It will continue logging and displaying values but will not take any action. It is also possible to manually set values while the software is actively running. To enable this the software always checks the current output voltage before it sets a new voltage. It always does the increase steps from the last voltage measured. This has proven very beneficial, the user can manually increase or decrease the voltage, but longer phases of ramping can be done smoothly by the software and the spark detection is always active and will immediately decrease the voltage in case of breakdown. The reaction time of the software to sparks is in the order of hundred ms and therefore much faster than an operator. From experience with experiments it seems that a reaction time below 500 ms is sufficiently small. Figure 3 shows the user interface with data from an actual conditioning process carried out in our lab.

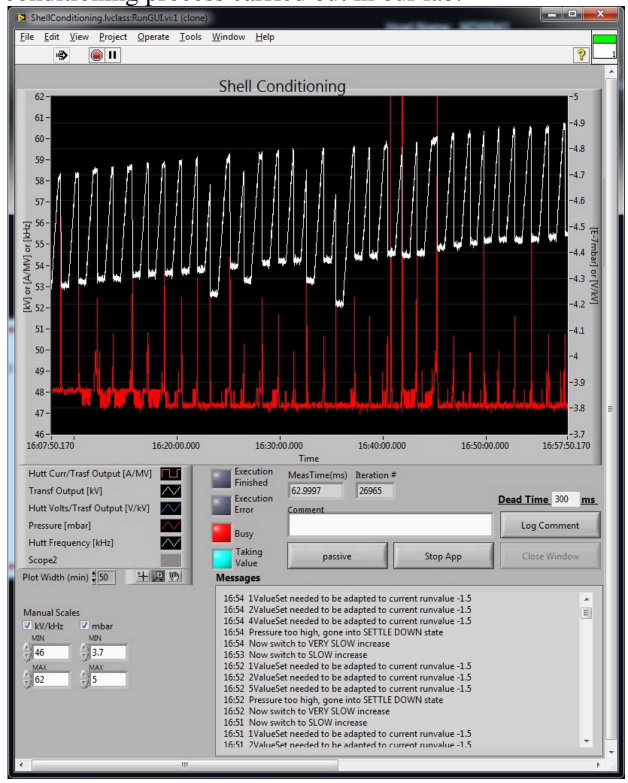

Figure 3: A screenshot of the GUI. The red trace displays the system pressure and the white trace the transformer output voltage. Whenever a breakdown occured (red trace spikes) the software immediately decreased the voltage by 5 kV to stop the breakdown and subsequently increased it again. The displayed conditioning run increased the breakdown threshold by about 3 kV over the course of 50 min, this illustrates that conditioning can take many hours.

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