# Slow chopper prototype for the SPIRAL 2PP project

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A.Caruso[a,*], F. Consoli[a,*], D. Rifuggiato[a], G. Gallo[a], T. Spartà[a], E. Zappalà[a], A. Longhitano[b], M. Di Giacomo[c]

*a) INFN Laboratori Nazionali del Sud, Catania, Italy*
*b) ALTEK, San Gregorio, Catania, Italy*
*c) CEA/GANIL, Caen, France*
** Corresponding authors, e-mail: caruso@lns.infn.it; consoli@lns.infn.it*

*Abstract*

A preliminary prototype of the slow chopper [1] for the Spiral 2 Preparatory Phase project [2] has been designed, developed and tested at INFN-LNS. The final version of the slow chopper will be placed along the beam line common to protons, deuterons and A/Q = 3 ions. This activity report shows the study, the hardware and the measurement results of the chopper prototype.

## THE LOW ENERGY LINE

The low energy (LEBT) line of the Spiral 2 driver is designed to transport CW and high intensity beams of protons (5 mA), deuterons (5 mA) and ions (1 mA) with A/Q = 3 to the radiofrequency quadrupole (RFQ). The RFQ input energy is 20 keV/A and source voltages of 20, 40 and 60 kV are used for the 3 kind of particles. As shown in Figure 1, the chopper is located at the beginning of the common section just before the beam stop.

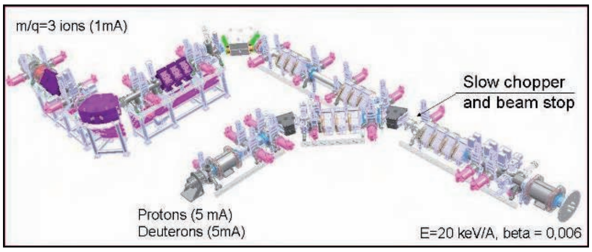


Figure 1: The injector low energy lines and the slow chopper position.

The chopper will be used to progressively increase the beam power during accelerator tuning, to rapidly remove the beam in case of failure detection, to avoid hitting the wheel spokes of rotating targets similar to the one shown in Figure 2 (FULIS or S3 experiences).

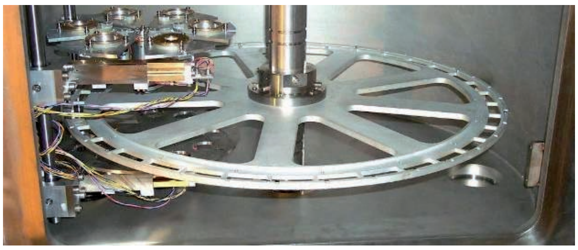

Figure 2: FULIS rotating target wheel (courtesy of C. Stodel)

## CHOPPER REQUIREMENTS

The accelerator tuning is performed at quite low frequency. Due to the high beam power of 200 kW, a very large range of duty cycles will be used, starting from very low fractions ($10^{-4}$). The rotating target asks for pulse repetition rates around 1 kHz. In both cases rapid transition times are required to avoid fractions of beam, neither accelerated nor deviated, to be lost through the LINAC.

The chopper voltage depends on the ion source voltage, on the distance and length of the plates and on the beam stop location. Due to the LEBT line architecture and to the current intensity, the beam transversal section at the chopper location is quite large and relevant voltages have to be applied to the electrodes to compensate their distance.

In our case, the beam section has a diameter of 76 mm, the electrode hard-edge length considered in the beam dynamics simulations is of 160 mm, the deflection at the end of the plates is of 10 mm, and *a total deviating voltage of 17 kV* has therefore to be applied. Transient times for the pulse have to be shorter than 100 ns, and an amplitude stability of a few percents is required

High reliability and easy maintenance are also important requirements of the device.

## ELECTRODE GEOMETRY

The preliminary geometry shown in Figure 3 was designed to have a flat transversal field and to produce field maps for beam dynamic simulations. It was chosen to feed the chopper with one plate positively biased and one grounded, because this solution let a easier water cooling of the ground electrode if some beam is eventually lost. The deflection plane is horizontal because the beam section is smaller on this plane than on the vertical one. In Figure 4 the simulation for the electric field is shown. To obtain the deviating field, a pulse of 9.2 kV has to be applied to the electrode, whose capacitance is around 15 pF. The pulse duty cycle defines the attenuation on the beam.

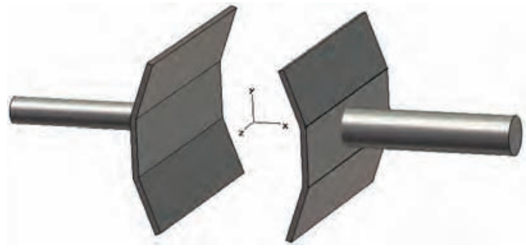

Figure 3: The electrode geometry; the plate bending angle is 20°.

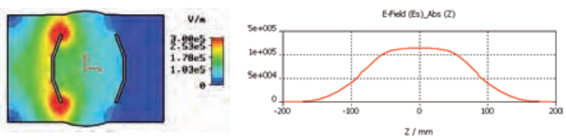

Figure 4: Electric field on the transversal plane and on the beam axis.

## SLOW CHOPPER DEVELOPMENT

The development of the Spiral 2 device regards a two years period. In this first year, the power circuit, the feed-through and the assembling concept have been studied and tested on a prototype.

The design approach was strongly addressed towards reliability and decreasing of the maintenance time, both being very important issues in high power accelerators.

### *Electrical design*

The principle scheme of the chopper is represented in Figure 5.

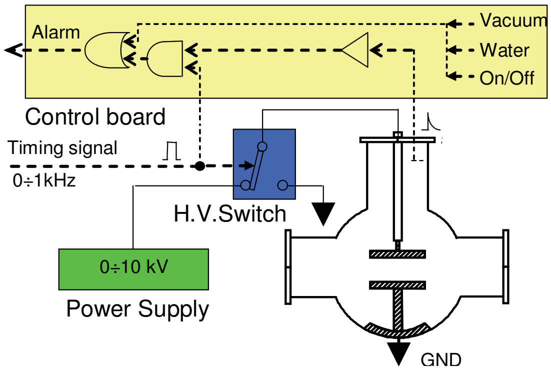


Figure 5: Principle scheme of the chopper.

A high voltage switch, alternatively connects the electrode to ground or to the high voltage power supply, following the timing signal repetition rate and the duty cycle. A high voltage sealed connector is used as feed-through. Numerical values, considered for the design, are summarized in Table 1.

Table 1: Design Parameters for the Chopper Power Circuit

| | |
|---|---|
| Maximum voltage: | 10 kV |
| Rise/fall time under | 100 ns |
| Duty cycle variable from | 0 to 100% |
| Repetition frequency | from few hertz to 1 kHz |

To fit the requirements, 10 Watt, off-the-shelf devices have been selected. A standard pulse/function generator AFG310 by Tektronix is used to drive the switch, while the main components of the system are:

- Power supply MPS10P10/24 by Spellman
- Solid state switch HTS151-03-GSM by Behlke
- Vacuum feed-through SHV-20 by Caburn
- Coaxial cable HTC-50-7-2 by Draka

Figure 6 shows the scheme of the electronic cabinet. The high voltage switch, the power supply and the 1 nF buffer capacitance are visible in the rack. The solid state switch consists of two identical mosfet switching paths that form a so-called half bridge circuit configuration. Both switching paths are controlled by a common logic driver. The power supply can deliver up to 10 kV, 1 mA. The switch and the electrode are connected by a low loss coaxial cable. Great care was taken to assemble these modules into the rack. Special attention was given for grounding and shielding all the components.

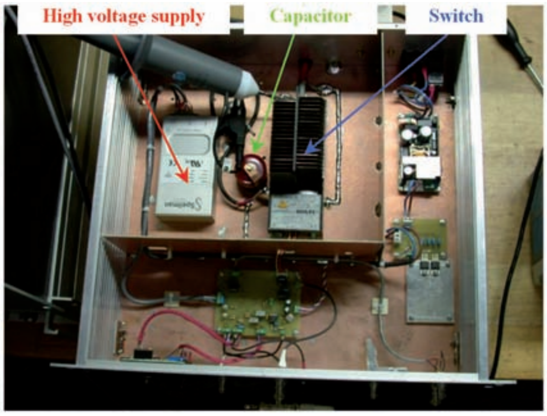


Figure 6: Scheme of the electronic cabinet.

### *Mechanical design*

The mechanical assembling of Figure 7 was designed to test the feed-through in operating conditions and to verify the assembling concept and the plate alignment.

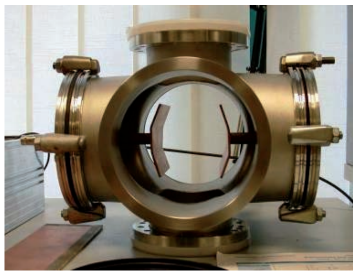

Figure 7: Cross-section of the assembled electrodes.

A standard beam line cross section with six gates was used to host the electrodes. Each electrode is constituted of a plate of 3 mm thick copper sheet supported by a copper column. They are inserted from opposite sides and each one is supported by its vacuum flange. The ground electrode is connected directly to the flange while the high voltage plate is brazed to the feed-through connector. The ceramic feed-through is a standard 20 kV single ended coaxial SHV connector. A capacitive pick-up is inserted near the feed-through to be used to check the pulse presence, but the alarm board still has to be developed.

### *Feed-through study*

A delicate point in the chopper realization is the proper high voltage feed-through. Different solutions were taken into account. A suitable numerical study was performed on this purpose. The MDC-Caburn SHVE20-1-W weldable feedthrough was therefore employed. In Figure 8 it is shown a section of it, with the indication of the two parameters *d* and *r*. The related electrostatic simulation, for a 10 kV feed, is shown in Figure 9. In the *A* point the voltage assumes its maximum. In Figure 10 the values of this maximum, for different values of *d* and *r*, are given.

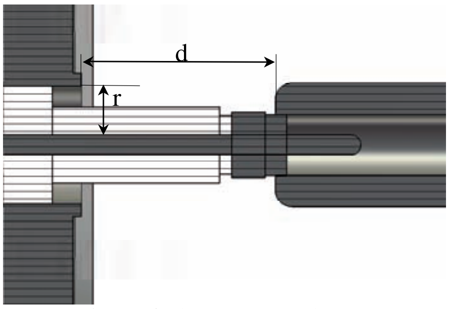


Figure 8: Section of the MDC-Caburn SHVE20-1-W feed-through.

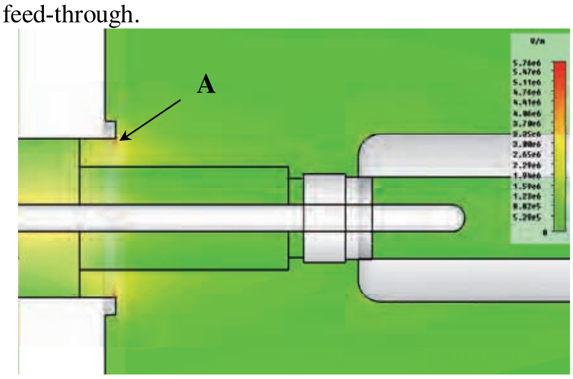


Figure 9: Electrostatic field on the section of the MDC-Caburn SHVE20-1-W feed-through.

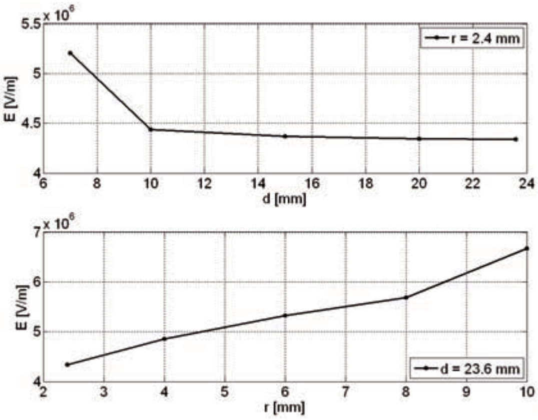


Figure 10: Field in the *A* point for the structure of Figure 8, for different values of the *d* and *r* parameters.

## EXPERIMENTAL RESULTS

A total capacitance of about 30 pF was measured at the feed-through connector input. The cable adds some 70 pF and the data sheet gives a value of 30 pF for the switch output capacitance. With a total capacitance lower than 150 pF, the system should be able to work up to a repetition rate of 1 kHz. Anyway, the measured and stable operating range (Figure 11) was smaller, and was limited by the current of the high voltage power supply.

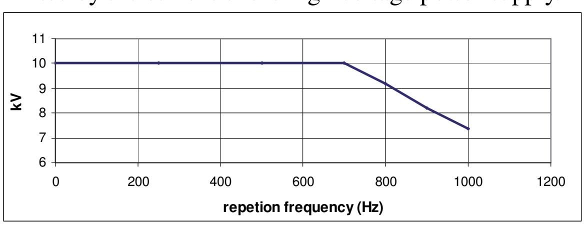


Figure 11: Measured and stable prototype operating range.

Some preliminary tests with a Spellman MPS10P20/24, 20 W power supply, were therefore performed, and the required 1 kHz repetition rate was reached. More tests about it have to be performed. Measurements of the transient times confirmed the data sheet performances: rise and fall times are around 30 ns (see Figure 12).

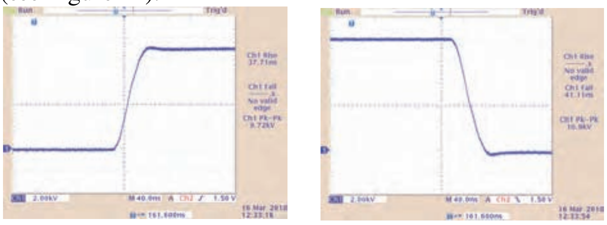

Figure 12: Measured rise and fall times.

Long time tests on the complete apparatus have been performed up to 10 kV, at the 50 Hz frequency, and with Duty Cycle in the range [0.01%, 99.99%] to check the circuit reliability and the stability of the pulse parameters. The amplitude stability is better then 1%, and no changes where observed in the delay between the driver and high voltage edges, which is of 160 ns as shown in Figure 13, for the 10 kV pulse at 700 Hz, and with 50% duty cycle.

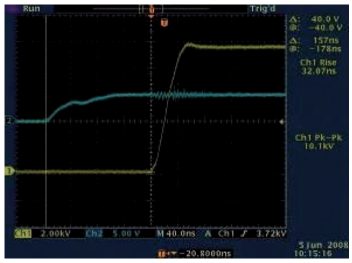

Figure 13: Pulse jitter @700 Hz, DC = 50%, 10 kV, between the driver and the measured voltage at the switch output.

## CONCLUSION AND PERSPECTIVES

The pulse amplitude, jitter and transition time measured on the prototype fulfil the requirements, while a more powerful high voltage supply has been required to achieve a 1 kHz repetition rate. A complete system (electronics and electrodes) is available today for beam tests and next efforts will be dedicated to the design of the alarm control card and of the computer control interface and to the manufacture of the final mechanical ensemble to be installed on the Spiral2 injector.

## AKNOWLEDGEMENTS

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[1] L. Calabretta et al: The radiofrequency pulsing system at INFN-LNS: Proceedings of Cyclotrons 2001, East Lansing, Michigan, USA.
[2] Caruso et al: Preliminary design of the Slow Chopper for the SPIRAL 2 project, Proceedings of LINAC 2008, Victoria, BC, Canada.