THE LEBT CHOPPER FOR THE SPIRAL2 PROJECT*

A. Caruso[#], F. Consoli [†], G. Gallo, D. Rifuggiato, E. Zappalà, INFN-LNS, Catania, Italy
A. Longhitano, ALTEK, San Gregorio di Catania, Italy
M. Di Giacomo, GANIL-SPIRAL2, Caen, France

Abstract

The Spiral2 driver uses a slow chopper situated in the common section of the low energy beam transport line to change the beam intensity, to cut off the beam in case of critical loss and to avoid hitting the wheel structure of rotating targets. The device has to work up to 10 kV, 1 kHz repetition frequency rate and its design is based on standard power circuits, standard vacuum feed-through and custom alarm board. The paper summarizes the design principles and describes the test results of the final device, which has been installed on the beam line test bench.

THE CHOPPER IN THE LEBT LINE

The low energy beam transport (LEBT) line carries continuous wave (CW), high intensity beams of protons (5mA), deuterons (5mA) and ions (1mA) with m/q=3 from the sources to the radiofrequency quadruple. The source voltage for the three different particles are 20, 40 and 60 kV respectively, to match the RFQ input energy of 20keV/A. The layout of the injector LEBT is shown in Fig. 1. The slow chopper [1] is placed just before the beam stop in the common section of the line.

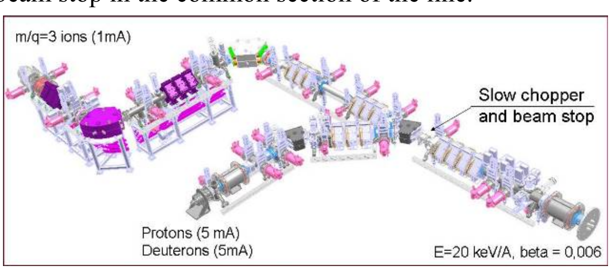

Figure 1: The injector low energy lines and the slow chopper position.

The proton/deuteron line section and the common one are presently installed at CEA Saclay to be tested before being installed in the SPIRAL2 building. The slow chopper system was moved to Saclay in June 2011 and is going to be tested with the beam in the next few months. The device assembled on the line is shown in Fig. 2. The yellow arrow, in frame A, shows the beam direction. The beam stop and the micro channel plate are shown in frame B and the deflecting electrodes in frame C.

REQUIREMENTS AND DESCRIPTION

The chopper will be used to progressively increase the beam power during accelerator tuning, to avoid hitting the wheel spokes of rotating targets and to rapidly remove the beam in case of failure detection by the machine protection system (MPS). The tuning of the high power (200 kW) beam requires low repetition rates but a very large duty cycle range: from 10^{-4} (0.01%) to CW. Rapid transition times are required to avoid losing the beam not being perfectly deviated on the beam stop, and for fast response to beam stop commands from the MPS.

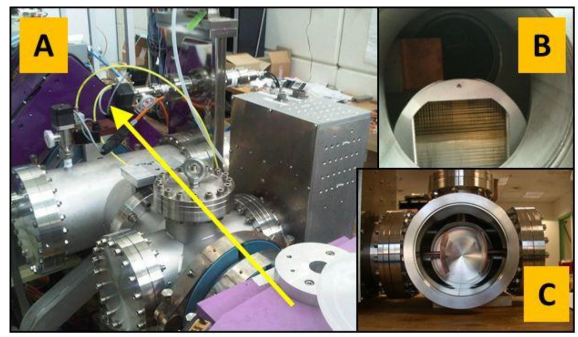

Figure 2: The slow chopper installed in the beam line

The applied voltage depends on the ion energy, on the geometry of the plates and on the beam-stop distance. The beam transversal section is quite large at the electrode position (76 mm), the equivalent hard-edge electrode length is of 160 mm and a total voltage of 17 kV has to be applied to deflect the beam onto the beam-stop. Electrode voltage of 10 kV with amplitude stability around 1-2% and rise/fall time less than 100 ns are requested.

Geometry of the electrodes

The geometry shown in Fig. 3 was chosen to obtain a flat transversal field. Field-maps were introduced in the beam dynamics simulation codes and two cases were simulated: a) one plate positively biased and one grounded and b) both plates biased with opposite voltages. No significant differences were observed in beam behaviour and the first geometry was implemented, requiring fewer electronics and vacuum components and then considered more reliable.

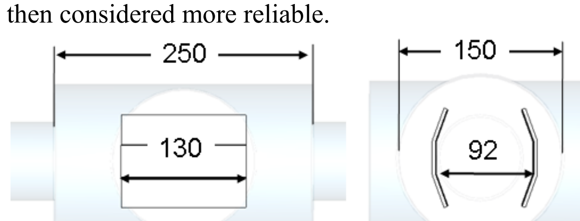

Figure 3: plate dimensions, the bending angle is 20°

*Work supported by EU commission 7th framework project n. 212692.
#caruso@lns.infn.it
†New affiliation: Associazione Euratom/ENEA sulla Fusione, CP 65-00044 Frascati, Rome, Italy

Slow chopper development

The development of the slow chopper system can be divided into two main steps: the construction of the first prototype and the realization of the final version. The first prototype played a fundamental role in understanding, studying and testing the different components of the high voltage circuit. Some of them were improved from the first to the final version, which have also been completed with an alarm board and remote control interface compatible with the architecture of the Spiral2 computer control and the MPS. The first prototype was moved to SARAF, slightly modified and used on the injector beam.

The entire system can be seen in two blocks: the mechanical parts and the electrical/electronic circuits.

Mechanical design.

Each electrode is made out of a plate from a 3 mm thick copper sheet supported by a copper column. No isolators are used between the plates and the electrodes are inserted from opposite sides of the cross line section shown in Fig. 2 (frame C). Each one is supported by its vacuum flange; the ground electrode is connected directly to the flange while the polarized plate is brazed to the feed-through connector, whose ceramic is brazed on the flange. A capacitive pick-up is inserted near the feed-through to be used to check the pulse presence.

Two different vacuum sealed coaxial feed-through have been used as shown in Fig. 4. The prototype was equipped with SHV-20, while the RF-35 device is mounted on the final version. Both are standard MDC products.

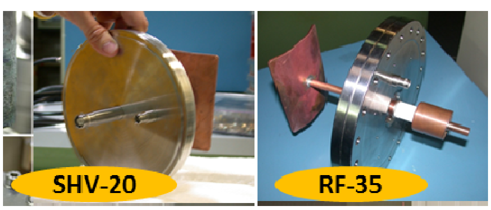

Figure 4: The two flanges with different feedthrough.

From the electric point of view, the main difference between the two feed-throughs is the air side connection. The first one requires an air side SHV connector, well crimped on a high voltage coaxial cable. The second one is designed to be matched with a high power rigid coaxial line. According to the manufacturer, both configurations should have worked at our specifications, but a sort of rapid aging (Fig. 5) was observed on the SHV-20 after a long time high voltage test, although the electrical behaviour was not affected.

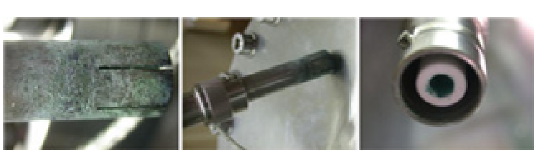

Figure 5: degradation of the outer coaxial surface

The SHV is a 20kV DC connector, but it seems that the manufacturer has never tested it in pulsed mode at 1 kHz repetition rate while the RF 35 is given for RF application. Several weeks of continuous 24-hour full power tests, have been already performed and no degradation has occurred on the second one.

Electrical and electronic design

The electronic circuit is divided into two modules: the high voltage and the alarm/control.

The HV module contains a HV switch, the HTS 151-03 GSM by Behlke and a HV power supply 10kV/1mA, the MPS10P10/24 by Spellman. Both off-the-shelf devices have been selected according to the initial requirements. Three parallel HV capacitors of 3nF and a shunt resistor of 33 Ω between the output of power supply and the switch complete the module. The new RF feed-through optimizes the electrical connection with the HV module, reducing stray capacitance because the output of the HV switch is directly connected to the ceramic feed-through. In this way, the whole high voltage module is attached to the mechanical part. Fig. 6 shows the internal view of the HV module on the right, the ceramic feed-through and the electric connection on the left.

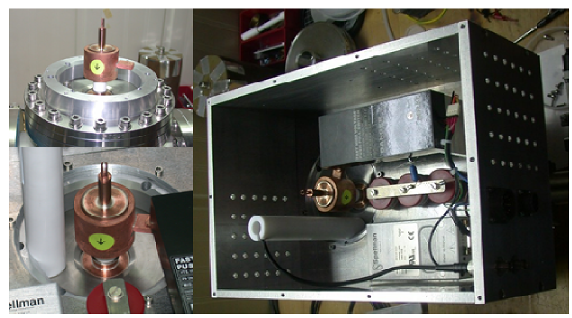

Figure 6: The HV module connected with feed-through.

The control module contains the alarm board (totally custom built), the interface with the Spiral2 computer control and the DC power supplies for the HV module and the control board itself. Fig. 7 shows the internal view of the control with the main components.

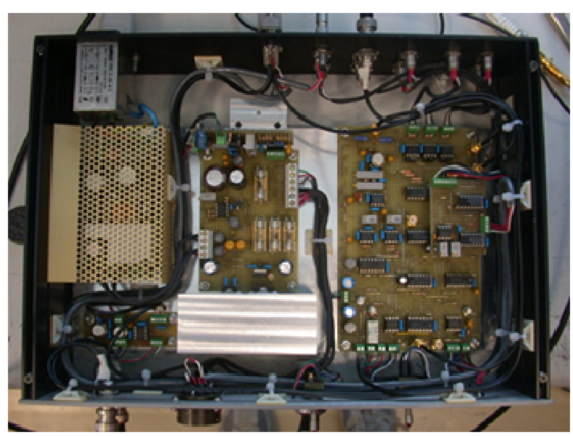

Figure 7: the internal view of the control module

Particular attention was paid to the realization of the alarm board. A capacitive pick-up, facing the polarized electrode, detects the HV pulse signal. This signal is re-shaped to be compared with the driving TTL signal to check the proper working of the whole system. A resistive probe, connected to the air-side feed-through can be used, but there would be a remaining margin of doubt about the presence of high voltage on the plate. The chopper is also used as a protection system, so it is necessary to be sure about the HV on the deflecting electrodes. Some useful maintenance and/or verification operations can be done also in local mode: a self-test push button is installed in the front panel of the control module. It produces a standard signal of 1 kHz, 50% duty cycle. The setting of the high voltage can be done through a precision knob.

The block diagram in Fig. 8 summarizes the electronic design with the internal sub-modules and the external connections with the Spiral2 remote control interface.

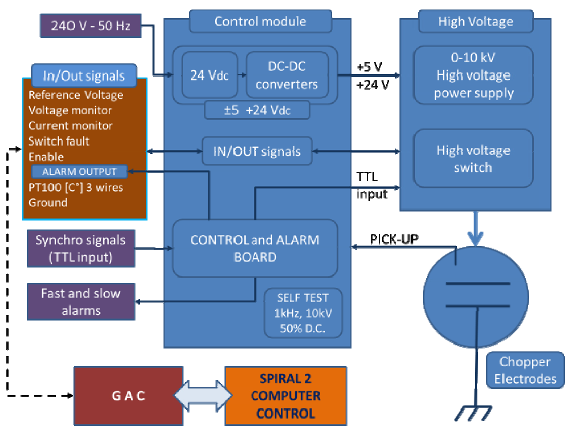

Figure 8: Block diagram of the slow chopper system.

EXPERIMENTAL RESULTS

The direct connection between the feed-through and the HV switch has notably reduced the total load capacitance, which is less than 70 pF: 30 pF due to the switch output capacitance and about 40 pF due to the electrodes and the feed-through. This has increased the operating frequency and reduced the rise/fall time of the system. Uninterrupted full power tests have been performed on the slow chopper for several weeks. The main experimental results are summarized in Table 1.

Table 1: experimental results

Maximum Voltage	10 kV
Maximum Current	1 mA
Rise/fall time	≅ 15 ns
Maximum frequency	> 1.5 kHz
Nominal frequency	Up to 1.0 kHz
Duty cycle (≤ 513 Hz)	0.01-99.99%
Duty cycle @ 1kHz	0.1-99.9%
Max beam stop delay	≤ 400 ns
MPS alarm delay	≤ 400 ns

The full power test bench set-up is shown in Fig. 9.

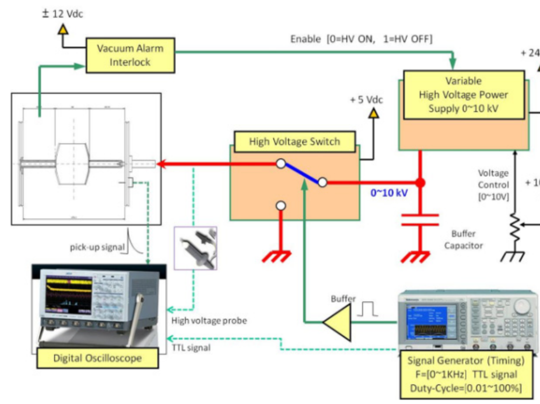

Figure 9: The chopper principle schematic test bench

Fig. 10 shows a series of oscilloscope acquisitions at 10 kV: rise and fall time of 13-15ns (A,B); repetition frequency of 1.3 kHz (C); an alarm simulation (D). The HV signal is in yellow, the TTL driver in blue and the pick-up signal in purple (A,B,C). For any failure the alarm board pushes the HV to 10 kV, to stop the beam. In Fig. 10 (D) the disconnection of the pick-up pushes the high voltage to 10 kV, despite the TTL driving signal (in green) switching off the HV. The delay of this safety operation is ≤ 400ns and at the same time an alarm signal is sent to the machine protection system.

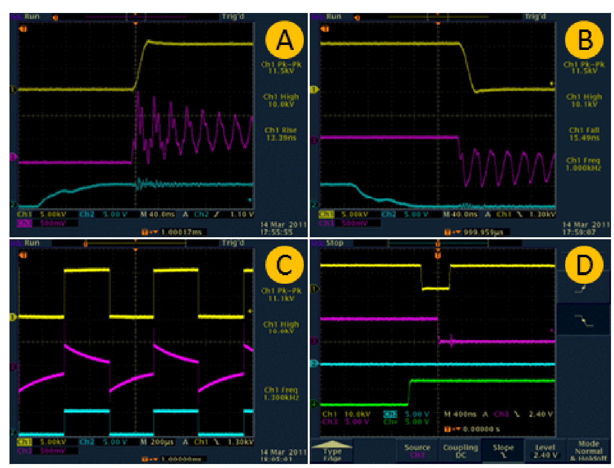

Figure 10: a sequence of oscilloscope acquisitions.

CONCLUSION

The present version of the slow chopper, developed in the frame of the Spiral2 PP European cooperation project, is ready for beam tests on the LEBT line. It has been significantly improved with respect to the first version, which has been sent to SARAF (Israel) and performances are well beyond required values. The design aims for high reliability and easy maintenance.

REFERENCES

[1] M. Di Giacomo et al," Preliminary design of the slow chopper for the spiral 2 project", Linac08, Victoria, BC, Canada, Sept-Oct 2008, THP046, p. 891 (2008).