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THE SARAF-LINAC PROJECT JULY 2024 STATUS

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Abstract

SNRC and CEA collaborate to the upgrade of the SARAF accelerator to 5 mA CW 40 MeV deuteron and proton beams (Phase 2). CEA is in charge of the design, construction and commissioning of the linac downstream the existing RFQ (SARAF-LINAC Project).

The MEBT is now installed at SNRC and has been commissioned with both proton (cw) and deuteron (pulsed) beams. Transverse and longitudinal emittances have been measured and beam transport has been compared with TraceWin simulations.

Cryomodules have been assembled and tested at Saclay. CM1 has been delivered to SNRC and is being integrated at SNRC.

This paper presents the results of the qualification of the cryomodules at Saclay and the commissioning at Soreq.

INTRODUCTION

The last status has been presented in IPAC23 [1]. After design (2015-2016), prototype (2017-2018), series manufacturing (2018-2022), individual qualification (2020-2023), critical components are now integrated into linac subsystems (MEBT and Cryomodules) and have been qualified at Soreq (MEBT) and Saclay (Cryomodules).

This paper presents the last results of these qualifications tests.

MEBT COMMISSIONING

The MEBT has been delivered in August 2020, but its commissioning has been complicated by the COVID19 travel restrictions and the co-activity in the facility. After an update (to EPICS) of the ECR Ion source, LEBT and RFQ control system, the proton and deuteron beams have been transported to a D-plate downstream the MEBT [2]. The transmission reaches close to 100% of the RFQ accelerated particles. The results of the beam characterization are in accordance with the simulations with TraceWIN [3].

Longitudinal Emittances Measurements

The longitudinal beam profile and emittances were measured with a FFC through the gradient variation method. The measured profiles were compared with the one obtained with TraceWin simulations from RFQ input with Gaussian beam, including diagnostic transfer function simulation (Fig. 1). The profiles fit remarkably well.

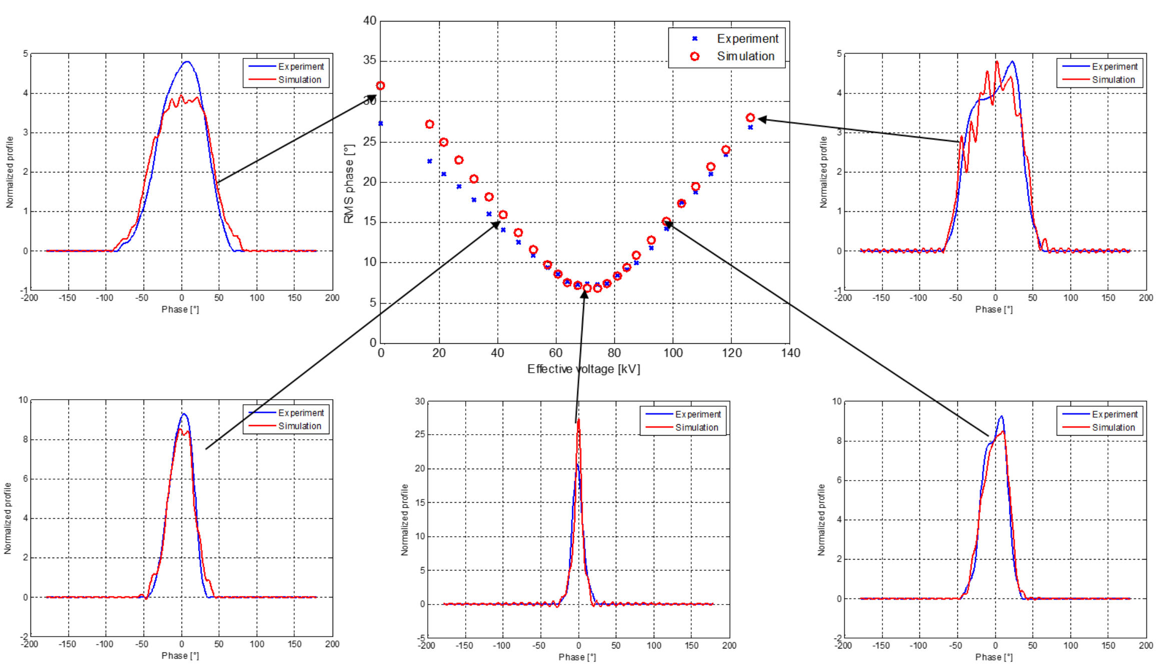

Figure 1: comparison between calculated and measured longitudinal beam profiles at FFC position.

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In addition, many other measurements have been done with proton and deuteron beams at 3 positions and the beam RMS ellipse has been "classically" reconstructed at RFQ exit and compared with the linac acceptance from that position (Fig. 2). Some margins can be seen and will be welcomed to limit the losses in the downstream linac.

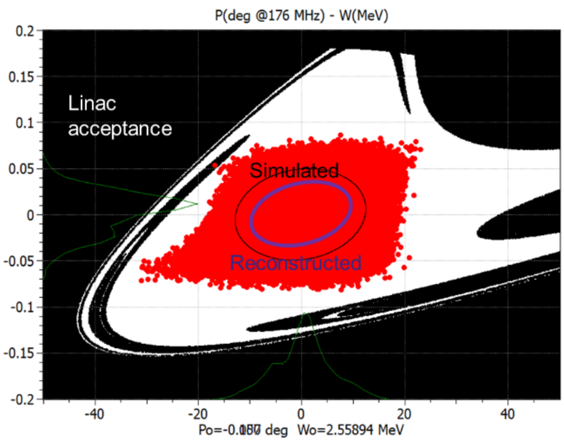

Figure 2: Simulated and reconstructed beam distribution in linac longitudinal acceptance at RFQ exit.

Transverse Emittances Measurements

The transverse bunch sizes were measured at 3 different positions with a wire scanner and a Harp profile monitor as a function of a quadrupole strength. From these measurements, the beam Twiss parameters and rms emittances have been reconstructed at RFQ exit. An example has been shown on Fig. 3.

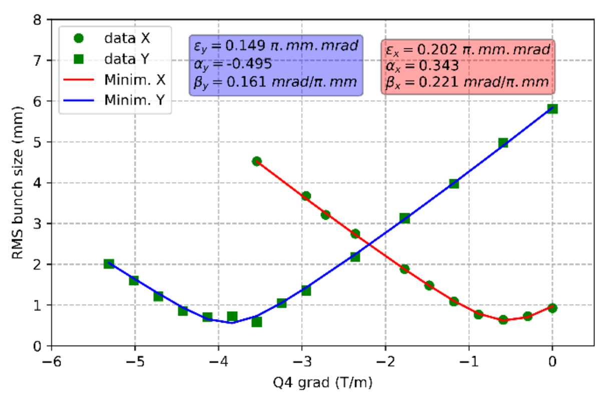

Figure 3: calculated transverse Twiss parameters at the exit of the RFQ from measured wire scanner data.

In addition, the beam transverse distribution in 2D sub-phase-space have been measured in the Dplate and are plotted on Fig. 4. Emittances are as expected and compatible with the transport in the linac. Note that most of the losses obtained by simulation are longitudinal losses.

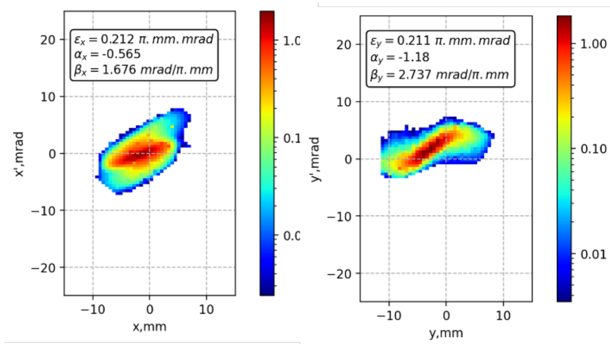

Figure 4: Beam transverse distributions measured in the DPlate downstream the MEBT.

Much more details on beam commissioning in the LINAC MEBT can be found in [4].

CRYOMODULE QUALIFICATIONS

Cryomodules (CM) are handled at Saclay in 4 stations:

- Clean Room (cavity/solenoid-string assembly),
- Assembly hall (top-plate and vacuum vessel),
- Cryomodule Test Stand at 4 K,
- Transportation preparation hall.

Explanations and pictures can be found in [1].

HWR Performances

In vertical cryostat, all HWR cavities, 14 low-beta (LB, 0.09) cavities and 15 high-beta (HB, 0.18) cavities reached at least twice the required Q_0 at nominal accelerating field [5].

In cryomodules, 11 requirements on HWRs were controlled.

The design accelerating fields of 7 MV/m (LB) and 8.1 MV/m (HB) have been easily reached (only one quench was observed for 1 LB at 6.5 MV/m, rapidly conditioned). No multipactor was observed.

X-rays associated to over cryogenics consumption (20W) have been observed on 2 LB cavities (CM1-HWR#6 and CM2-HWR#5). They have been conditioned at nominal field, and in a few hours, X-rays disappeared and cryogenics consumption returned close to normal (<10 W). No field emission were observed on HB cavities.

The sensitivities of the cavities to the helium bath pressure are much less than the maximum requirement of 5 Hz/mbar.

On CM1-HWR#5, when using its tuner at high field, vibrations were transmitted to the cavity changing its frequency too much that LLRF was not able to control it. The problem was investigated, reproduced (measured with a piezo sensor), reduced by changing the motor operation mode and qualified on CM2.

The dynamics heat load of all cavities were about 2 times lower than the requirements, confirming the Q_0 measured twice higher than requirements.

In CM4 first test, a gap between tuner and cavity reduced significantly the tuner capability (from 120 kHz down to 55 kHz) and 3 cavities were not able to be tuned at the right

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frequency (by 10, 30 and 40 kHz). The issue was reproduced on prototype, a solution has been found by adding and moving small wedges between tuners and cavities.

Solenoid Performances

In dedicated 4.2K cryostat, the 23 solenoids have been successfully tested at their test current of 91 A for the focusing coils and 21 A for the steering coils which is 10% more than their nominal currents (20% higher than the need). As anticipated, the focusing solenoids have quenched several times before reaching their nominal current following the classical training curves. The steering coils did not quench before reaching their nominal current. The quench distribution of the focusing solenoids is represented in Fig. 5.

In cryomodules, 14 requirements on Solenoids were controlled.

All solenoids reached their maximum field in nominal schemes. Four quenches were observed only once for four solenoids, very close to the maximum field and having finally reached the maximum field in the second attempt.

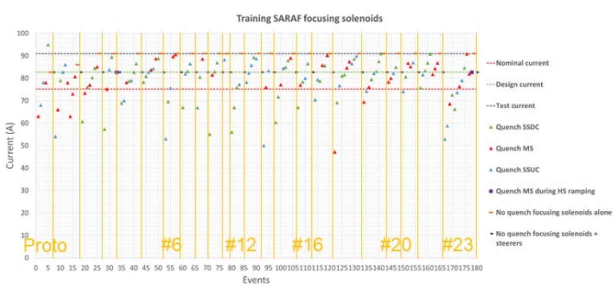

Figure 5: Distribution of the test of the 23 solenoids. Different types of quenches are represented by different colours.

Cryostat Performances

In cryomodules, 19 requirements on cryostat were controlled.

Cryostat contains 3 independent volumes: for beam, helium and insolation. A large number of leak tests are done all along the assembly. At several leaks have been observed and solved. Most of them were attributed to faulty feedtrough or seal sometimes not correctly tight. Because it was polluted with helium during the individual tests, some leak tests of the helium volume have been done with hydrogen.

Alignment is also checked and adjusted at many moment. In clean room on the trolley with specific assembly jigs, then with laser tracker on the trolley before connection to the top plate, after the connection to the top-plate, once loaded in the vacuum vessel, during cool-down (through windows and targets), before and after transportation, in the linac tunnel. The requirements are +/- 1 mm for all elements at final position. For CM1, some points were misaligned by more than 1 mm, but beam dynamics calculation showed that these specific misalignments were fully acceptable (with margins).

Cool-down is controlled by 5 vanes and about 60-70 temperature sensors (some at 300K, some at intermediate temperature of about 70K, some at 4K). A few temperature sensors did not work correctly during the tests. This is not critical as they are many redundancies in the cryomodule. These failing gauges were (or will be, depending on cryomodule) changed before or after transportation to SNRC.

The control-system (Fig. 6) and the cooling process were checked at Saclay, but the cool-down conditions differ at SNRC (the thermal shield is cooled by Nitrogen @ Saclay, and by 60K helium at SNRC). Up to now, the cooling of CM1 has not been done at SNRC. We hope to do it very soon.

Figure 6: cryogenics control-system during tests.

CONCLUSION

The MEBT is fully qualified with protons (pulsed to cw) and deuterons (only pulsed).

All cryomodules (CM1-4) have been qualified at Saclay. CM1 is installed in linac tunnel. CM2 and CM4 should be delivered to SNRC before the end of the year.

Recent events in Israel complicate significantly the commissioning of the machine. CM1 should be cooled soon and first beam is expected at the end of the year.

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