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DISCUSSION ON SARAF-LINAC CRYOMODULES

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Abstract

CEA is in charge of the design, construction, installation and commissioning at SNRC of the Linac of the SARAF project. The linac is composed of an MEBT and a Superconducting linac (SCL) integrating 4 cryomodules. Nowadays, the HWR cavities and superconducting magnets prototypes are being built. The Critical Design Review of the cryomodules has just been passed in March 2018. This paper present the status of the SARAF-LINAC cryomodules.

INTRODUCTION

CEA (Commissariat à l'Energie Atomique, France) is in charge of the design, construction, installation and commissioning at SNRC (Soreq Nuclear Research Center, Irsrael) of four cryomodules for the SARAF (Soreq Applied Research Accelerator Facility) project [1]. The HWR cavities and superconducting magnets prototypes are being built. The Critical Design Review of the cryomodules has just been passed in March 2018.

This paper is presented in a workshop (HB2018) whose most of the participants are not cryomodule experts. For this reason, in order to enlarge the discussions among all participants, it is not addressing technically advanced concepts but the cryomodules through their requirements and functions and not through their solutions. Of course, these discussions can also address advanced solutions which will be described during the presentation.

SARAF-LINAC TLR

SNRC defined following Top-Level Requirements for the SARAF-LINAC:

- Input beam: Proton or Deuteron; 176 MHz; 40 µA-5 mA; cw to pulse (0.1-1 ms @ 0.1-400 Hz); 0.2 π.mm.mrad rms norm. emittance; 1.3 MeV/u;
- Output beam: 40 MeV for deuterons or 35 MeV for protons; Emittance growth < 25%.
- Operation: beam losses lower than 150 nA/m below 5 MeV, 40 nA/m below 10 MeV, 5 nA/m below 20 MeV and 1 nA/m above; 6000 h/y 90% availability.

These TLR drives the SARAF-LINAC solution (Figure 1).

CRYOMODULE MAIN FUNCTIONS

The main functions of the cryomodules (and the linac) is to accelerate the beam to the final energy (satisfied by HWR cavities). Other functions with respect to the beam is to keep it focused and on path to allow its acceleration and maintain its emittance low (satisfied by Solenoid Packages). Finally, other functions with respect to these critical components are necessary to maintain them in operating conditions (satisfied by Cryostats):

- cool down (4 K) /warm up (300 K) cavities and magnets with controlled pressure and temperature conditions, limit thermal loss
- align cavities, BPMs and magnets,
- reduce magnetic field at cavities,
- distribute electrical power and signals,

Finally a cryomodule has to be controlled from the Main Control System relying on the EPICS technology. The interface layer is satisfied by a Local Control System.

Acceleration Function

Initial beam dynamics studies led to the choice of 2 families of HWR superconducting cavities (Figure 2). 13 low-beta (0.092) are used at "low" energy in 2 cryomodules and 14 high-beta (0.182) are used at "high" energy in 2 cryomodules.

The other requirements on these cavities are mainly based on their accelerating field (respectively 7 MV/m and 8.1 MV/m, by limiting the peak magnetic field to 70 mT) and their cryogenics power consumption (based on a 40 nOhm surface resistance). RI Company is in charge of the manufacturing of these cavities. In operation, the volume enclosed in the cavity should be as clean as possible to keep the field performances.

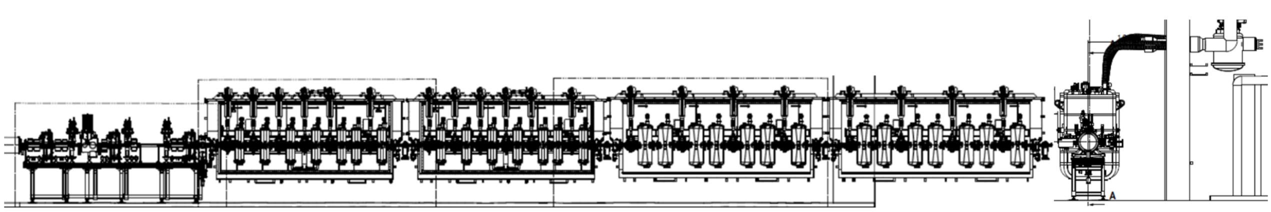

Figure 1: SARAF-LINAC layout, side view (left) and beam view (right).

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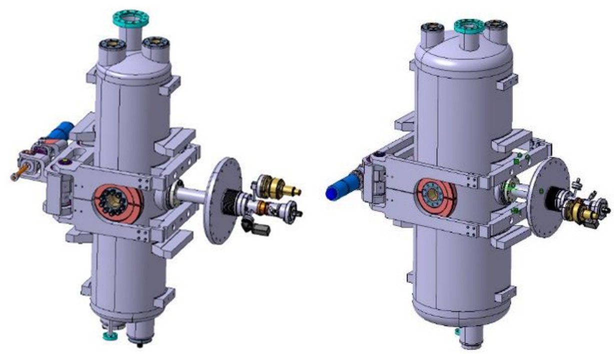

Figure 2: HWR cavities (left-LB; Right-HB).

The phase (and amplitude) cavity field law is set to maintain the beam bunched and accelerated within acceptable beam losses, even in case of errors on components (iterative process). The unhooked particles are the main sources of beam losses (Figure 3).

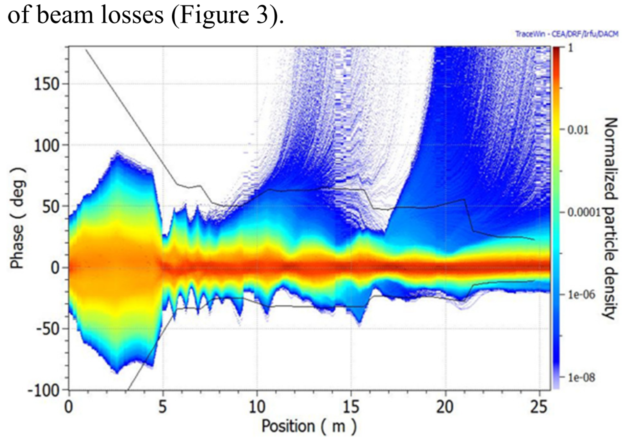

Figure 3: Longitudinal beam profile (log, with errors).

Transport Functions

During the acceleration, the beam is naturally growing (emittance, cavity defocusing, space-charge) and deviating (dipolar field, electromagnetic component misalignments). The superconducting coils in the Solenoid Packages (Figure 4) combine the function of focusing and steering the beam as BPM placed upstream are here to measure the position, charge and phase of the beam.

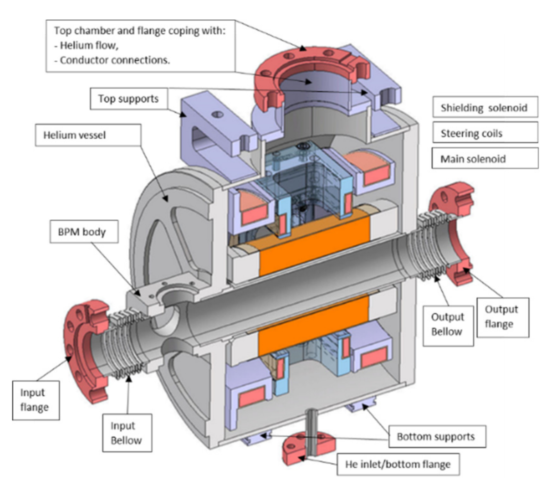

Figure 4: Solenoid Package.

Initial beam dynamics studies led to the choice of 1 family of solenoid package. 12 in the 2 low-beta cryomodules and 8 in the 2 high-beta cryomodules. The design focusing force is 3.5 T^2.m and the design steering force is 8 T.mm. Active shielding (compensation coils) are used to limit the fringe magnetic field below 20 mT on neighbouring cavities. Elytt Company is in charge of the manufacturing of these solenoid packages.

The field law is set to limit emittance growth and to maintain the beam on accelerator axis even in case of errors on components (iterative process). The particle lost in the linac are not lost transversally but are firstly unhooked in the cavities (Figure 5).

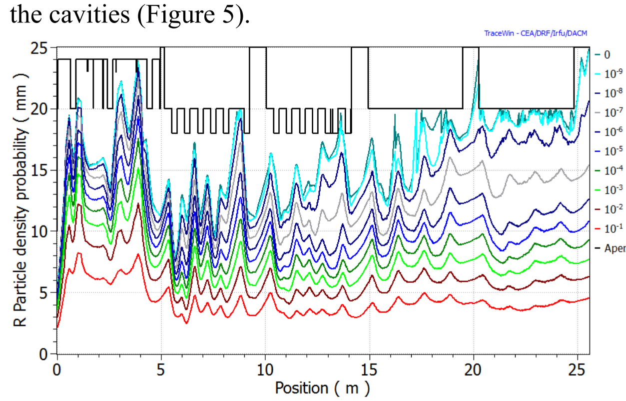

Figure 5: Transverse beam contour plot (log, with errors).

Operation Functions

The cryostat (Figure 6) is in charge of keeping the SC cavities and solenoid package in operation conditions:

- At cryogenic temperature (4.45 K),
- On linac axis (± 1 mm),
- With beam pipe under vacuum,
- < 2 μT on cavity surfaces during NC/SC transition,
- Feed by power (DC current or RF),
- Connected to control system (BPM, LLRF, operation sensors…),
- With easy access for some "fast" maintenance procedures.

Cryogenics The cryogenics distribution (4.45 K LHe and 60 K GHe) is done with valve boxes and circuitry in the cryomodule. The cryogenics consumption is reduced by using an intermediate thermal shield (cooled by 60 K) and putting all the components in a cryostat under vacuum ($<10^{-4}$ mbar) to limit warming by convection.

Alignment Because of required cleanness of cavities, all the major components are assembled in clean room. They are then attached on a frame then on the cryomodule top plate. They are then aligned to positions taking in account the calculated displacement from future cryomodule pumping and cool down. The position of each element can be controlled though optical system when the cryomodule will be pumped and cooled.

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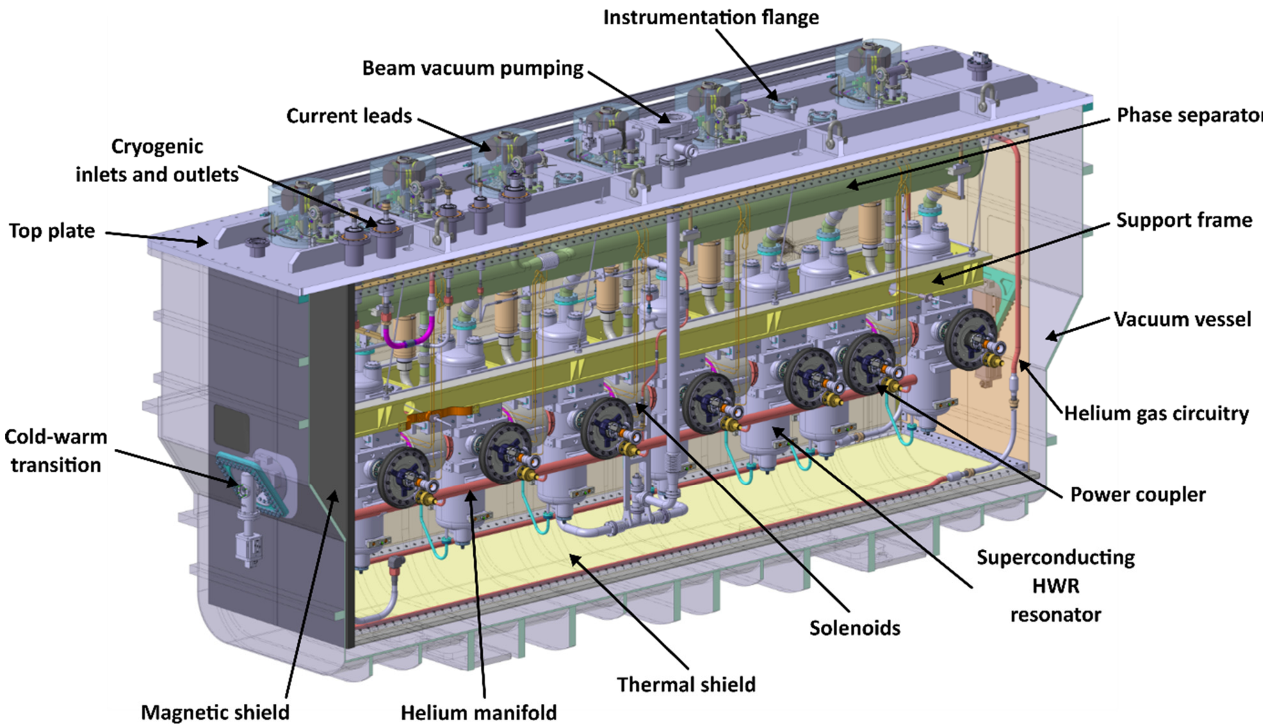

Figure 6: SARAF Cryomodule 2 overview.

Beam vacuum The beam pipe should be under vacuum for many reasons: reduce interaction with beam, limit possible pollution of cavities, limit warming of components by convection. The pumping is made through beam port (pumping in warm section at both ends of cryomodules) and through one HPR port of the 2 central cavities. The warm section pumping is more efficient (better conductance) but the pumping through central cavities is made necessary to keep the vacuum when end valves are closed.

Magnetic hygiene The impact of the trapped magnetic field on cavity surface resistance is estimated to about 2nΩ/µT during NC/SC transition. This means that a special care should be made to material used in the cryostat (depending on their distance with respect to the cavities), but also the earth magnetic field (~50µT) should be screened by a dedicated magnetic shield in the cryomodule.

Power feeding Each solenoid package is feed by 3 power supplies (100 A for the focusing solenoids and 2×20 A for the steering coils). The current goes to SC coils through cryostat top-plate feedthroughs and current leads half plunged in LHe. The SC cavities are feed by RF amplifier (10 kW max. for LB and 20 kW max. for HB cavities). The RF power goes to cavities though RF coupler attached to the cryostat side.

Instruments In order to control the operation condition, many sensors (temperature, magnetic field, voltage, RF…) are connected to the control-system through cryomodule top-plate.

Trap doors In order to allow some access to potentially weak components (tuner motors, spare sensors…), the cryostat contains side trap doors which can be opened when the cryomodule is warm and at atmospheric pressure.

CONCLUSION

A special care has been performed for defining functional requirements for the cryomodules. This facilitates the selection and justification of the solutions and to prepare inspection and testing occurring during the integration and commissioning phases.

REFERENCES

[1] N. Pichoff *et al.*, “The SARAF-LINAC project 2018 status”, in *Proc. IPAC’18*, Vancouver, British Columbia, Canada, 2018, paper TUPAK015.