

HIGH INTENSITY LINAC DRIVER FOR THE SPIRAL-2 PROJECT : DESIGN OF SUPERCONDUCTING 88 MHZ QUARTER WAVE RESONATORS (BETA 0.12), POWER COUPLERS AND CRYOMODULES

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Abstract

A superconducting linac driver, delivering deuterons with an energy up to 40 MeV (5 mA) and heavy ions with an energy of 14.5 MeV/u (1 mA), is proposed for the Spiral-2 radioactive beams facility. For the high-energy section of the linac, a superconducting 88 MHz Quarter Wave Resonator (beta 0.12) has been designed and the optimisation of RF and mechanical performances will be presented. Based on the present state-of-art of the superconducting RF technology, maximum electric surface fields of 40 MV/m and magnetic surface fields of 80 mT have been adopted, which should allow to reach an accelerating field of 7 MV/m (energy gain 3 MeV per resonator). A first complete prototype is under construction. The high intensity deuteron beam specifications have imposed the design of an original power coupler (maximum power 20 kW). The RF, mechanical, and thermal characteristics will be presented. The design of the cryomodule for this high-energy section, integrating two QWR with its associated equipments (couplers, tuners, helium tanks), is presented.

and 2 cavities in the high- β section, whereas 4 to 5-metre long cryomodules were initially foreseen. The transverse focusing is now ensured by conventional quadrupole doublets inserted between the cryostats instead of the initial superconducting solenoids.

This new design appeared to be safer from a technological point of view and for beam dynamics optimization. One of the advantages of this choice is also that it simplifies the developments for RF amplifiers and low level systems.

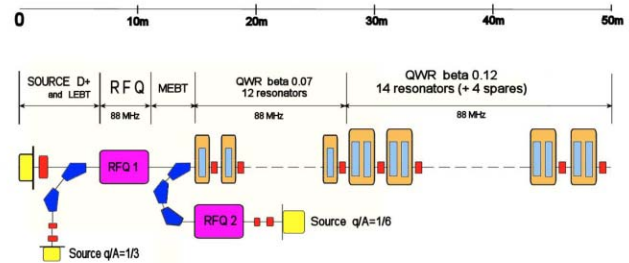


Figure 1: Spiral 2 Linac Driver layout

THE LINAC DRIVER

The main specifications of the Spiral 2 driver accelerator [1] are:

- 5 mA CW, 40-MeV for deuterons.
- Up to 1 mA (Ar), 14.5 MeV/u for $q/A=1/3$ ions.
- Optimisation of the accelerator for $q/A=1/3$, with the capability of accelerating a 5 mA deuteron beam to the required energy.
- Capability to accelerate ion beams of $q/A=1/6$ (up to 1 mA) in the future.

The initial choice for the linac architecture was a 36-cavities, 2-frequencies machine: 88 MHz QWRs for the low- β section and 176 MHz HWRs for the high- β section. The frequency choice has since been oriented towards having the whole machine operating at 88 MHz, with 30 QWRs cavities (12 at $\beta=0.07$, 14 at $\beta=0.12$ + 4 spares) [2].

This new linac architecture is based on the use of small cryostats containing only one cavity in the low- β section,

THE BETA 0.12 SECTION

The design of the beta 0.12 QWR is based on precedent developments, i.e. Legnaro [3] and more recent proposals (ISAAC at TRIUMF [4] and RIA at ANL [5]). QWR at a close frequency have been reliably operated with beam in different projects. During the last years, important technological improvements have been progressively applied to the fabrication and surface preparation of these resonators. Recent results on prototypes and small series confirm the expectations: accelerator gradients exceeding 10 MV/m have been achieved, corresponding to peak surface fields of $E_{\text{peak}} > 50$ MV/m and $B_{\text{peak}} > 90$ mT.

Beta 0.12 Quarter Wave Resonator

The expected performances of the beta 0.12 QWR for Spiral 2 rely on: 1) high quality Niobium RRR250, 2) High quality beam welding, 3) High quality chemical etching and 4) High Pressure Rinsing with high purity water. This design avoids also the presence of a

removable bottom plate. So, all niobium parts of the cavity are electron beam welded.

$E_{acc} \text{ max}$	6.5 MV/m	@ $E_p=36 \text{ MV/m}$ $B_p=66 \text{ mT}$
E_p/E_{acc}	5.54	
B_p/E_{acc}	10.1 mT/MV/m	
$P_{dissipated} \text{ max}$	8.2 W	@ $E_{acc}=6.5 \text{ MV/m}$

E_{acc} is normalized with respect to the $\beta\lambda$ length ($=0.41 \text{ m}$)

Table 1: QWR beta 0.12 parameters

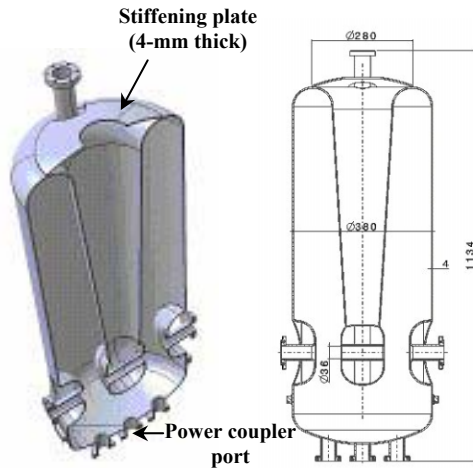


Figure 2 : Views of the QWR beta 0.12

Electromagnetic field calculations show (Figure 4) that the maximum surface fields are located around the inner conductor: magnetic field all along the stem and electric field in the beam axis vicinity.

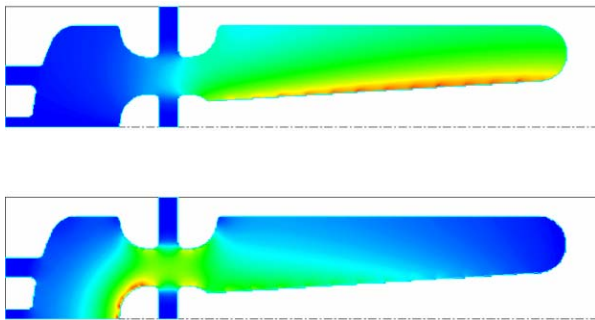


Figure 4 : Magnetic (up) and electric (down) surface fields on the QWR inner conductor

One of the main parameter that has been optimised was the shape of the stem. Conical geometry instead of cylindrical one, allowed to decrease the B_p/E_{acc} ratio. The upper stem diameter is 170 mm, and the lower stem diameter was optimised: going from 50 to 95 mm gives a reduction of the B_p/E_{acc} ratio, from 12 to 10 mT/MV/m.

Tuning System

Initial frequency adjustment will be performed during the fabrication phase. The pre-formed cups supporting the beam tubes and the bottom cup will be cut and welded after the resonance frequency measurement. This procedure should reduce the tuner shift range.

A stiffening plate will be welded around the torus shaped part of the cavity. It should reduce both the cavity sensitivity to Helium bath pressure variations and microphonic vibrations. With this plate, the external pressure sensitivity is -4.5 kHz/bar. The first vibration mode is increased from 40 to ~ 60 Hz.

Simulations performed in order to design the cold tuning system give a sensitivity of ~30 kHz/mm when acting on the axis at the level of the beam tubes, with a calculated stiffness of 16 kN/mm. The available room around the beam tubes is small and other possible locations for the tuning system are under study. Deformation of the cavity body above the beam axis, and plungers located on the top are also being considered and must be tested with the first prototype.

Power Coupler

The resonators of the two driver sections (beta 0.07 and 0.14) should, in principle, use the same power coupler design. The power range is: 1 KW for the first beta 0.07 resonator and 15 KW for the last 0.12 resonator. The coupler is based on a coaxial line, the inner conductor can reach a maximum temperature of 345 K at the antenna tip. The outer conductor is connected at three different temperatures (4.2 K at the SC resonator flange, the thermal shield temperature (60 – 70 K), and the room temperature in the vicinity of the ceramic window and the external cryostat flange). Its geometry and material composition govern the temperature distribution along this conductor.

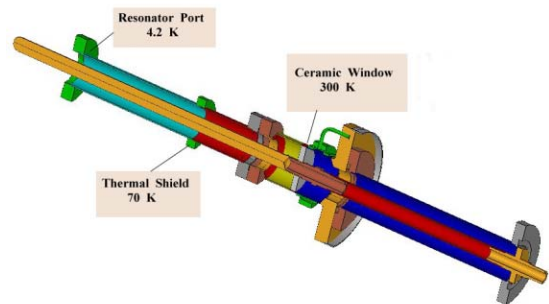


Figure 5: Power coupler (ceramic disk window)

The calculated dynamic cryogenic losses are: 1 W at the 4.2 K level, and less than 10 W at the thermal shield level. Two types of ceramic windows are presently studied: a cylindrical window and a disk window. Both designs are based on classical coupler designs (TESLA, KEK, SNS) that exhibit excellent performances for higher power levels. Two prototypes are under construction, with scheduled tests in the first quarter of 2005. A test facility, which includes a 40 kW CW amplifier, is also under development at the LPSC Grenoble laboratory.

Cryomodule

The high energy cryomodules (beta 0.12) are composed of two resonators with independent helium tanks and assembled in the same cryostat.

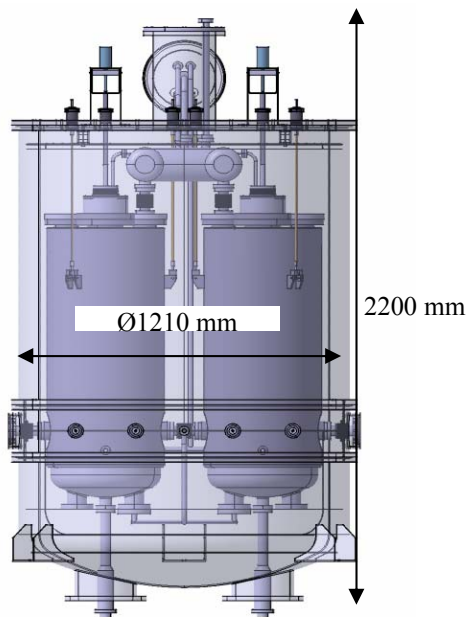


Figure 6: 3D view of the beta 0.12 cryomodule

A stiff ring structure located at the level of the beam tubes provides the basic support for the initial assembly and pre-alignment of both cavities and power couplers in the clean room. Afterwards, the thermal shield, the epoxy rods, the tuning system, and the overall instrumentation could be finalised before complete closing of the cryostat.

Following the preliminary cryogenic and RF tests, the cryomodule will be installed in the linac tunnel where final alignment with respect to the beam axis will be performed with the help of support tables having the needed multi-axis movements.

Estimation of the static losses were performed at the two temperature levels of the cryogenic system: 10 W at 4.5 K and 50 W at 60-70 K thermal shield temperature.

Cryogenic System

The associated cryogenic plant of the Spiral 2 facility has been specified, along with the helium transfer lines philosophy. The liquid helium will be produced from 1 (or 2) cold box(es) and stored in a 3000-litre tank. The design has a maximum power capacity of 900 W at 4.2 K, 2000 W at 60–70 K and must supply 10 l/hour for experiments. The dynamic thermal load of all the beta 0.12 cryomodules are: 170 W at 4.2 K, and 630 W at 60–70 K.

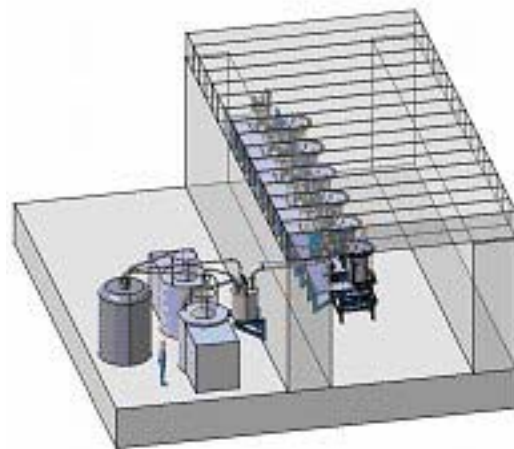


Figure 7: Cryogenic System, transfer lines and cryomodules in the linac tunnel

CONCLUSION

This first prototype of the beta 0.12 resonator is presently under fabrication at Zanon (Italy) and the first tests are scheduled for November 2004. A complete study of the cryomodule and accessories must be completed for next November 2004.

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