UPGRADE OF THE LOW-β SECTION OF THE PIAVE-ALPI LINAC AT LNL

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Abstract

The superconducting linac PIAVE-ALPI includes a low-β section made of 20 bulk niobium quarter wave resonators, working at 80 MHz, with β=0.047 and 0.055. Originally designed for operation at 3 MV/m with 7 W RF power, their high Q allows significantly higher gradient, limited at present by the existing RF system capabilities. An upgrade program has started at LNL that includes the construction of 4 additional cavities, the adoption of 1 kW RF power amplifiers and modifications of the cryostats that will allow for cooling of the RF couplers. The final goal is to increase the voltage gain in the low-β section from the present value of ~10 to above 20 MeV/q, allowing efficient acceleration of heavy ions with mass number around 200.

THE ALPI-PIAVE LOW-β SECTION

The ALPI low-β section includes, at present, three cryostats, each containing 4 bulk niobium quarter-wave resonators (QWR's) with β=0.055 working at 80 MHz [1]. Room for one more cryostat (named CR3) was left in the beginning of the line. Two cryostats of the same type, hosting β=0.047 cavities of similar design, but with a flattened inner conductor [2], are part of the PIAVE injector, for a total of 20 low-β cavities. These large cavities, powered by 150 W RF amplifiers, are equipped with mechanical dampers to reduce their sensitivity to ambient mechanical noise [3], rather pronounced in ALPI due to fast Helium pressure fluctuations. After numerous exposures to air followed by high pressure rinsing during their lifetime, the resonators have an average gradient which is still around 6 MV/m with the nominal 7 W power dissipation; this gradient, however, can be maintained in operation only in exceptionally stable conditions of the Helium pressure. For long term operation, to avoid cavity unlocking, the gradient is usually set within 3 MV/m in ALPI. The RF system, originally dimensioned for this gradient, allows a steady forward power of about 50 W per cavity. The resulting value of the P/E_a^2 ratio gives the minimum RF bandwidth for safe operation in ALPI, i.e. about ±15 Hz. To increase the gradient, a higher forward power is required. Above 50 W, however, the thermal drift of the RF coupler and RF lines inside the cryostat causes excessive power losses and unnecessary dissipation of liquid Helium. In PIAVE, where the cryogenic system guarantees a much more stable pressure in the Helium circuit, the operation gradient can be raised up to about 4.5 MV/m.

At present, the total voltage gain in the low-β section is around 10 MV, limited by the resonators RF system. In the view of the ALPI-PIAVE linac upgrade, that will lead to acceleration of ions of any mass above the Coulomb barrier energy, this value must be doubled.

UPGRADE PLAN

To set up the low-β section upgrade plan we took profit of the experience developed at TRIUMF, where similar resonators [4] are operated above 6 MV/m by means of a more powerful RF system and cooled RF couplers [5].

The upgrade actions are the following:

1. replacement of all the 150 W RF amplifiers with 1 kW units;
2. replacement of all existing 80 MHz RF couplers with new ones cooled with liquid Nitrogen;
3. Modification of all low-β cryostats to allow use of the new couplers;
4. construction and installation in ALPI of one more cryostat hosting 4, β=0.047 resonators.
5. Installation in ALPI-PIAVE of a liquid nitrogen distribution system.

The upgraded cavities are expected to operate at least at 5 MV/m, giving a total voltage gain of above 20 MeV/q, as required. The average forward RF power required to guarantee ±15 Hz RF bandwidth at 6 MV/m is about 200 W, but up to 600 W are needed for safe long term operation and for pulsed power RF processing.

In a first phase the new amplifiers will be installed in the old cryostats. This will allow operation at a slightly (~20%) higher gradient than the present one, since the available extra power will allow operation with a narrower bandwidth. In a second phase the new cryostat, equipped with the new RF system and with the cooled couplers, will be installed in ALPI, becoming the test bench for the new equipment. In a third phase, all the cryostats will be modified and upgraded for coupler cooling. The work, to be performed in background in order to avoid interference with the linac operation, will last about 2 years.

HARDWARE DEVELOPMENT

Quarter-wave resonators

The 4 new cavities are of the β=0.047 type with flattened inner conductor. Compared to the existing PIAVE ones, they have been modified in the stainless steel top flange, in order to allow removal of the mechanical damper without the necessity of opening the indium seal, and in the tuning plate, to allow a tuning range of about 30 kHz, three times larger than the present one. The resonators construction is nearly completed.

Figure 1: The low-β cavities under construction

RF system

A 1 KW solid-state RF amplifier working at 80 MHz has been developed for us by a local company. These small size units can replace the old 150 W ones with no modification to the system. They can deliver continuously an average power up to 500 W in full reflection, and more than 1 kW in pulsed mode. A lot of 24 units is being purchased.

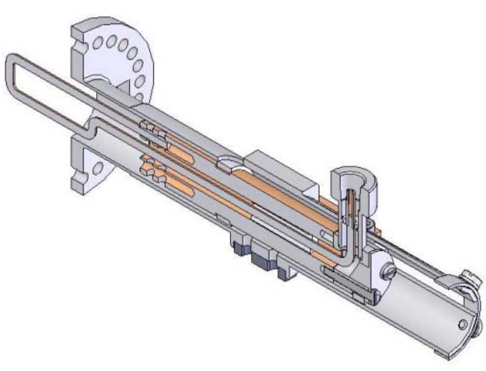

Figure 2: Cut view of the new cooled coupler

New RF coupler

The new RF coupler, inspired by the ISAC_2 one [6], has been designed in order to maintain stable temperature with a forward power up to 500W, while limiting the thermal load to the liquid helium system within 1W. Both the inner and the outer conductor are made of copper and they are thermally connected by means of a split ring piece of SHAPAL-M dielectric with high thermal conductivity. Two Teflon sliding rings reduce heat exchange with the stainless steel housing, which is shaped with a reduced section near the holding flange. The coupler is moved in and out through a rotating shaft driven by a stepping motor on the cryostat top flange with a pinion-rack mechanism on the housing. The main difference from the TRIUMF model is the 90 degrees corner near the connector, that allows keeping the overall length within 160 mm (the maximum available space in our cryostats) while leaving an effective stroke of 80 mm. A first prototype, with a copper braid linking the outer connector to a LN_2 line at 77 K, is used for testing the thermal characteristics of the coupler in operation. The next step will be the construction of a prototype with direct LN_2 cooling.

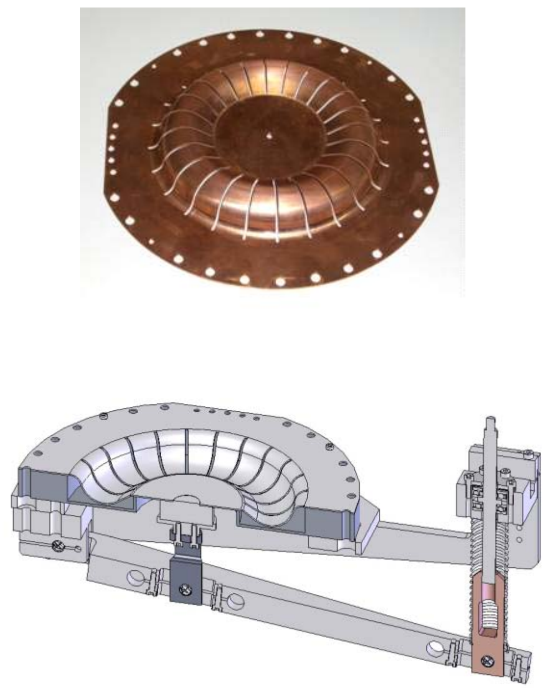

Figure 3: New tuner assembly. Top: Cu prototype of the slotted tuning plate.

New tuning plate

The new tuning plate for the QWRs is also a modification of the TRIUMF design. The plate is cold shaped from an annealed bulk niobium sheet with a thickness of 1.25 mm and a 264 mm diameter. A central 80 mm diameter circular flat surface is surrounded by a S-shaped deformation zone wire-spark cut, with 24 radial slots in order to reduce the load required for displacement and to increase the tuning range.

An aluminium cover, fixed to the plate, keeps the slots closed when the tuner is in rest position, preventing dust contamination of the cavity during assembly. A cylindrical niobium block is welded to the centre of the flat surface, interfacing it with the mechanical tuner already in use on QWRs.

The new tuning plate, once mounted in the cavity, will allow both initial frequency adjustment at room temperature and frequency tracking at 4.2K without any further machining. A first plate prototype, made from 1 mm thick, annealed copper, has been constructed and tested. It was capable of 14 mm displacement, going beyond yield point at room temperature, without any modification of the mechanical tuner. The corresponding frequency tuning range is about 30 kHz. Similar results are expected for niobium plates presently under construction.

Cryostat upgrade

The low-β cryostats have to be upgraded in order to cope with the increased RF power. A new line is required to bring liquid nitrogen inside the cryostat with an adjustable flow rate to fit the RF power requirements. A copper sheet, cooled to 77 K, shields the helium reservoir from the heat radiated by the RF cables. Four strips of copper braid, brazed to copper blocks linked to the liquid Nitrogen pipe by tight thermal contacts, provide heat removal from the couplers. The shield, all the tubes and joints can be easily dismantled during cryostat and cavities maintenance. A first estimation, using material properties available in literature, shows that a serial connection of the couplers and the shield downstream should assure an efficient cooling with a flow rate of 5 litres per hour of LN_2. However, careful testing is required to validate this simple design, both regarding the cooling capability and the possible dust contamination of the vacuum from Cu braid (in these cryostats there is direct communication between thermal isolation vacuum and beam vacuum). Direct cooling of the couplers through stainless steel pipes and bellows, already validated at TRIUMF, is also possible with small modifications and is being considered.

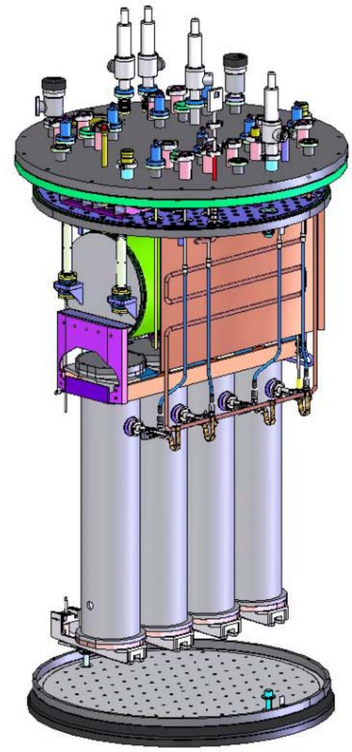

Figure 4. Sketch of the modified cryostat internal part. The RF couplers are linked to a 77 K pipe via a 20 cm long strip of Cu braid. A Cu shield at 77 K prevents heat irradiation from the RF cables to the He reservoir.

CONCLUSIONS

The upgrade of the ALPI-PIAVE low-β section, that will nearly double its effective acceleration voltage to more than 20 MV, has started. The construction of 4 new cavities, with modified tuning plates and dampers, is near completion, and 24 new RF amplifiers have been ordered. A compact RF coupler, suitable for liquid Nitrogen cooling, is under development together with the required cryostat modifications. The new cryostat is expected to be installed in summer 2008, while the remaining 5 cryostats will be modified one by one to avoid interference with the beam runs. The upgrade operations will last about 2 years.

ACKNOWLEDGMENTS

We thank V. Zvyagintsev and R. Laxdal of TRIUMF, Vancouver, for their precious suggestions in the coupler and tuner development.

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