FIRST YEAR OPERATION OF THE ALPI POST-ACCELERATOR

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Abstract

During the last year test beams of different injection energies and ion species was accelerated with the medium beta section (β=0.11) of ALPI and delivered to the experimental halls. The main components of the post-accelerator, namely the cryogenic plant, the pulsing system, the optical and diagnostic elements for the beam transport, the vacuum, rf and control systems were widely tested under different conditions. The average accelerating field over the 44 installed superconducting lead on copper resonators turns out to be 2.65 MV/m. In June 1995 four cavities made of niobium sputtered on copper were added with an average accelerating field for these cavities of 4.2 MV/m. The phase locking procedure for the 53 resonators (accelerating and buncher cavities) is normally completed in about 10 hours. The overall beam transmission towards the post-accelerator is 70% with the DC beam and up to 50% with the pulsed and accelerated beam with currents on the target of the order of some p-nA.

KEYWORDS: heavy-ion, linac, superconducting-RF

1 INTRODUCTION

The ALPI complex of the Laboratori Nazionali di Legnaro consists of a 15 MV XTU tandem and of the superconducting linear booster ALPI [1, 2, 3]. The complete project for the ALPI super-conducting booster foresees three different sections where Quarter Wave Resonators (QWR) with different optimum velocity are hosted. A first low-β section with β=0.055 (21 cavities) is followed by a medium-β section with β=0.11 (44 cavities). The high β section with 24 cavities will have a β=0.14.

A super-conductive positive ion injector is also part of the project. The main components are a 14.4 GHz Electron Cyclotron Resonance Ion Source (ECRIS), now under installation on a 350 kV platform [5] and a super-conducting Radio Frequency Quadrupole (RFQ) with 4.5 MV equivalent voltage followed by two new low-β cryostats [6]. The super-conducting RFQ is now in a design phase and it will be installed in the next three years.

After the commissioning phase the post-accelerator starts a period of preliminary operation. In this period a variety of isotopes was accelerated and delivered to the experimental halls. At the same time a carefull check of the sub-systems was carried out in order to improve the overall reliability of the machine.

2 OPERATING EXPERIENCE ON CRYOGENIC SYSTEM

The phase II of the cryogenic plant, i.e a cryogenic system ready to work with all the three velocity sections of ALPI, was completed and tested by the end of 1993 [4]. The total refrigerating power of 3900 W, at 60 K, foreseen on the original project, was reached while the design value of the refrigerating power at 4.5 K was 1300 W and the attained value is 1137 W.

The foremost improvement of the cryogenic system is the installation of an emergency heat exchanger for the 60 K helium gas flowing in the thermal shields of the cryostats. This emergency system allows the maintenance of the thermal shield at 80 K, avoiding cryopumping by the resonator surfaces.

The emergency heat exchanger consists essentially of a spiral line in a bath of liquid nitrogen. The He gas flows along the spiral line circulated by two blowers in series. The recirculation power is 80 g/s of He gas and each blower produces a pressure drop of 0.5 bar. The system, powered by an emergency generator (diesel engine), is switched on when a black out occurs. An emergency battery with a power of 30 kVA and 3 hours autonomy is also foreseen.

The liquid nitrogen consumption in the heat exchanger dewar is 160 l/h with 13 cryostats without refilling from the main dewar (20 kl of LN_2). The total liquid nitrogen consumption on the main dewar turns out to be about 270 l/h (essentially due to the transfer line from the main dewar to the heat exchanger).

3 RESONATORS AND RF SYSTEM

In the last year, further improvements of the accelerator performances, associated with increased stability of the accelerating field at 7 W, was obtained using RF conditioning, even days long, in a low pressure He-gas ($4{\cdot}10^{-5}$ mbar). To use this method, a dedicated He-gas distribution system had been installed in the ALPI tunnel. The system allows operating of low power RF/He conditioning (10$\div$20 W) for 12 resonators at the same time. A flat curve of quality factor versus the accelerating field was obtained for most conditioned resonators up to the working power of 10 W.

Fig. 1 shows the accelerating fields, at 7 W, along the medium-β section, as obtained during the acceptance test of the Italian Agency for Environment Protection (ANPA) in May 1996.

The poor performance of some resonators is connected to a set of copper substrates which were revealed to have diffuse defects due to bulk porosity. This was soon realized but the resonators were still mounted on the machine in order to test the overall reliability of the RF system. In other words, all the produced cavities were accepted with the intention that, after one year of test, the more poorly performing cavities would be replaced by new ones.

The lead-plated cavities have shown good reliability, remaining locked for days at the maximum field with the chosen phase.

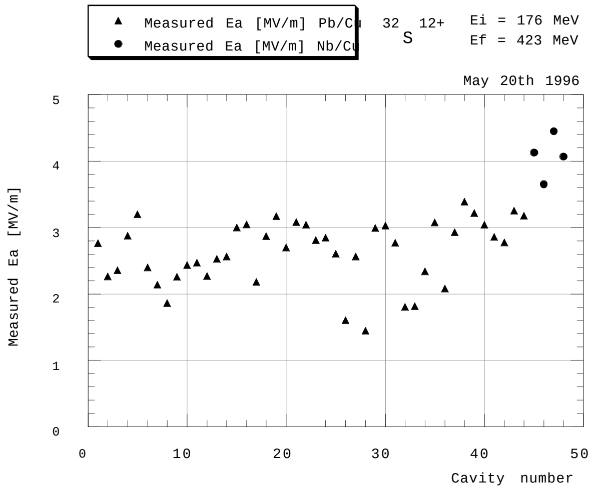

Figure 1: Accelerating fields at 7 W in the medium-β resonators of the ALPI post-accelerator on the acceptance test of May 1996.

4 CONTROL SYSTEM

The commissioning of ALPI put in evidence the need for some improvements in the control of the two principal subsystems, i. e. the cryogenic system and the RF system.

The major implementation concerning the control of the cryogenic system was the automatic refilling of the liquid helium. The procedure allows the maintenance of the level of the liquid helium in the reservoir of each tank around a user-defined set- point. Usually the pre-defined level is set in the range between $50\% \div 70\%$. The sampled-time control procedure is based on the classical proportional feedback algorithm between the level error and the proportional valve position.

The RF system is now equipped with an alarm management system running on VME in a VxWorks environment and recording and displaying processes on a UNIX workstation. The real-time tasks on the VME system execute periodic local checks and force an automatic shut-down of power amplifiers when a steady alarm condition is detected. The UNIX processes gather, display and store alarm messages acquired through the network from the distributed VME system.

The sequence of actions for the amplitude and phase lock of RF cavities are also automated. In the first months of 1995, they were extensively tested during the cavity tuning. The procedures allow one to look for the self-exciting condition for the QWR's, to scan the loop-phase parameter looking for the resonance peak, to set the quiescent power in order to nullify the amplitude error and finally to move the slow mechanical tuner for the QWR tuning with a maximum frequency error smaller than 2 Hz.

5 BEAM TRANSPORT AND ACCELERATION

The pulsing system [7] had an overall reliable behaviour for each component, namely the double drift buncher, the sweeper, the post-chopper and the passive cavity.

The pulsing system, together with the superconducting cavity of the high energy buncher, are normally able to focus longitudinally the bunches at the ALPI input to about less than 300 ps and with losses on the vertical slits of the post-chopper of about 45% of the continuous beam.

The two central resonators of the rebuncher cryostat are normally set up at fields usually around 1 MV/m. With these fields, the bunch length at the beginning of the high energy branch turns out to be of the order of 300 ps.

The average beam transmission across the internal U-bend is usually around 80% while in the high energy branch is usually above 90%.

The time structure after the extraction line, before the experimental halls, was measured with different beams and, without any rebunching, it turned out to be made of bunches of about 2 ns wide separated by 200 ns and with a ratio of the number of particles between two subsequent pulses to the particles in the leading bunches of less than 10^{-4}.

The beam currents were in the range of few p-nA for all the beams delivered to the targets in the experimental halls.

6 TEST BEAMS

In march 1995 a series of beam tests started to study accelerator performances with some of the ion species normally asked for by the users. In particular, the interest of these beam tests was devoted to control the beam quality on target and its stability in time. A list of the delivered test beams during the last year is reported in Table 1. For all beams, the working phase of the cavity was -20 degrees. The chosen ion species and energies were defined by the normal session of the LNL Physics Advisory Committee following the nuclear physics experiments requested by the users.

As expected, because of different transit time factors, the table shows a higher energy gain per cavity (and per charge unity) for light ions in comparison with heavier ones.

Isotope	Cavities	Final energy (MeV)	Energy gain (MeV)	Energy gain/cavity charge u. (MeV/cavity charge u.)	Date
S^{32} (12^+)	32	324	147	0.38	May 30th 1995
S^{32} (12^+)	48	423	247	0.43	May 20th 1996
Cl^{35} (12^+)	37	355	179	0.40	November 30th 1995
Cl^{37} (12^+)	12	234	58	0.40	June 21st 1995
Ni^{64} (12^+)	41	390	195	0.40	May 28th 1996
Ge^{74} (13^+)	23	323	113	0.38	November 6th 1995
Ge^{76} (13^+)	44	429	219	0.38	May 25th 1995
Br^{81} (13^+)	33	363	153	0.36	June 8th 1995
Zr^{90} (13^+)	40	400	190	0.36	May 5th 1996

Table 1: Accelerated beams with the ALPI post-accelerator during the first year of operation

7 NIOBIUM CAVITIES

In June 1995 two further cryostats were installed in the ALPI post- accelerator. The first cryostat is a prototype of the low-β section made of bulk niobium QWR's with 80 MHz operating frequency [8]. The second cryostat hosts 4 high-β QWRs made of sputtered niobium over a OFHC copper substrate [9] operating at 160 MHz, the same frequency of the medium-β cavities.

During the first preliminary test with the bulk niobium low-β cavity an accelerating field of 3 MV/m was reached. Higher accelerating fields (5 MV/m) were sustained for short periods without any fast tuning device.

The niobium sputtered cavities showed also good performances of the accelerating fields and they was employed with good reliability in the normal runs of the last year as shown in Fig. 1(last four cavities of the post-accelerator). The average accelerating field of the installed niobium sputtered cavities turns out to be 4.2 MV/m.

8 CONCLUSIONS

The beam stability on target was demonstrated to be quite satisfactory but some improvements have to be implemented in order to reduce the contribution to the beam envelope due to the energy spread.

When possible, the final energy spread is reduced with the last cavities of the post-accelerator; nevertheless a systematic reduction of the energy spread will be obtained with the installation of a bunching cryostat before the extraction L-bend.

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