OPERATION OF THE KARLSRUHE SUPERCONDUCTING POST ACCELERATOR TEST SECTION IN THE SACLAY TANDEM HEAVY ION BEAM

K. W. Zieher, G. Hochschild, A. Hornung
Kernforschungszentrum Karlsruhe, Institut für Kernphysik
Karlsruhe, Federal Republic of Germany

and

J. P. Fouan, J. Gastebois, P. Joly
Centre d'Études Nucléaires de Saclay, Service de Physique Nucléaire à Basse Énergie
Gif-sur-Yvette, Republic of France

Summary

The test section of a superconducting heavy-ion post accelerator (SNB-Karlsruhe) was set up at the C.E.N.-Saclay Tandem Lab. It was operated with beam in order to demonstrate the feasibility of a superconducting booster accelerator for heavy ions behind a tandem accelerator. In addition, the cavities were used as a beam rebuncher. The energy modulation due to the test section was measured and reproduced the original calibration. In bunch experiments beam pulses were generated and measured.

Introduction

The ion energy of an existing tandem accelerator can be increased appreciably only by a post-accelerator. One possible approach, a linear accelerator of independently phased cavities, has many advantages as a booster: the transmission of the prebunched and stripped ion beam can be 100%. The good tandem beam qualities can be maintained (small transverse emittance, energy resolution of a few 10^{-4}), and, simple energy variation is possible. In addition very narrow beam bunches can be obtained on the experimental target. The use of superconducting cavities is quite cost saving both in investment and running expenses.[1,2] Also the radiated rf power can easily be kept at a low level, which is valuable for the sensitive detection devices used in nuclear physics experiments. Two such boosters are already under construction.[3,4]

Reliability and handling is best demonstrated by an experiment. This was the first reason for repeating some of the Heidelberg experiments[5] at the CEN Saclay Tandem Lab, using the SNB test section. The second purpose of this installation is to use the velocity modulation given by a cavity in order to compress a prebunched beam down to the 100 ps range. Such short beam pulses allow mass identification on flight distances below 50 cm for the tandem mass-energy ranges. This is intended to be used in the fusion-evaporation cross-section measurements presently in progress with a less effective setup at the Saclay tandem. This time structure will also be used in the search and measurement of medium life-time isomeric states expected among the high spin levels populated by heavy-ion reactions.

The cavities were originally optimized for accelerating bromine ions with charge q=23 from 1.67 to 6 Mev/n. Figure 1 shows a cross-section of the cavity. At design field the maximum electric field is ∿ 16 MV/m, the effective accelerating travelling wave amplitude is E_{acc} = 1.05 MV/m (cosϕ = 1, flange-to-flange) and the stored energy is 0.172 J.

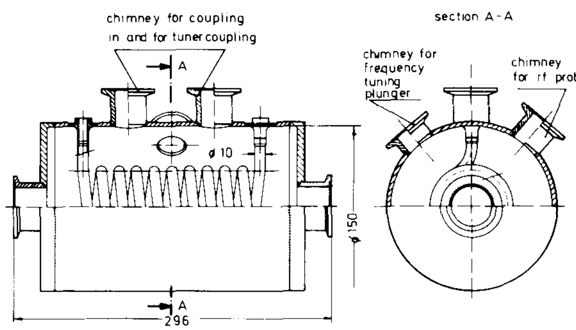

Fig. 1: Cross-section of the rf resonator.[2]

Treatment of the Cavities and rf Measurements

The cavities had been operated at MPI-Heidelberg up to January 1977.[2] Thereafter the test cryostat was moved to KfK-Karlsruhe, where it was standing idle without any pumps installed. In August 1978, the cryostat was opened and the two cavities HD 1,2 were removed for laboratory measurements. By oxipolishing HD 1 two cycles, and HD 2 three cycles, E_{acc} ≥ 1.2 MV/m was achieved in laboratory experiments in both cavities. The two cavities were then mounted into the test cryostat and cooled down. The first cool-down was accompanied by oscillations due to a modification in the helium-gas-fluid system, not allowing rf measurements. There were also indications that an uncontrolled burst of gas might have entered the cavities. Rinsing with methanol in the mounted position after warm-up was not sufficient to achieve the old performance of the cavities due to high field electron emission. After oxipolishing two cycles, HD 1 was limited at E_{acc} ∿ 1.4 MV/m by thermal breakdown, while HD 2 showed a sharp limitation at E_{acc} = 1.2 MV/m (local breakdown).

At the end of November 1978, the cryostat was moved to CEN-Saclay and cooled down to 4.2°K. The performance of the cavities was unchanged. Later warm-up and cool down cycles did not degrade the resonators either.

The zero field frequency of HD 1 was 108.452 kHz and the one of HD 2 could be adjusted with the slow tuner[6] between 108.429 kHz and 108.493 kHz. The frequency shifts due to radiation pressure are 44 kHz (HD 1) and 26 kHz (HD 2) at E_{acc} = 1.05MV/m.

Figure 2 shows the principle of the rf control system as it had been designed for the experiment at MPI Heidelberg.[7,8]

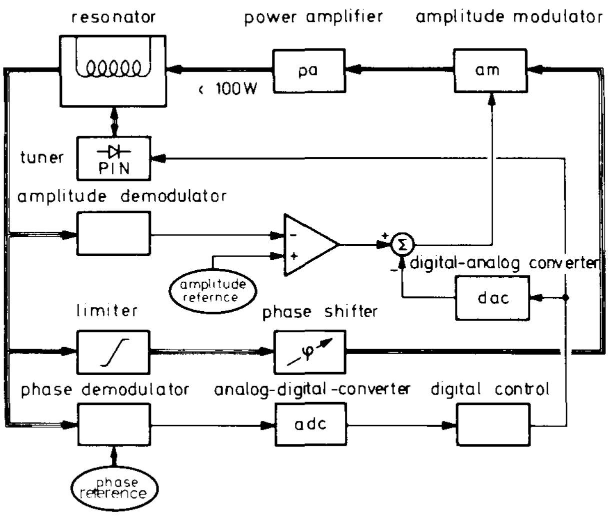

Fig. 2: Principle of the rf system.[2]

After being set up at Saclay, the amplitude stability was $\Delta U/U \simeq 3\times10^{-3}$ peak-to-peak. The eigenfrequency changes of the resonators which had to be corrected by the tuner were ∿ 700 Hz peak-to-peak while the ponderomotive feedback loop reduced it to ∿ 220 to 450 Hz. The tuning range was 1.4 kHz peak-to-peak. The cavities were phase locked to a frequency synthesizer for several hours. An experiment with a different tuner has been reported elsewhere.[9]

The two phase cooling[10] worked without problems. Figure 3 shows the cooling principle. The cool-down time was between 18 and 12 h depending on the pressure in the dewar. For constant level operation 1.15 bar was sufficient. The heat flow into the LHe was measured as 0.6 ± 0.1 W due to cavity losses and 0.6 ± 0.1 W due to rf power losses of the tuner for each cavity at E_{acc} = 1.05 MV/m, while heat conduction in the 500 l LHe dewar contributed 0.17 ± 0.02 W.

The losses of two cavities at E_{acc} = 1.05 MV/m, with the tuners plus one dewar connected by the transfer line to the cryostat maintaining a constant level, was 6.6 W.

Beam Experiments

The experimental arrangement is shown in Fig. 4. The beam optics system is designed to deliver an intermediate image at the center of the cryostat and a final one at the center of the scattering chamber with an overall magnification of 1 (from the analyzing magnet image slits). The drift lengths are ∿ 24 m from tandem to cryostat and 5.5 m from cryostat to target.

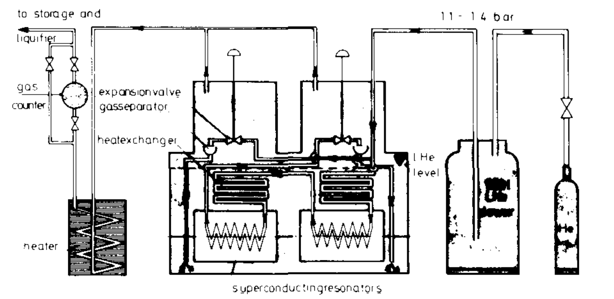

Fig. 3: Cooling principle in the test cryostat

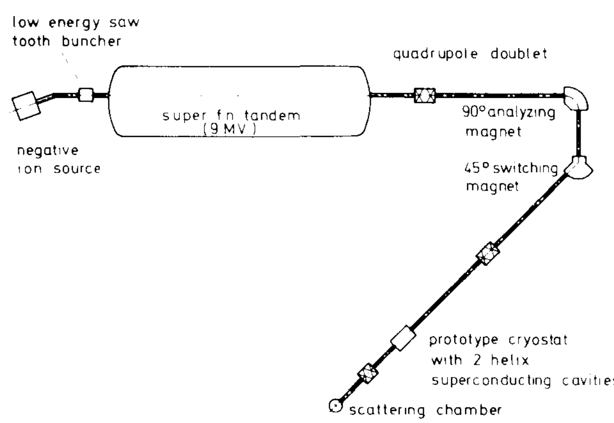

Fig. 4: Experimental arrangement

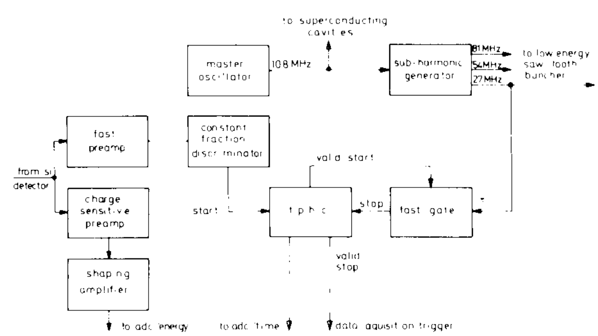

Fig. 5: Block diagram of the time-energy measurement

In order to measure the longitudinal emittance of the beam, particles elastically scattered by a 100 μg/cm^2-thick gold foil were detected at various forward angles. Figure 5 shows the electronic setup used. A Si surface barrier detector 120 μm thick at 120 V delivered ∿ 3 ns rise time pulses. Both a fast and a charge integrating preamplifier[11,12] were connected to the detector. For each scattered particle the total energy and time difference with the master oscillator phase were digitally encoded and sent to the on-line data acquisition computer. Live displays of the energy and time distributions (spectra) were thereby obtained. The raw data (event-by-event) could also be written on tape and a 256 × 256 array of a limited portion of the time-energy space was also integrated on line. The intrinsic resolution of this detection setup is ∿ 200 keV for the energy measurement (mostly due to target thickness and angular opening of the detector). The intrinsic time resolution could not be measured but can be estimated to be ∿ 100 ps coming mostly from the Si detector rise time.

The first two experiments were performed with a d.c. ^{16}O beam ($q=7^+$, $U_{Tandem}=8.5$ MV, T = 68 MeV). The very first run took place as early as December 22, 1978, and lasted only for a limited time. The energy modulation given by cavity HD 1 close-to-nominal field could be measured. In addition, operating the same cavity at reduced field delivered a slightly overbunched beam. A width of 230 psec was observed without any fine adjustment of the electronics and rf field.

During the second run (January - February 1979), the same beam at 64 MeV was energy-modulated by both cavities. The relative phase of the modulation amplitude due to each cavity could be determined after two energy modulation measurements from a simple vector addition. The maximum energy modulation obtained with the two cavities phase-locked at nominal field is shown in Fig. 6. Using a single cavity, the appropriate setting for optimum bunching on target could be determined fast by comparison between the time distribution obtained in the overbunched case with the calculated one.

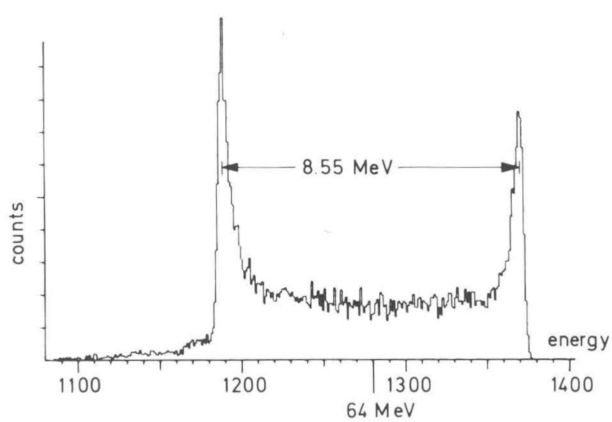

Fig. 6: Energy distribution of a $^{16}O^{+7}$ (T=64 MeV) beam energy modulated by both cavities close to design field at optimum relative phase

A fluctuation of the pulse timing was then observed to be correlated with terminal voltage variations of the tandem (ΔU ∿± 5 kV). This could be partially compensated by adding the generating voltmeter differential signal to the time-to-pulse height converter information. Thereafter a width of 120 psec could be observed over several minutes as shown in Fig. 7.

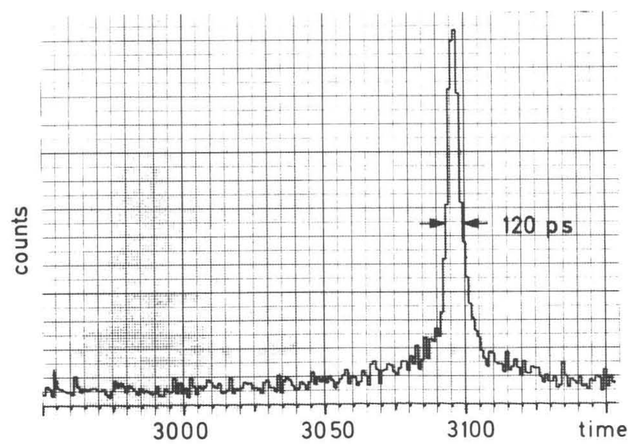

Fig. 7: Time distribution of a $^{16}O^{+7}$ (T=54.6 MeV) beam bunched by the high energy buncher

The following set of beam measurements (March and June 79) used the newly-constructed low energy buncher in connection with the superconducting cavity. This low energy buncher is similar to the ANL buncher [13] and consists of a gridded 1.5 mm long modulation gap which is fed with three frequencies (27, 54, 81 MHz) from two coaxial resonators. It provided a linear energy modulation for 70% of the beam. The distance of about 37 ns between bunches is quite suitable for most experiments. Details on the construction and performances of this device will be published elsewhere. The 100 kV injector under construction was not operational for these measurements and the bunching system could only be tested with a $^{16}O^-$ beam at 70 keV from a duoplasmatron exchange source and a $^{12}C^-$ beam at 20 keV from a standard sputter source. The bunches observed on target were 6 and 3 ns FWHM, respectively. About 70% of the intensity were in the peak for ^{16}O accelerated to 55 MeV and ^{12}C to 48 MeV.

The low energy buncher was then phased with the superconducting cavity at required field. One measurement was performed with the master oscillator replaced by a self-oscillating loop consisting of the superconducting cavity with a simple amplitude regulation; a typical time distribution observed is shown in Fig. 8. Bunching performance was identical to the previous case.

Conclusion

The tests showed that the superconducting helix cavities can be considered as reliable components for technical applications, if the maximum surface electric design field stays below some value around 16 MV/m. Most of the failures were related to conventional technique and not to superconductivity nor to the vacuum seals at low temperature nor to thermal expansion and contraction during the thermal cycling between 4.2°K and 300°K.

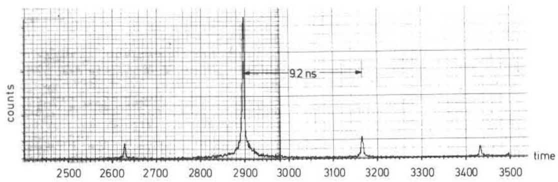

Fig. 8: Time distribution of a prebunched (27, 54, 81 MHz) and rebunched (108 MHz) beam of $^{16}O^{+7}$ (T = 55 MeV)

From early December 1978 to June 1979, the cryostat was cooled down and warmed up to room temperature five times and no difficulty was encountered in reaching the maximum fields even for operators of little experience.

The beam experiments have confirmed the accelerating capabilities of such phase-locked cavities. The major components of the beam bunching are now in routine operation and with the use of the 100 kV injector and a high energy chopper presently under design, intense bunches of ∿ 100 psec with low background will be used in nuclear physics experiments.

Acknowledgement

The help of L. Schappals, P. Schlick, M. Frauenfeld, B. Messerschmidt, N. Münch as well as the helpful discussions with J. E. Vetter were essential for the successful run of the test section.

The contributions of E. Chamaux and L. Bianchi to the experimental setup and that of J. L. Gizma and the tandem crew were important for the various beam experiments.

We are also indebted to J. P. Passérieux for the electronics design (low energy buncher and detection system) and for his help during the beam runs.

References

1 H. Deitinghoff, H. Klein, M. Kuntze, J. E. Vetter, E. Jaeschke and R. Repnow, KfK-Bericht 2141 (Karlsruhe,1975)

2 G. Hochschild, H. Ingwersen, E. Jaeschke, W. Lehmann, B. Piosczyk, R. Repnow, F. Spath, J. E. Vetter and Th. Walcher, KfK-Bericht 2624 (Karlsruhe, 1978)

3 K. W. Shepard , IEEE Trans. NS-26, 3659 (1979)

4 J. R. Delayen et al., IEEE Trans. NS-26, 3664 (1979)

5 G. Hochschild, B. Piosczyk, J. E. Vetter, H. Ingwersen, E. Jaeschke, R. Repnow, H. Schwarz, Th. Walcher, IEEE Trans. NS-24, 1150 (1977)

6 B. Piosczyk, Int. Ber. 77-223-SNB (Karlsruhe, 1977) unpublished

7 G. Hochschild, Bericht 10.01.06 P 01 D (Karlsruhe, 1978) unpublished

8 G. Hochschild, Bericht 10.01.06.P 01 E (Karlsruhe, 1978) unpublished

9 D. Schulze, A. Hornung, P. Schlick, IEEE Trans. NS-26, 3748 (1979)

10 J.E. Vetter, Int. Ber. 77-226-SNB (Karlsruhe, 1977) unpublished

11 B. Delaitre et J. P. Passerieux Rapport Interne D. Ph. N./B.E/75/4

12 J. P. Passerieux et al., Compte rendu d' Activité du Departement de Physique Nucleaire C.E.A.-N-2070 (1979) p. 291

13 F. J. Lynch, R.N. Lewis, L. B. Bollinger, W. Henning and O. D. Despe, Nucl. Instrum. Methods, 159, 245 (1979)